Final Report

Design of Phosphorus Management Strategies for the Cannonsville Basin

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Preface

The study described in this report has been executed as a thesis project for the Master of Science degree from the sub-faculty of Systems Engineering, Policy Analysis and Management at the Delft University of Technology in the Netherlands. During the project I have received support from numerous people, both in the Netherlands and in New York.

For his hospitality during my stay at Cornell and for his help in finding an interesting subject for my thesis project I would like to thank Pete Loucks of Cornell University. I would also like to thank Steve Pacenka of the New York State Water Resources Institute for his help in getting this project off the ground during the first months at Cornell. Furthermore I would like to express my gratitude to Keith Porter and to the research assistants of the Water Resources Institute as well as to the numerous other persons that provided me with useful information.

During the second half of the project I have worked in Delft where I had some useful discussions with Wil Thissen, Giampiero Beroggi and Igor Mayer. I would like to thank them, as well as Pete and Steve, for their advice and support during my project.

For their contribution to the funding of my stay at Cornell University I would like thank Mrs. De Graaf of the Delft University of Technology and the Committee for Study- and Travel Funds of the Dutch Royal Institute of Engineers (KIvI).

Finally I wish to express my hope that this study can make a useful contribution to the management of phosphorus loads in the Cannonsville basin.

Leon Hermans

Delft, May 1999

Summary

The Cannonsville reservoir in Delaware County is part of the reservoir system that is operated by New York City for the drinking water supply of its nine million inhabitants. The water from the reservoirs is currently not filtered before distribution. Because of the high costs associated with filtration, New York City wants to continue this filtration avoidance in the future operation of its water system. This means that the water quality in the reservoirs must meet high standards. One of these standards concerns the phosphorus concentrations in order to prevent eutrophication of the reservoirs. Currently the Cannonsville reservoir does not meet the standards for phosphorus. Therefore the phosphorus loads in the Cannonsville basin must be reduced. This has to be done on the short term and may have severe negative impacts on the economic development of the region.

To deal with this issue, Delaware County is looking for ways to reduce the existing phosphorus loads and to manage new sources of phosphorus so that the total load meets the requirements imposed by New York City's drinking water supply. Delaware County wants to achieve this reduction of phosphorus loads without excessively inhibiting the economic activity in the region. To support Delaware County in developing a phosphorus management strategy for the Cannonsville basin, a quantitative analysis has been executed. The purpose was to identify and evaluate alternative management strategies for managing the phosphorus loads in the Cannonsville basin.

To describe and analyze the phosphorus management issues, an analytic modeling approach has been followed. The relevant aspects have been incorporated in both a conceptual and a mathematical model. The mathematical model could be optimized and has been used to see how individual phosphorus reduction measures could be combined to form phosphorus management strategies. The elements that have been modeled can be categorized into decision makers, decision variables (the individual measures/alternatives), criteria, scenarios, content goals and structural goals.

At first a selection has been made of alternatives that seemed to be promising ways to achieve phosphorus reductions in the Cannonsville basin. An analysis of the different sources of phosphorus in the basin led to a selection of alternatives related to agriculture and wastewater treatment. For agriculture the selected alternatives are related to the dairy farming activities that are dominant in the basin. The considered agricultural alternatives are composting, anaerobic digestion or transportation of manure, dairy cow nutrition management and implementation of traditional Best Management Practices (BMPs). BMPs are practices that aim mainly at minimizing phosphorus loads from rainwater runoff. Alternatives related to wastewater treatment are the upgrading of the municipal wastewater treatment plants and the rehabilitation of the septic systems in the basin.

To evaluate the effects of the alternatives, criteria have been identified: short-term phosphorus reduction (should be effective before 2002), long-term phosphorus reduction (balancing of phosphorus loads in the basin), pathogen reduction, costs and the distribution of costs over the various actors. Scenarios have been used to deal with the uncertainties in model parameters. Five scenarios have been formulated which range between estimations for the most optimistic and the most pessimistic situations. Content goals are associated with certain values for the identified criteria. They consist of a minimization of the total costs, a target value for short-term reduction of phosphorus loads, a target value for long-term reductions of phosphorus loads, a target value for pathogen reductions, and an acceptable distribution of costs.

Mainly because of the kind of data that were available for this study, the mathematical model has been formulated as an integer programming optimization model. This model could be solved to identify least cost strategies for various combinations of values for the identified content goals The analysis was done first for a variation of only short-term phosphorus reductions and costs, because these two

were considered to be the most important content goals. This analysis showed that unfortunately the short-term reduction targets were not met in any of the identified scenarios, which means that there was no feasible solution to the model. Therefore it has not been possible to identify different strategies that meet the short-term reduction target of 17,000 kg/y. Consequently also no trade-offs between secondary criteria such as pathogen reduction and variable costs could be identified.

Information in DEP's Phase II TMDL calculations showed that there might be feasible solutions to the model if a target concentration for phosphorus in the reservoir of 20 μg/l would be applied instead of the proposed target concentration of 15 μg/l. Unfortunately this information only became available after most of the analysis already had been completed. However the performed analysis is still considered to be valid, because it is most likely that the target concentration will be set at the level of 15 μg/l which was used in the analysis.

Analysis of the model results made it possible to draw certain conclusions and to formulate recommendations for phosphorus management to Delaware County based on these conclusions. The following recommendations are made:

1. Evaluate current target values
   It seems very useful to evaluate the current targets for critical phosphorus loads and for the critical phosphorus concentration in Cannonsville reservoir. In this evaluation attention should be given to the possibilities to develop reservoir-specific guidance values for the reservoirs of the New York City water supply system and to the consequences of shifting the accent in targets from total to dissolved phosphorus and from annual to seasonal loading. Furthermore targets for water bodies should be accompanied by a plan on how these targets can be realized.

2. Upgrade wastewater treatment plants
   The municipal wastewater treatment plants of Delhi, Stamford, Walton and Hobart should be upgraded as planned. However the costs are higher than was foreseen, so the arrangement with New York City should be reassured to prevent future discussions about the funding.

3. Continue the implementation of traditional agricultural best management practices
   The implementation of best management practices (BMPs) should be continued, either in combination with manure processing/transportation or individually.

4. Implement either composting or nutrition management on farms
   Composting might a good alternative for phosphorus reductions on farms if the market situation for compost is promising. If this is not the case, nutrition management might be a better alternative. Transportation of compost is only preferred if current soil conditions urgently require balancing of phosphorus loads. To make a good choice between composting and nutrition management some further investigations are recommended.

5. Review the execution of the rehabilitation program for septic systems
   The prioritizing procedure for septic systems rehabilitation should be reviewed. The current procedure is first come, first served, which results in a very inefficient use of funds. The use of more specific selection procedures may make it necessary to loosen the regulations for septic failures because else people will hesitate to report failures. To ensure cost-effectiveness, the failing systems on 'safe' locations do not have to be rehabilitated right away, while failing systems on sensitive locations do.

6. Study further possibilities for phosphorus reductions
   The alternatives that are included in the executed study are not sufficient to realize the necessary short-term phosphorus reductions. Therefore it is necessary to identify additional possibilities to

reduce phosphorus loads. These possibilities can be related to the non-dairy farms in the basin, to urban areas and to forests.

7. Prepare economic development plans
   Economic development is impaired by the current phosphorus management problems. It is not likely that these phosphorus problems are solved on the short-run, so economic development will probably remain impaired in the immediate future. To ensure at least some room for economic development, plans on the desired economic development and its implications for phosphorus loading could play a useful role.

8. Analyze policy options from physical, economic and social perspectives
   The phosphorus management problems are mainly caused by physical phenomena, but they also affect economic and social issues. Therefore decisions regarding the phosphorus management problems should also be analyzed from social and economic perspectives. It could be advantageous to combine the model developed for this study with the simulation models developed by NYCDEP.

The extent to which the study described in this report will contribute to the decision making process for phosphorus management in the Cannonsville basin depends on the extent to which the decision makers are willing to use its results. But regardless of their willingness, it is hoped that this study can make some of them aware of certain issues that deserve additional discussion and of the possibilities that quantitative models offer to produce insights that are useful to support decision making.

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BMP	Best management practice
BRE	Delaware County Office for Business Retention and Extension
CCE	Cornell Cooperative Extension
CNCPS	Cornell Net Carbohydrate and Protein System
CRF	Capital recovery factor (amortization factor)
CU	Cornell University
CWC	Catskill Watershed Corporation
DP	Dissolved phosphorus
EPA	U.S. Environmental Protection Agency
EPF	Environmental Protection Fund
FAD	Filtration Avoidance Determination
GWLF	Generalized Water Loading Function
IP	Integer programming
lb.	Libra or librae: pound or pounds
MOA	Memorandum of Agreement
NRCS	Natural Resources Conservation Service
NYC	New York City
NYCDEP or DEP	New York City Department of Environmental Protection
NYS	New York State
NYSDAM	New York Sate Department of Agriculture and Markets
NYSDEC or DEC	New York State Department of Environmental Conservation
NYSDOH	New York State Department of Health
NYS SWCC	New York State Soil and Water Conservation Committee
P	Phosphorus
PCPI	Per capita personal income
PSC	Phosphorus sorption capacity
PP	Particulate phosphorus
SDWA	Safe Drinking Water Act
SPDES	State Pollutant Discharge Elimination System
SRP	Soluble reactive phosphorus
SWCD	Soil and Water Conservation District
TDP	Total dissolved phosphorus
TMDL	Total Maximum Daily Load
TP	Total phosphorus
TPI	Total personal income
TSS	Total suspended solids
USDA	U.S. Department of Agriculture
USDC	U.S. Department of Commerce
WAC	Watershed Agricultural Council
WAP	Watershed Agricultural Program
WOH	West of Hudson: the watersheds in NYC's reservoir system that are located west of the Hudson River.
WRI or NYSWRI	New York State Water Resources Institute (part of Cornell University)
WWTP	Wastewater treatment plant

1. Introduction

Delaware County in the state of New York contains two reservoirs that are used for the water supply of New York City's nine million inhabitants. Because of drinking water quality requirements, the water quality of the water in the reservoirs must meet certain standards. One of these standards concerns the phosphorus levels in order to prevent eutrophication of the reservoirs. Currently these phosphorus standards are not met by one of the reservoirs in Delaware County, the Cannonsville reservoir. To protect the water supply of New York City, the phosphorus loads in the Cannonsville reservoir basin must be reduced. This has to be done on a short-term and it may have severe negative impacts on the economic development of the region.

To deal with this issue, Delaware County is looking for ways to reduce the existing phosphorus loads and to manage new sources of phosphorus so that the total phosphorus load meets the requirements imposed by New York City's drinking water supply. Delaware County wants to achieve this reduction of phosphorus loads without excessively inhibiting the economic activity in the region. In this process, Delaware County intends to work with the local communities and businesses, with various New York State and New York City departments and with academic researchers.

This case is of relevance to the whole of the U.S., because it is a test-case for showing that local government and local communities are capable of managing environmental resources in a sustainable way that permits economic development while still satisfying higher level government interests and constraints.

The New York State Water Resources Institute (WRI) at Cornell University is involved in this project to assist Delaware County in guiding the phosphorus management activities. The project described in this report is closely linked to the WRI-activities. It focuses on possible phosphorus management alternatives and it uses a quantitative analysis to determine promising management strategies, based on the identified alternatives.

In this report, the results of the project are described. It is divided in five main parts. In Part I the background of the project is described. This part starts with an introduction to the problems related to phosphorus loads in the Cannonsville basin in Chapter 2. Chapter 3 contains the problem statement and the general approach of the project.

Part II describes the economic and institutional framework in which the phosphorus issues are embedded. Chapter 4 deals with the economy of Delaware County and Chapter 5 introduces the main actors and their relationships.

After this necessary background information is given, Part III focuses on the possibilities to reduce phosphorus loads in the Cannonsville basin. This part starts with a description of the difficulties related to the assessment of phosphorus loads in Chapter 6. It continues with possible ways for reductions in the Chapters 7 to 10. Chapter 7 deals with phosphorus loads from agriculture, Chapter 8 with phosphorus loads from wastewater treatment plants and Chapter 9 with phosphorus loads from septic systems. Chapter 10 describes the sources that are not to be addressed in this project and the reasons for not addressing them.

The quantitative analysis is done with the use of models, which are introduced in Part IV. Chapter 11 contains a description of the structural model. This model is used as a conceptual model that identifies the relevant elements and their relations. Chapter 12 translates this structural model into a formal model, using mathematical expressions. This formal model can be solved to identify relevant solutions to the original problem. The resolution procedure for the formal model is described as the resolution model in Chapter 13.

The model results and their interpretation are the subject of Part V of the report. First the results of the modeling efforts are presented in Chapter 14. This chapter also contains a discussion of these model results, combined with a sensitivity analysis and an evaluation of the model use. The project's conclusions and recommendations to Delaware County are stated in Chapter 15. Finally the general approach used in this project is evaluated in Chapter 16. This chapter contains a discussion about the contribution that quantitative policy analysis could make to the quality of decision making on phosphorus management strategies for the Cannonsville basin.

Part I: Introduction to the project

2. Phosphorus management in the Cannonsville basin

2.1 New York City's water supply system

The Cannonsville reservoir is part of the drinking water supply system of New York City (NYC). The need for New York City to protect its drinking water sources explains for most of the current phosphorus management issues in the Cannonsville basin. It is the reason for the involvement of New York City in Delaware County's environmental management activities and for the phosphorus restrictions that are currently affecting some of the activities in the basin.

New York City's drinking water supply system was established in the 1800s and expanded to draw from catchments west of the Hudson River at the beginning of this century. It uses surface water storage in several reservoirs located in eight counties north and northwest of the city. Its watersheds cover some 4,921 square km (*this equals 1,900 square miles*). This system daily provides approximately 5.3 million m^3 (1.40 billion gallons) of drinking water to more than nine million consumers located in New York City and some of its surrounding regions. [WAC, December 1997]

The NYC water supply system can be divided in three main systems: the Croton system, located east of the Hudson River, and the Catskill and Delaware systems both located west of the Hudson River. Roughly ninety percent of the water is supplied by the west of Hudson (WOH) systems. The Catskill/Delaware watershed covers over 4,144 km^2 (1,600 square miles) of land in five counties. It consists of six major reservoirs, one of which is the Cannonsville reservoir. [WAC, December 1997]

Due to the high water quality in the west of Hudson systems, New York City does not filter this water before supplying it to consumers. This avoidance of a filtration step in the water treatment process is only possible if the water quality in the delivering reservoirs is constantly maintained at a high level. However, the Cannonsville reservoir does not meet the quality standards with regard to the phosphorus concentrations [NYCDEP, September 1996]. Therefore the phosphorus loads in this basin must be reduced, or else New York City might have to build a costly filtration plant.

To help avoid filtration, New York City has signed a Memorandum of Agreement (MOA, also referred to as Watershed Agreement) with the watershed communities in 1997 to protect the water quality in the reservoirs [MOA, 1997]. The basis of this MOA is that the local communities will control their polluting sources with assistance and money from New York City. This agreement gives Delaware County an opportunity to enhance its environmental standards with assistance and funding from New York City and State agencies. The other side is that if the agreed MOA-activities prove to be insufficient, New York City will use the strong legal powers it has for the protection of its water supply. Use of these powers to enforce phosphorus reductions will have serious negative impacts on Delaware County's economy. The MOA will be evaluated in 2002, five years after it was signed. If Delaware County is not able to reduce phosphorus loads in the Cannonsville basin before this time, it will be controlled to a large extent by strict New York City rules and regulations.

2.2 General description of the Cannonsville basin

Cannonsville basin characteristics

The Cannonsville basin is mainly located within Delaware County, State of New York, with only a very small part of the basin in Schoharie County. Its location is shown on the map in Figure 2.1. The basin covers 118 thousand hectares, which makes it the largest of the New York City watershed. The basin has approximately 23 thousand inhabitants and has a low population density [NRDC, 1993]. The land use in the watershed is dominated by forests and agricultural activities. Most agriculture is dedicated to dairy farming. Delaware County is aiming at increasing the economic activities to further develop the region. Some general data regarding the land use in the Cannonsville basin are stated in the following table:

Land Use	Area (ha)	Percent (%)
Corn	1530	1.3
Alfalfa	<118	<0.1
Grass	30254	25.7
Bare soil	<118	<0.1
Grass shrub	12478	10.6
Forest	69572	59.1
Impervious surface	706	0.6
Water-reservoir	1884	1.6
Water-other	1177	1.0
Total	117719	99.9-100.1

Table 2.1. Land use in the Cannonsville basin
(source: NYCDEP, January 1998, p.84)

Cannonsville reservoir characteristics

The Cannonsville reservoir is located at the western edge of Delaware County, about 190 km (120 miles) northeast of New York City. It was placed into service in 1965 and was formed by the damming of the West Branch of the Delaware River. The reservoir covers a surface area of approximately 15.8 to 19.4 km^2, depending on its actual storage [NYCDEP, May 1993 & September 1996]. Its capacity is 366 million m^3 (96.7 billion gallons) [NRDC, 1993]. Water enters the reservoir primarily from the West Branch of the Delaware River which drains 80% of the watershed, with minor contributions from Trout Creek (draining 5%) and several smaller tributaries [Auer et al. 1998].

Uses of reservoir water

Besides the water supply for New York City, a part of the water in the Cannonsville reservoir flows to the lower West Branch of Delaware River. This is necessary to maintain the flow in this river and to provide downstream users with the water they are lawfully entitled to. The water of the Delaware River serves numerous purposes, among others the protection of ecosystem values and the water supply of the city of Philadelphia.

The water flow in the City's Delaware aqueducts also serves hydroelectric power plants operated by New York City, to which the flow from the Cannonsville reservoir makes a significant contribution.

For the people in the Cannonsville basin, the reservoir has little practical value. It is used for restricted recreational purposes such as fishing. For this a license has to be obtained from New York City, which owns the reservoir and the riparian lands.

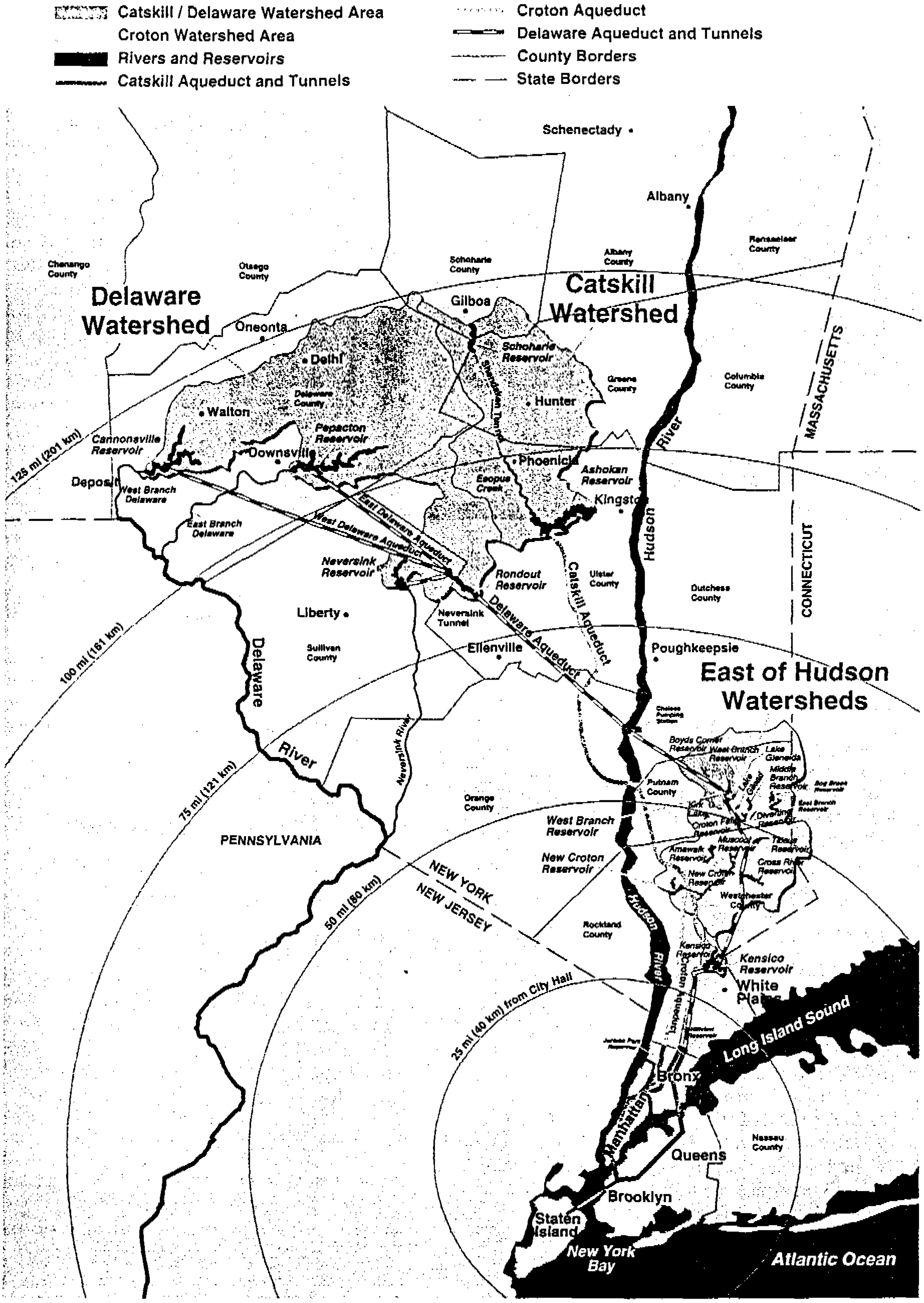

Figure 2.1. Location map of the Cannonsville basin and its surrounding region

2.3 Phosphorus management issues

Consequences of high phosphorus concentrations in the reservoir

The phosphorus loads in the Cannonsville basin exceed the standards, leading to higher phosphorus concentrations in the reservoir. This causes eutrophication, because the algae growth in the reservoir is restricted by the limiting availability of phosphorus. The impacts of higher phosphorus concentrations are shown in a diagram copied from [NYCDEP, December 1993], which is shown below in Figure 2.2.

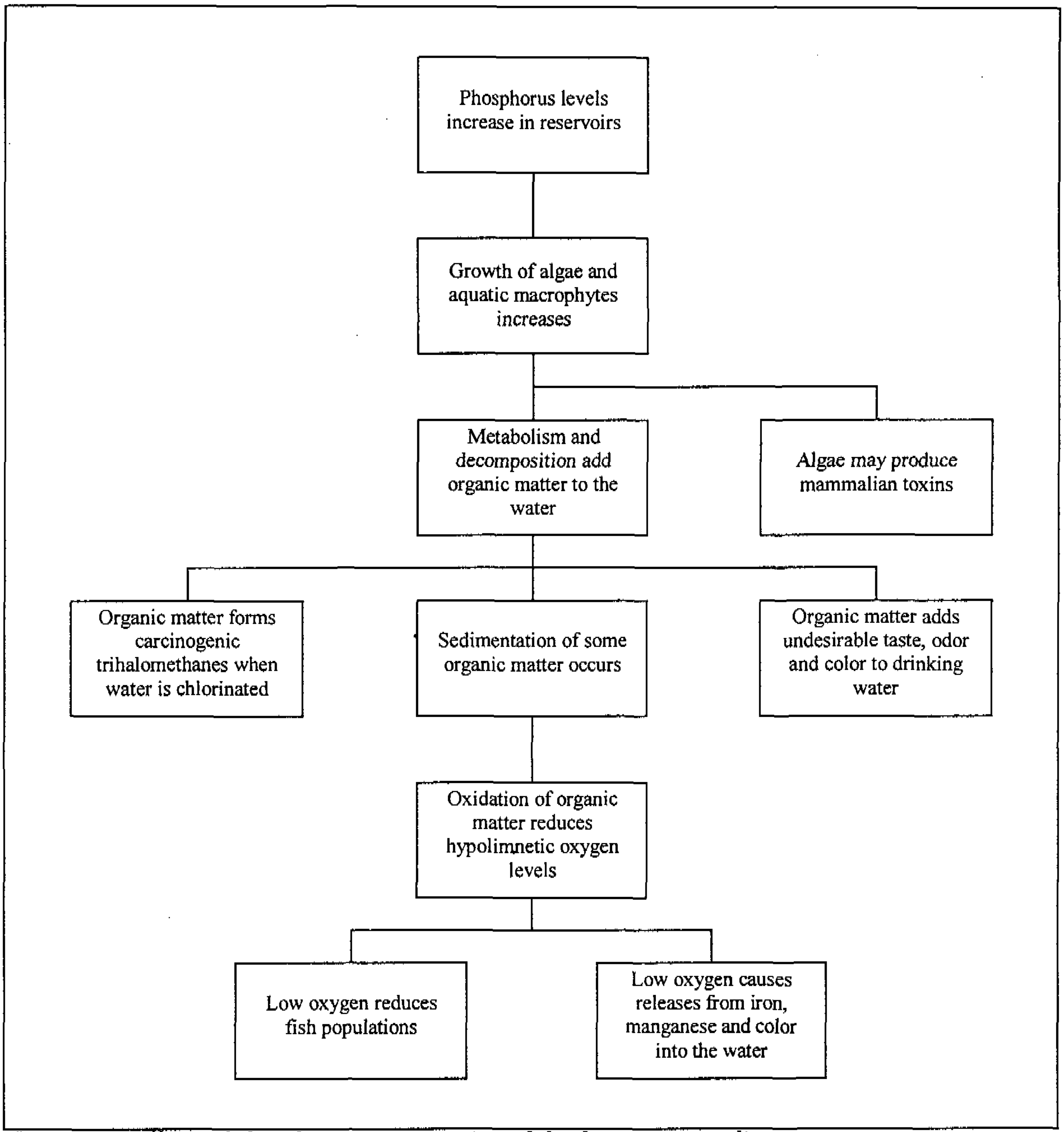

Figure 2.2. Effects of phosphorus on reservoir and drinking water quality
(source: NYCDEP, 1993)

From this diagram, it becomes clear that a high phosphorus concentration imposes health risks, affects taste, odor and color of drinking water and affects the ecosystems in the reservoir. Because of the phosphorus concentrations, the Cannonsville basin is officially labeled as phosphorus restricted basin, which means that the phosphorus loads inside the basin should be decreased.

The phosphorus problems are not new to the Cannonsville reservoir. Reservoir conditions typical of eutrophication have been reported since the 1970s. In several reports since 1979, excess loading of nutrients, primarily phosphorus, has been identified as the principal cause of the eutrophic conditions. [Longabucco and Rafferty, 1998]. During the period 1990-1997, the Cannonsville reservoir was taken offline for New York City's water supply at an average of ten times a year, for approximately 35% of the year. The late summer/early fall shutdown due to high algae levels can be as long as 2.5 months. [NYCDEP, November 1998].

Phosphorus offset pilot programs

To protect the water supply of New York City, the city's Department of Environmental Protection (NYCDEP) has issued revised "Rules and Regulations for the Protection from Contamination, Degradation and Pollution of the New York City Water Supply System and its Sources", which became effective May 1, 1997 [NYCDEP, July 1997]. A section of these regulations prohibits increases of discharges of wastewater treatment plants (WWTP) in phosphorus restricted basins. The only way to mitigate this section of the regulations is to participate in a phosphorus offset pilot program [NYCDEP, March 1997]. In this program, phosphorus loads from WWTPs may increase, but only if certain conditions are met. One of these conditions is that every kilogram of increase in phosphorus loads from WWTPs must be offset by a decrease of at least three kilograms of phosphorus loads from another eligible polluting source in the basin.

A general impression of the elements related to the general phosphorus management issues is given in Figure 2.3 on the next page. The figure shows a diagram containing some of the most important elements and their relations. These relations are indicated by arrows which have a plus or a minus assigned to them. A plus means that an increase of the element from where the arrow starts, will lead to an increase of the element at the arrow's destination. A minus means that an increase of one element leads to a decrease of another.

Phosphorus concentrations in the Cannonsville reservoir

The phosphorus concentrations in the Cannonsville reservoir are monitored by the New York City Department of Environmental Protection. This is done annually to determine which basins are designated as phosphorus restricted. For the reservoirs, total phosphorus concentrations are assessed, as well as the total phosphorus loads flowing into the reservoir from the basin.

For the analysis of the concentrations in the reservoirs, samples from all depths are used (as opposed to samples from surface water only). The phosphorus status is calculated as the geometric mean of measured phosphorus concentration in each year's growing season (May 1 to October 31), after which these values are averaged over a five year time period. This is done to reduce the effects of unusual hydrology or phosphorus loading for any given year. Based on the calculated phosphorus status, a reservoir basin is designated as restricted or unrestricted. [NYCDEP, July 1997]

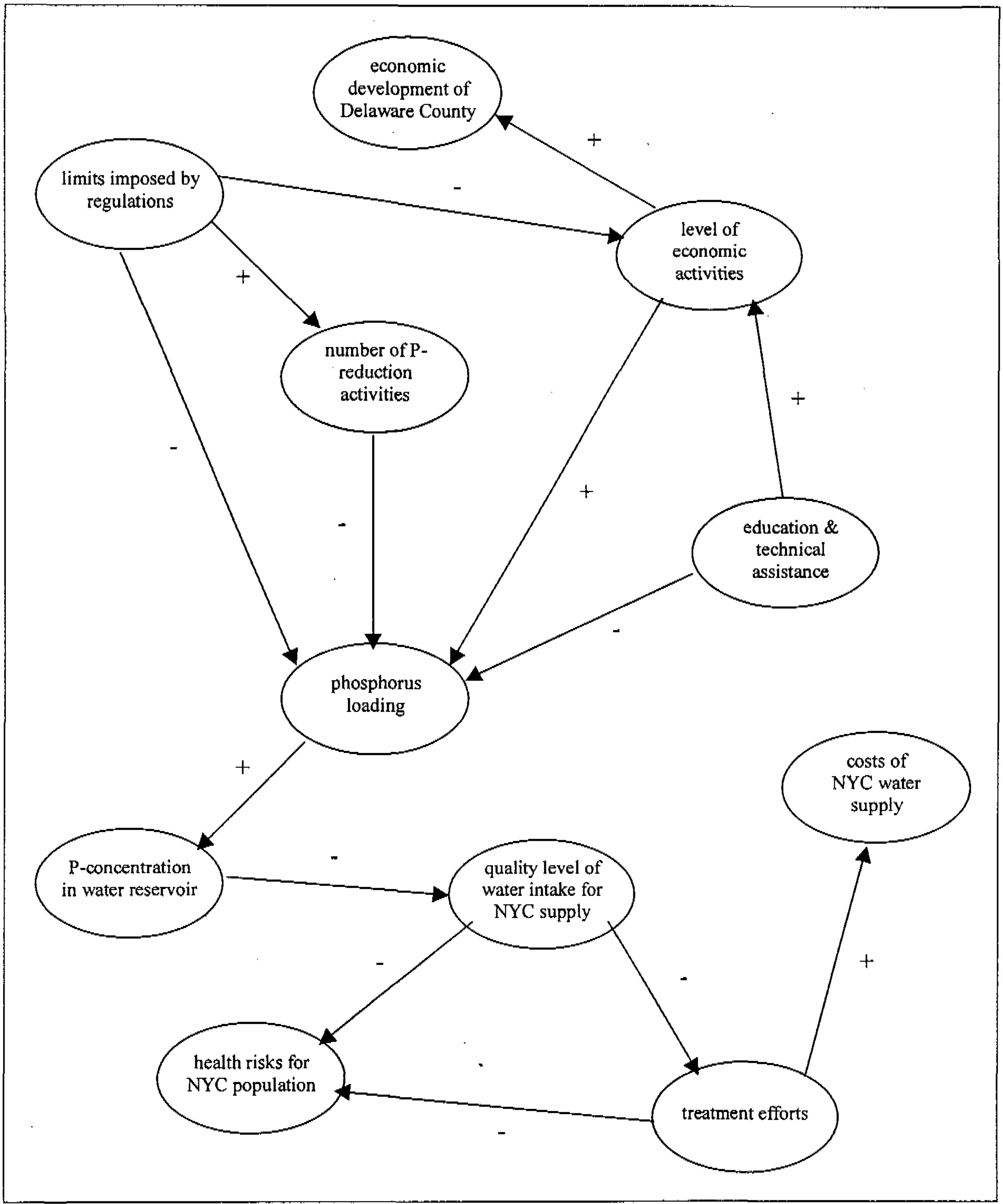

Figure 2.3. Relations diagram for the phosphorus problem in the Cannonsville basin

Phosphorus loads to the Cannonsville reservoir

The phosphorus loads are calculated as the annual geometric means with a five year running average. These loads are the basis for New York State to manage phosphorus in basins. This process is specified in the federal Clean Water Act and it uses Total Maximum Daily Loads (TMDL)[1]. The TMDL functions as a critical load for the pollution of a water body, which should not be exceeded.

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[1] Although the term Total Maximum Daily Load implies a mass load per day, the TMDL for phosphorus is actually expressed as kg per year. TMDLs are a federal instrument used for all sorts of polluting materials. In the case of toxic metals a daily value is appropriate, but in the case of nutrients an annual cycle or growing season is.

These TMDLs are based on the guidance value for the critical phosphorus concentration in the reservoir, which is currently set at 20 µg/l for the Cannonsville reservoir [NYCDEP, 1998]. This guidance value for the critical concentration is based on water quality requirements for recreational uses. It is proposed by New York City that in the near future this guidance value is lowered to 15 µg/l to better reflect drinking water considerations [NYCDEP, March 1999].

The TMDL combines loads from both point and nonpoint sources. It is expressed as the sum of wasteload allocation for point sources (WLA), load allocation for nonpoint sources (LA) and a margin of safety (MOS) which accounts for uncertainty involved in the modeling process. This sum should be less than the loading capacity (LC) which represents the critical load:

$$TMDL = WLA + LA + MOS \leq LC$$

The TMDL that was calculated in the Phase I report [NYCDEP, 1996] based on the current critical phosphorus concentration was 16642 kg/y. However these calculations were made using a very rough loading model based on land-uses and export coefficients (the Reckhow Land Use Model). The proposed Phase II TMDL calculations have been released in March 1999 [NYCDEP, March 1999]. They are based on the more accurate Generalized Watershed Loading Function (GWLF) model. The most important results of these Phase II calculations are shown in Table 2.2. This table shows that there are large differences between the TMDL calculations of Phase I and Phase II. Unfortunately, the Phase II calculations were not available until the spring of 1999, when this report was already in its final stage. Therefore it has not been possible to make optimal use of the most recent Phase II figures, but they have been incorporated in the study as much as possible.

	15 µg/l guidance value	**20 µg/l guidance value**
TMDL (kg/y)	40237	53650
MOS (12.5% of TMDL; SE=1.5)	5030	6706
Available Load (TMDL - MOS) (kg/y)	35207	46944
WLA (kg/y)	1059	1059
LA (kg/y)	34148	45885
Current Load (kg/y)	52368	52368
Total load reduction required (kg/y) (current load – available load)	17161	5424

Table 2.2. Proposed Phase II calculations for Cannonsville reservoir
(source: NYCDEP, March 1999, Table 5.1)

There have been various studies in the past that have estimated phosphorus loads to the Cannonsville reservoir from different sources. An overview of these studies can be found in the Phase I document[2] that has been prepared for the Delaware County Phosphorus Study Committee [WRI, December 1998]. Currently it is generally believed that the NYCDEP 1998 estimations based on the GWLF model are the most accurate estimations available [WRI, 1998]. These estimations are shown in Table 2.3. These estimations differ a little from the load estimates in the TMDL Phase II report (see the current load estimate in Table 2.2). This is mostly due to a higher estimate in loads from wastewater treatment plants in the TMDL Phase II report (between 6000 and 8000 kg/y). However other details of the TMDL Phase II loading estimates are not known, so the GWLF estimates calculated in 1998 will still be used here.

The figures of Table 2.3 illustrate that the major part of the phosphorus loading is coming from agriculture, wastewater treatment plants and forests. The sources of phosphorus in groundwater are not specified, but it is likely that a substantial part of this comes from farmlands and forests. The shown

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[2] Phase I here refers to the phases in the process of phosphorus management in Delaware County. The phases of this process are not the same as the phases for the development of TMDLs by NYCDEP and NYSDEC.

GWLF estimates are consistent with estimations based on event-based sampling. These estimated the phosphorus loading to be approximately 43000 kg/y [Longabucco and Rafferty, 1998]. But as stated above, the most recent NYCDEP estimations are around 52000 kg/y.

Phosphorus sources	**Phosphorus Load (kg/y)**	**Part of Total Load (%)**
Corn	11200	24
Hay and pasture	9800	21
Barnyard	700	2
Urban and bare soil	1200	3
Forest and grass-shrub	10000	22
Groundwater	7800	17
Septic Systems	1100	2
WWTPs	4300	9
Total Phosphorus Loading	46152	100

Table 2.3. Phosphorus Loading for 1993.
(source: NYCDEP, January 1998)

Recently several Best Management Practices (BMP) have been proposed to decrease phosphorus loads from various sources in the New York City watersheds [NYCDEP and NYSDEC, 1997]. These BMPs relate to improvements in agricultural activities, storm water discharges, WWTPs and several other elements, which are all shown in Figure 2.4. The interpretation of this relations diagram is similar to that of the diagram in Figure 2.3.

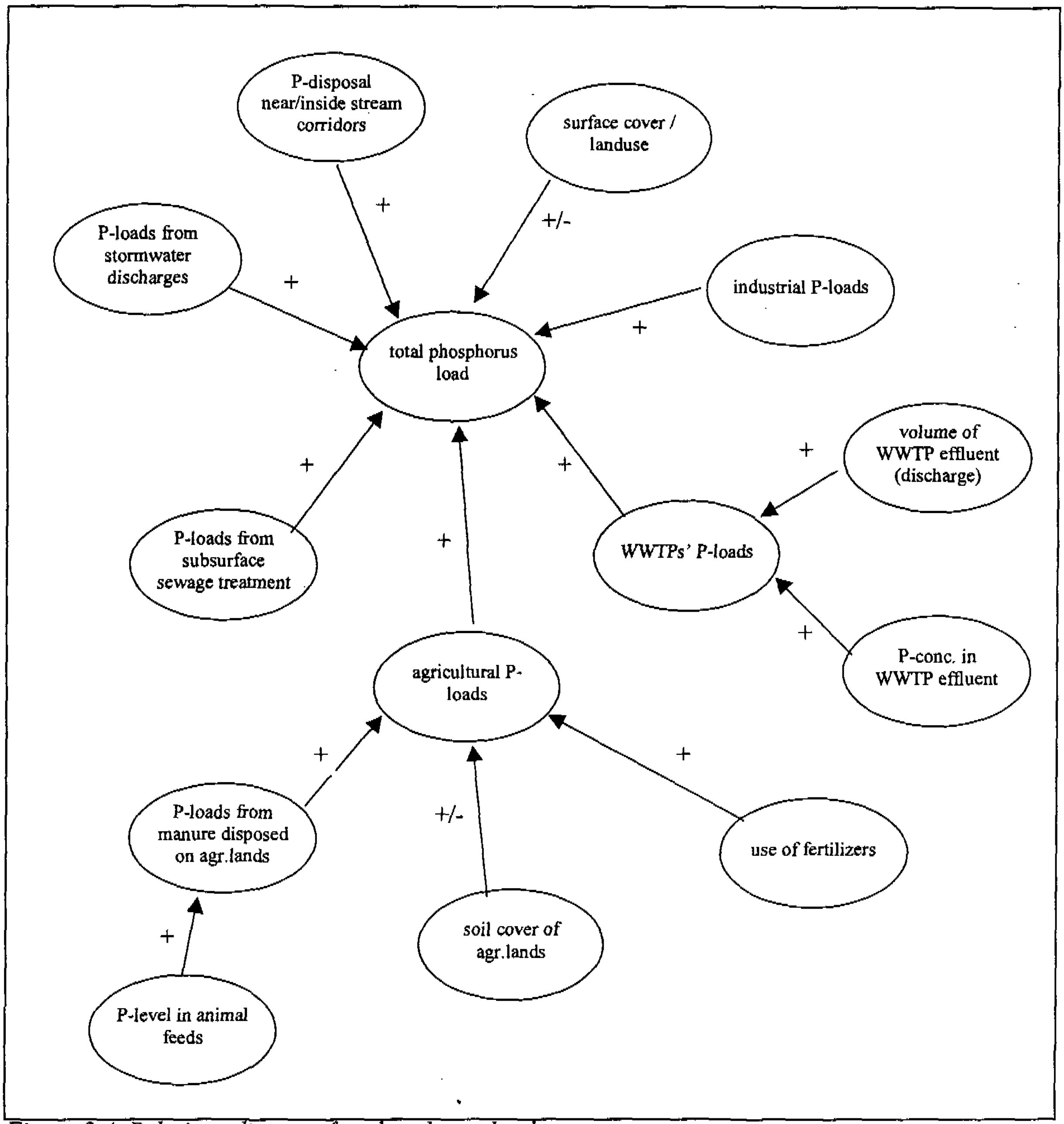

Figure 2.4. Relations diagram for phosphorus loads

3. Problem statement

To deal with the phosphorus management issues in the Cannonsville basin a special group has been formed: the Delaware County Phosphorus Study Committee. This group consists of representatives of all the key participants and stakeholders. One of them is the New York State Water Resources Institute (WRI) at Cornell University. As a first activity, the Water Resources Institute has prepared a Phase I report that contains an overview of the current situation regarding the phosphorus reductions and of the possibilities to further reduce phosphorus loads [WRI, December 1998].

3.1 Objective

The project described in this report, has been closely linked to the activities of the WRI. Its goal has been to contribute to the identification of promising alternatives or management practices. These promising alternatives have been analyzed using quantitative techniques, mostly from an economical point of view. This has been done to see how these alternatives could be combined into management strategies for the Cannonsville basin.

This has led to the formulation of the following project objective:
Identify and evaluate alternative management strategies for the phosphorus loads in the Cannonsville basin based on a quantitative analysis.

3.2 Research questions

With the use of the previous information, a central research question has been formulated for this project. The central question has been subdivided in several sub-questions which are stated after the central question.

Central research question:
What management strategies are promising ways towards phosphorus reduction in the Cannonsville basin without impairing the economic development?

Sub-questions:
The identified subquestions are related to the following issues:
1. Reductions to be reached:
2. Past and planned phosphorus management activities
3. Actors involved in phosphorus management
4. Sources contributing to phosphorus loading
5. Possible alternatives
6. Problem formulation in models
7. Problem resolution
8. Interpretation of results

3.3 Project approach: the analytic modeling process

The project has been executed following an analytic modeling approach [Beroggi, 1999]. This means that the problem has been analyzed with the use of models to describe the system under investigation. In the analytic modeling process, three main steps are recognized: structuring, formalization and resolution. These steps have been executed in an iterative manner.

During the first step, the problem structuring, a structural or conceptual model has been constructed. This model identifies the relevant elements and their relations. This step has been executed parallel and in interaction with the preparation of the first draft of the WRI report which was finished in December 1998. The results of this first step are presented in the immediate following chapters of this report.

The next step in the analytic modeling process consisted of the formalization of the problem, based on the structural model. This has been done using mathematical expressions. The result is the formal model as described in Chapter 12.

The third step was to define a resolution model. This resolution model should describe a procedure to resolve the problem based on the formal model. There are numerous algorithms available, and the most suitable one had to be selected. The choice for a certain algorithm might require some adjustments of the formal model, because it should be expressed in a form that suits the algorithm

After these three steps, it was possible to identify solutions for the problem model. However, the derived solutions had to be interpreted carefully because modeling approaches can never provide a complete substitution of real world mechanisms. This interpretation lead to conclusions related to the real problem. Based on these conclusions, recommendations could be made to Delaware County, which are described in Chapter 15.

As a last activity the general approach followed for the project has been evaluated in the final chapter. In this evaluation, the emphasize lies on the use of quantitative policy analysis for the development of phosphorus management strategies for the Cannonsville basin.

Part II: Economic and institutional framework

4. Economy of Delaware County

This chapter contains information on the economy of Delaware County and the existing plans for future economic development. This information provides a useful background to assess whether or not certain activities impair economic development. This is of importance for this project because the central research question concerns with ways towards phosphorus reductions in the Cannonsville basin without impairing economic development (paragraph 3.2).

The natural boundaries of the Cannonsville basin do not match the administrative boundaries of Delaware County. Some information is only available for the whole county and cannot be de-aggregated to basin level. It is assumed that information about the economy of Delaware County also provides a good insight in the economy of the Cannonsville basin; the basin covers more than half of the county's land area and comprises more than half of the county's population.

4.1 General economic features

Personal income
In 1996, Delaware County had a population of 47,142 people. The per capita personal income (PCPI) was $17,382. With this PCPI, Delaware County ranked among the lowest of the New York State counties. The PCPI was 59% of the State average and 71% of the national average. The total personal income (TPI) in 1996 was 819,435 thousand dollars. This reflected an increase of 4.2% from 1995. On State level the TPI increased 4.9% and the national increase was 5.6%. The TPI includes the earnings (51.8%); dividends, interest and rent (21.8%); and transfer payments received by the residents of Delaware[3] (26.4%). The average wage per job in Delaware County was $22,650; for New York State this was $36,272. [USDC, 1996]

Earnings
The earnings by persons employed in Delaware totaled 497,558 thousand dollars in 1996. The most important industries in Delaware and their contribution to the total earnings are stated in Table 4.1.

Industry	Earnings	Percent
Manufacturing	161,751	32.5
Government	119,754	24.1
Services	76,181	15.3
Retail trade	56,454	11.3
Construction	22,932	4.6
Transportation and public utilities	17,509	3.5
Finance, insurance and real estate	17,267	3.5
Wholesale trade	13,870	2.8
Farm earnings	5,416	1.1
Agricultural services	3,649	0.7
Mining	2,436	0.5
Forestry, fishing	339	0.1
Total	497,558	100

Table 4.1. Earnings by industry in Delaware County (thousands of dollars)
Source: Regional Economic Information System [US DC, 1996]

Employment
In 1996, the total full- and part-time employment in Delaware County comprised 24,047 persons. Of this total employment, 17,039 was wage and salary employment. Farm proprietors' employment was

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[3] By far the largest part of transfer payments is formed by government payments to individuals (for retirement, medicaid etc.)

812 persons and nonfarm proprietors' employment equaled 6,196 [USDC, 1996]. The employment by industry is shown in Table 4.2. As far as government employment is concerned, most people are employed by local government agencies (3,236). State government employed 712 people, federal government 266.

Industry	Employment	Percent
Manufacturing	4,920	20.5
Services	4,901	20.4
Government	4,214	17.5
Retail trade	4,134	17.2
Finance, insurance and real estate	1,638	6.8
Construction	1,312	5.5
Farm employment	1,174	4.9
Transportation and public utilities	578	2.4
Wholesale trade	559	2.3
Ag. services, forestry, fishing	377	1.6
Mining	240	1
Total	24,047	100

Table 4.2. Employment by industry in Delaware County (persons)
Source: Regional Economic Information System [US DC, 1996]

Most businesses are small businesses that employ only one to four people. The two largest businesses are manufacturers of electronic equipment and printing. They employ approximately 1,400 persons each. In total there are some 2,500 businesses, but less than 30 businesses have more than 200 employees. [BR&E, November 1998].

Agriculture in the local economy

Although agriculture does not seem to be the most important industry when one looks at earnings and employment, it does play an important role in the county. A lot of (economic) activities are influenced by the presence of a large agricultural sector. This can be understood when one compares Delaware County with some other regions:

Region	Earnings	Employment
Delaware County	1.1	4.9
Schoharie County[4]	1.7	6.4
New York City	0.0004	0.006
New York State	0.1	0.6

Table 4.3. Contribution of farming to total earnings and employment in several regions (percent).
Source: Regional Economic Information System [US DC, 1996]

It is important to notice that the farm cash receipts were about ten times the earnings, but for the earnings the production expenses are subtracted from the receipts (as with the other industries). In general agriculture is an important part of the economic activities in Delaware, although it is not as profitable as some other enterprises.

4.2 Future perspectives

An idea of the future perspectives of Delaware County's economy has been obtained through discussions with people at the County Department for Planning and Economic Development and the County Office for Business Retention and Extension. Additional information was found in the

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[4] Schoharie County is located adjacent to Delaware County and is also a rural area (and part of the New York City watershed).

proceedings of a local conference on economic development in Delaware County [Delaware County Economic Summit, 1997].

In large, the economic development seems to be limited by two important factors. The first is formed by the watershed regulations that are perceived as a barrier for the expansion of economic activities. The second factor is the absence of a higher technically trained workforce which causes problems related to the recruitment of higher educated employees.

Besides these two major factors, there are some other issues that have a negative influence on the local business climate. Taxes and worker compensation rates in New York State are amongst the highest in the country; costs for utilities such as electricity are high; there is no public transportation system; there is a low availability of banking credit to businesses; and the distance to markets for products is long.

The ideas for Delaware County's economic development focus on incremental growth. Important issues are the retention and expansion of the existing businesses, and the attraction of small new businesses. At this moment, several potential areas for economic growth are identified:

- Internet businesses (for example a regional internet business mall);
- Diversification of agriculture;
- Tourism and outdoor recreation.

From these future projections and plans, it can be concluded that economic development in the county requires the opportunities for expansion of small, either existing or new, businesses. It is favorable when there is room for a large industry to settle in the area, but the chances of attracting such industries do not seem very high at this point.

5. Important actors

5.1 Identification of actors

There are several actors that play an important role in the phosphorus management issues in Delaware County. Most of these actors are government agencies or organizations that are strongly related to them. These actors can be categorized into three levels: federal, state and county level. There are a lot of actors involved in the phosphorus management issues in Delaware County, but only the major ones are introduced in this paragraph.

Federal level
U.S. Environmental Protection Agency
On the federal level the most important organization is the U.S. Environmental Protection Agency (USEPA or EPA). This is the agency that makes the final determination on filtration avoidance for New York City's water supply. The EPA oversees most of the activities by state and local agencies that are related to environmental issues. Besides controlling the local agencies, EPA also assist them in their activities through guideline documents and technical support. Federal laws like the Safe Drinking Water Act give EPA strong legal authorities.

U.S. Department of Agriculture
Another important organization on federal level is the U.S. Department of Agriculture (USDA). This department runs several programs to implement agricultural nonpoint pollution source management. USDA has agencies on local level, like the USDA-National Resource Conservation Services.

State level
New York State Department of Environmental Conservation
On state level a major role is played by the New York State Department of Environmental Conservation (NYSDEC or DEC). This agency is responsible for protecting and preserving the quality of the state waters. NYSDEC administers the permits for wastewater treatment plants in the state. Related to the phosphorus issues, NYSDEC establishes guidance values and TMDLs for phosphorus. Furthermore the DEC develops guidance documents on topics like management practices and watershed planning. [NYSDEC, 1997].

New York State Department of Health
The New York State Department of Health (NYSDOH) is the agency responsible for a safe drinking water supply for the citizens of New York State. The New York City Watershed Rules and Regulations that are formulated by New York City are subject to approval by the NYSDOH.

New York State Department of Agriculture and Markets
The New York State Department of Agriculture and Markets (NYSDAM) is the main State agency concerned with agricultural issues. The NYSDAM is part of the Delaware County Phosphorus Study Committee and started an Agriculture Environmental Management initiative a few years ago.

New York State Soil and Water Conservation Committee
The New York State Soil and Water Conservation Committee (NYS SWCC) is concerned with nonpoint source management in the State. It administers the funds for New York's Nonpoint Source Implementation Grant Projects and it cooperates with NYSDAM in the Agriculture Environmental Management initiative. The SWCC supports the County Water Quality Coordinating Committees that are responsible for developing county water quality strategies.

Local level – New York City Watershed agencies

On the local level both county and other local government agencies related to the New York City watershed are identified. First the watershed agencies will be introduced.

New York City Department of Environmental Protection

The New York City Department of Environmental Protection (NYCDEP or DEP) is responsible for the operation of New York City's water supply system, the pollution control in the New York City Watershed and the water quality in the City's reservoirs. Because this is of importance for the drinking water supply of millions of people, NYCDEP has some strong legal and financial means at its disposal. Based on the State Public Health Law, NYCDEP has the authorization to make watershed rules and regulations to protect the City's drinking water supply from contamination, although these rules are subject to the approval of the NYS Department of Health [Pfeffer, 1998]. NYCDEP approval is needed for a lot of activities that may affect the water quality in the City's watershed. NYCDEP cooperates with the NYSDEC in the assessment of TMDLs and it decides whether or not a basin is phosphorus restricted, based on the monitored phosphorus concentrations in the reservoir [NYCDEP, March 1998].

Watershed Agricultural Council

In August 1994 an agreement was signed to execute a Watershed Agricultural Program (WAP) in the New York City Watershed. The objective was to protect the City's reservoirs from agricultural pollution, while maintaining the economic viability of farming in the Catskill/Delaware Watershed region. The Watershed Agricultural Council (WAC) guides the Watershed Agricultural Program's implementation. It is a farmer-led not-for-profit organization and its board consists of farmers, agribusiness representatives and the Commissioner of NYCDEP. NYCDEP provided $35.2 million for the implementation of the WAP in the first five years. The WAC has contracted the local Soil and Water Conservation Districts (SWCD), the Cornell Cooperative Extension Association (CCE) and the USDA Natural Resources Conservation Service (USDA-NRCS) to assist in implementing the program. [WAC, 1997]. Currently 115 farms in the Cannonsville basin are participating in the WAP. For these farms, Whole Farm Management Plans have been or are being established [WRI, 1998]. This is done with assistance of Planning Teams, consisting of people from SWCD, CCE and USDA-NRCS. The scientific base for the Whole Farm Planning activities is provided by the involvement of Cornell University and its New York State Water Resources Institute. The WAP is concerned with all the agricultural pollution and not with phosphorus specifically, but recently the focus has shifted more and more to phosphorus.

Catskill Watershed Corporation

Part of the 1997 Memorandum of Agreement between New York City and the Watershed communities, was the establishment of several Watershed Protection and Partnership Programs for the West of Hudson watersheds. The Catskill Watershed Corporation (CWC) was established under the MOA to administer and manage some of these programs. The CWC is an independent locally-based not-for-profit organization, and its members consist of twelve representatives of West of Hudson communities (of which six are from Delaware County), two members appointed by the State Governor (one with approval of environmental organizations) and one New York City employee appointed by the Mayor.

Local level - Delaware County agencies

Delaware County Soil and Water Conservation District

The Delaware County Soil and Water Conservation District (SWCD) is concerned with the conservation of the County's soil and water resources, including the control of pollution from nonpoint sources. Currently the SWCD is participating in the Watershed Agricultural Program in Delaware County. The SWCD is involved in the septic systems rehabilitation program, in wetland protection and in groundwater quality protection near landfills. The SWCD is actively participating in the activities to reduce phosphorus loading in the county and is represented in several of the related committees.

Cornell Cooperative Extension

The Delaware County Cornell Cooperative Extension Association (CCE) is related to Cornell University and was established as a partnership with local communities to put experience and research knowledge to work. CCE provides technical and managerial expertise to assist farmers in meeting their objectives. It is participating in the Watershed Agricultural Program, as well as in the various committees dedicated to phosphorus reductions in the County.

USDA Natural Resources Conservation Service

The USDA Natural Resources Conservation Service (NRCS) of Delaware County is a local agency of the USDA that is to promote the sustainable use of privately held land. It provides information and technical assistance and encourages voluntary land stewardship by individual landowners. The NRCS is participating in the WAP and has a lot of experience in working with Best Management Practices (BMPs) for nonpoint sources of pollutants.

County Department of Planning and Economic Development

The Department of Planning and Economic Development is responsible for the comprehensive planning of the County's future physical and economic structures. The Department assists local businesses that want to expand and it helps starting businesses. This task has become more important due to the watershed regulation and the phosphorus restriction of the Cannonsville basin. Expanding businesses have to comply with numerous requirements based on the watershed regulations.

County businesses

There are numerous businesses in Delaware County, most of which are relatively small (see previous chapter). Due to the fact that the Cannonsville basin is phosphorus restricted, it is very difficult for these businesses to expand their activities. Expansion requires compliance with several regulations and can only be done according to the conditions of the pilot phosphorus offset program (Chapter 2). Control of phosphorus pollution seems critical for a healthy future perspective for the local business community.

Farmers

The farmers form a part of the county business community that requires special attention with regard to phosphorus issues. Agriculture has been identified as a major contributor to the phosphorus loading in the basin. Currently the Watershed Agricultural Program addresses the pollution from agriculture in a cooperative effort between the farming community and the government agencies. Representatives of the farming community are part of the WAC and of the phosphorus steering committee. In January 1998 a Manure Infrastructure Committee has been formed to address the problems that are related to the manure on a basin level. Represented in this Committee are five farmers, the SWCD, NRCS, CCE and NYSWRI.

Wastewater treatment plants

Point sources of phosphorus loading in the basin are the wastewater treatment plants (WWTPs). Most of the bigger ones are municipal plants. As part of the MOA, the WWTPs have to provide tertiary treatment for phosphorus removal. The costs of the upgrades that are not required by State or federal laws, but only as part of the MOA, are reimbursed by NYC. Each WWTP needs a State Pollution Discharge Elimination System (SPDES) permit to operate. Within the New York City watersheds, the SPDES program is effectively administered by NYSDEC and NYCDEP.

5.2 Relations between actors

The description of actors in the previous paragraph already shows that there are various relationships between them. Some of the types of relations that can be distinguished are relations based on legal authority, relations based on communication and relations based on money flows between actors. Some insight in the influence that actors have over each other can be derived from diagrams depicting important legal and financial relations. Actors can also have strong influence based on communication or personal structures. An important platform for communication is formed by the Delaware County Phosphorus Study Committee in which all the state and local actors mentioned above are represented. A diagram for the communication relations has not been constructed because the importance of such relations is very difficult to assess.

The relation diagrams in Figures 5.1 and 5.2 show the organizations on the various levels that have been identified. The county government agencies have been depicted as one actor, because they work closely together and often have the same sort of relationships with other actors. It should be noted that the diagrams only show a selective part of the existing relations, though it is believed that this gives an adequate general impression of the existing relationships.

Figure 5.1 shows the legal means actors have to influence each other. From this diagram it becomes clear that the USEPA has a lot of control based on the Safe Drinking Water Act (SDWA). Based on this Act, USEPA makes the Filtration Avoidance Determination for New York City's water supply. The State agencies have some influence over NYCDEP as their approval or permits are needed for some of NYCDEP's activities. NYCDEP and NYSDEC are jointly responsible for SPDES permits and TMDL calculations, as regulated under the MOA. As a water supplier, NYCDEP is authorized to develop and implement rules and regulations to protect the water quality in the City's watershed, providing that NYSDOH approves of these rules. This gives NYCDEP a strong position towards the Delaware County agencies.

Some of the money flows between actors are shown in Figure 5.2. There are several State funds, such as the Environmental Protection Funds and funds under the Clean Water/Clean Air Bond Act. A lot of these funds are administered by NYSDEC. This gives NYSDEC an important instrument to influence activities that need additional funding, which is the case for a lot of local phosphorus reduction efforts. NYCDEP has agreed to pay for the programs under the MOA and it funds the WAC. Based on the MOA the approval of NYCDEP is needed for a lot of the spending of these MOA-funds, but the primary responsibility for their administration lies with the Catskill Watershed Corporation in a lot of cases. More information on some of the funds that have been identified can be found in Appendix A. This appendix may provide some additional insight of the relations shown in Figure 5.2. Of course the Delaware County agencies have their own funds to support the local farmers and businesses, but these are not shown because they are often of a smaller size than the funding that can be obtained from the various State and Watershed programs.

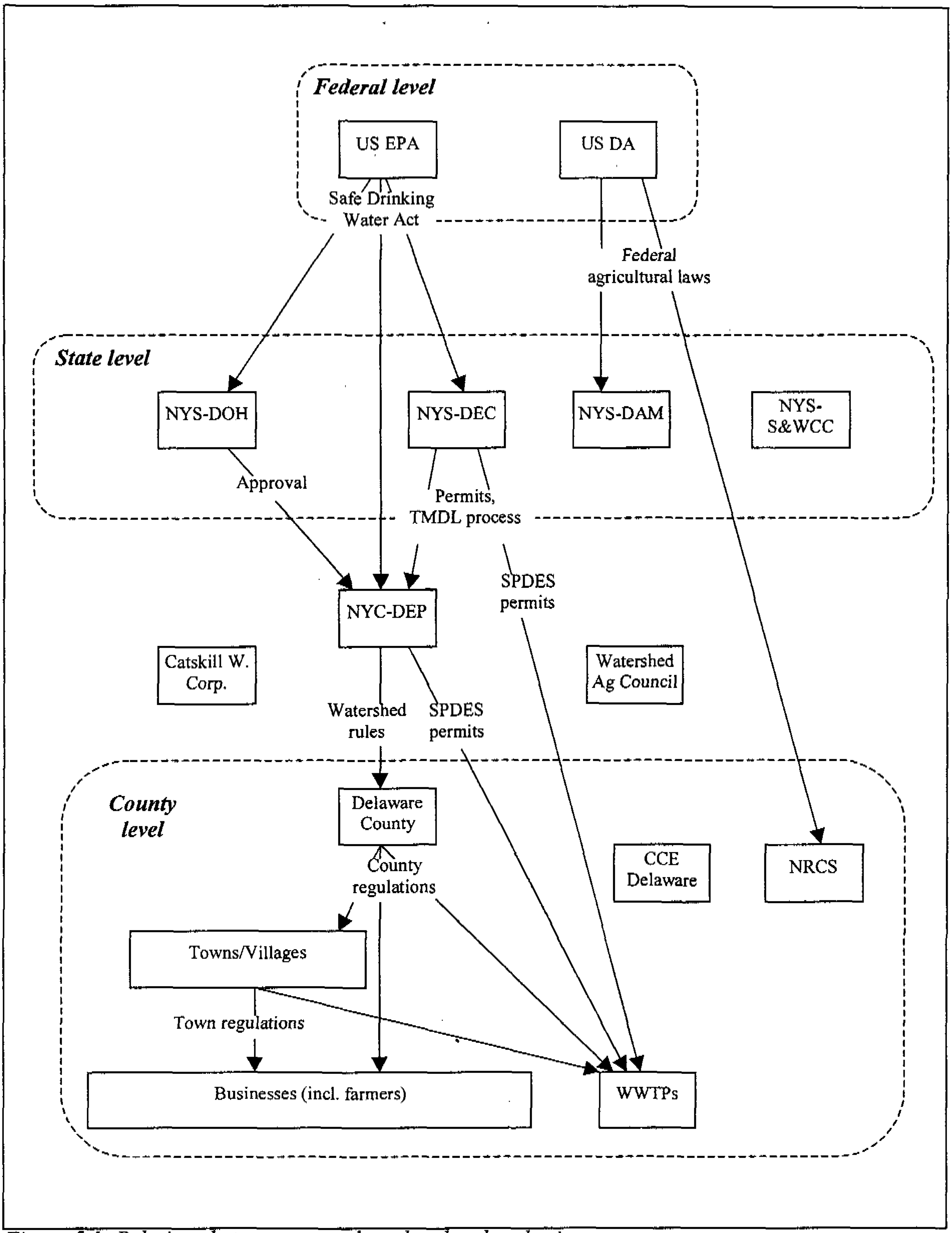

Figure 5.1: Relations between actors based on legal authority

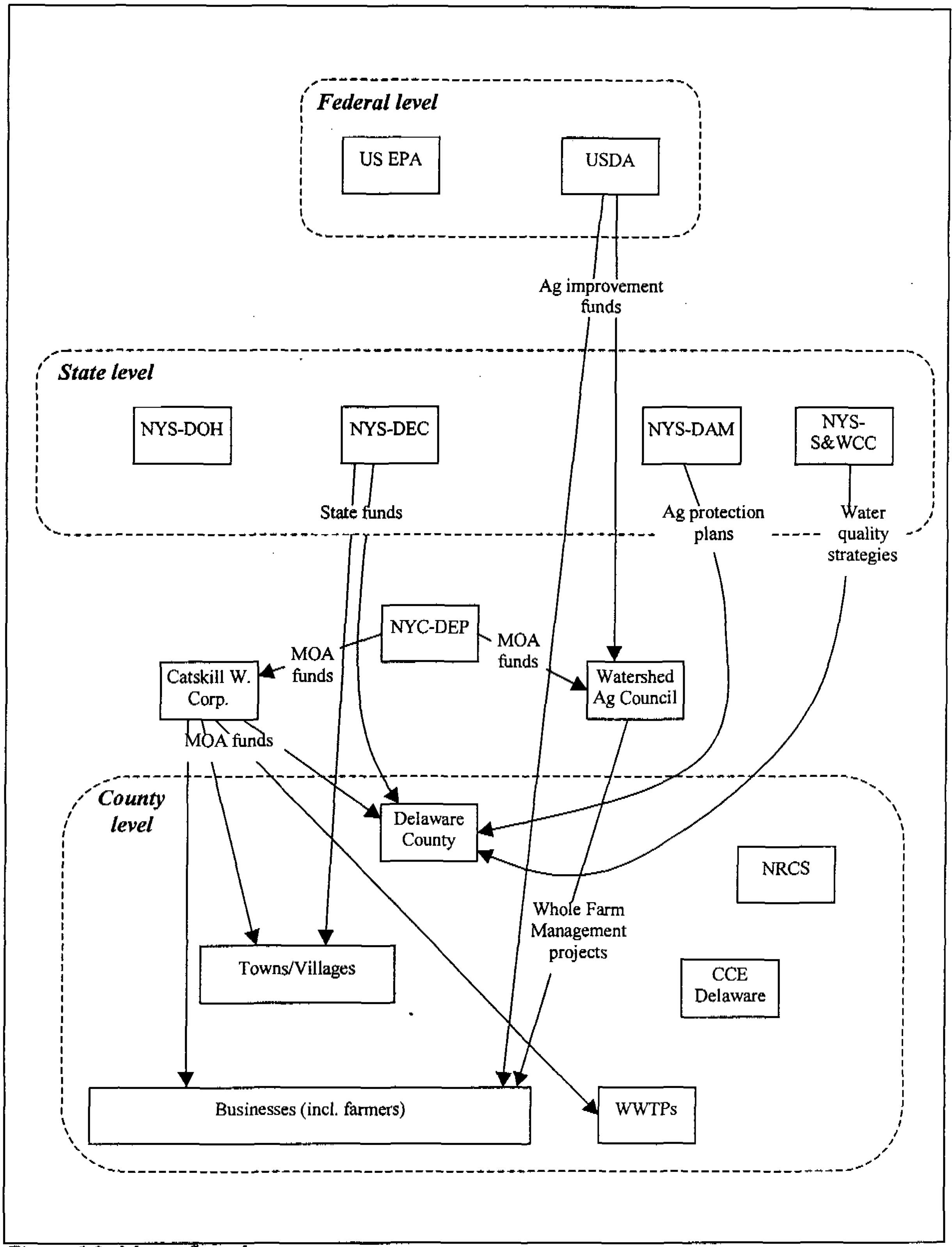

Figure 5.2: Money flows between actors

Part III: Phosphorus reduction

6. The assessment of phosphorus loads

Before the possible reductions of phosphorus loads are identified, it is useful to have some understanding of the way in which phosphorus loads are assessed as well as the behavior of phosphorus in the environment. These topics will be the subject of this chapter.

6.1 Phosphorus in the environment

Classification of phosphorus

There are several different forms in which phosphorus is present in the environment. To classify these different forms, a distinction is usually made between dissolved phosphorus (DP) and particulate phosphorus (PP). Dissolved phosphorus can be further divided into soluble reactive phosphorus (SRP) and dissolved organic phosphorus (DOP). Particulate phosphorus is further partitioned into phytoplankton-phosphorus (PhyP), zooplankton-phosphorus (ZP) and available and unavailable nonliving particulate phosphorus (respectively ANLPP and UNLPP). The sum of all phosphorus, dissolved and particulate, is called total phosphorus, TP. [Auer et al. 1998].

Phosphorus in soils

A large part of the phosphorus in soils is bound by sorption with iron (Fe) and aluminum (Al) oxides. This makes the phosphorus largely immobile in most soils, accounting for low phosphorus concentrations in most groundwater from subsurface drainage [Culp et al. 1978]. However this phosphorus sorption capacity (PSC) of a soil is finite. To account for this, soil phosphorus saturation is defined as a measure of a soil's remaining capacity to bind the soluble phosphorus additions. As phosphorus is added to the soil in manure or fertilizers, the soil's capacity to absorb additional inputs of soluble phosphorus diminishes. [Kleinman et al. 1998]

As the soil saturation increases, so will the risk of phosphorus leakage. A linear relationship between soil saturation and dissolved phosphorus in runoff has been reported [Sharpley, 1998]. Agricultural soils of farms under the Watershed Agricultural Program have been tested for their agronomic phosphorus, which is correlated to soil saturation. These test results indicate that almost 90% of the lands on the 115 tested farms have "low" or "medium" agronomic phosphorus contents (less than 40 lb./acre) [WRI, 1998]. For the Delaware soils, the threshold of saturation beyond which all added phosphorus becomes mobile, is about 62 lb. of agronomic test phosphorus per acre [WRI, 1998]. However, the phosphorus balances that have been computed for fifteen of these farms show that there is a yearly surplus of total phosphorus of 18 pounds per acre of crop and pasture lands [WRI, 1998]. If this would be spread evenly over these farms' lands, and if it is assumed that half of this is available for crop uptake [Wild, 1993], than this leaves an annual accumulation of 9 pounds of total phosphorus per acre. Although it is unknown precisely how much of this will be agronomic available phosphorus, it is still clear that such an accumulation leads to a high risk of saturation in the future.

Bioavailability of phosphorus in reservoirs

Phosphorus is the primary limiting nutrient controlling eutrophication of the Cannonsville reservoir, as described in Chapter 2. However not all forms of phosphorus are equally available to support algae growth; there are differences in the bio-availability of the forms of phosphorus loaded to a reservoir. Dissolved phosphorus is thought to be generally available for uptake. For particulate phosphorus, there are marked differences in the bio-availability. Bio-availability varies with hydrologic conditions (more available in dry-weather run-off) and has been strongly correlated to the presence of Fe/Al-P. Unavailable sedimented phosphorus may undergo biological and chemical transformations that change the bio-availability of the particulate phosphorus later reintroduced to the water column through resuspension significantly. [Auer et al. 1998]. Simulations have indicated that large loads of particulate phosphorus, such as occurred in 1996, would elicit noticeable response in phytoplankton growth [Longabucco and Rafferty, 1998]

For the algae growth in the Cannonsville reservoir, dissolved phosphorus is of primary importance. Dissolved phosphorus was found to contribute 4-7 times more phosphorus to the algal pool than the particulate fraction. [Auer et al. 1998]

Transportation of phosphorus
Event-based sampling during the early 1980s and from 1992 to 1996 has shown that the amounts delivered during rainfall events constituted the bulk of the annual phosphorus loads to the Cannonsville reservoir. This is caused by the variety in loading from nonpoint sources. Loading from point sources (wastewater treatment plants) was not so much influenced by rainfall events because they delivered continuous effluent discharges to the surface waters. [Longabucco and Rafferty, 1998]

Most rainfall events in the basin occur in late winter-early spring. In those periods, rainfall combined with snowmelt often produces the highest flows of the year. The other rainy periods are in the fall and early winter. Fall and spring runoff recharges Cannonsville reservoir, both in terms of water volume and nutrient supply. The reservoir is usually at it lowest level by September or October due to drawdown and reduced summer inflows. [Longabucco and Rafferty, 1998]

During dry-weather periods of baseflow ($10m^3/s$ or less), most of the phosphorus is in the dissolved form. During rainfall events, more sediment is transported by surface runoff and particulate P is higher. Particulate P concentration had a strong, direct correlation with the total suspended solids (TSS) concentration, as does SRP with TDP. [Longabucco and Rafferty, 1998]

In years with large single events (1981, 1992, 1993 and 1996), the large event produced from one-fifth to nearly half of the year's nonpoint TDP load. These single large events dominated the annual nonpoint source loading of PP and TSS even more, producing between 60% and 85% of each year's total loads. [Longabucco and Rafferty, 1998]

The strong influence of rainfall events accounts for the large variability in phosphorus loading in subsequent years. In the hydrological year[5] 1995, which was a dry year, 8,200 kg of PP and 9,600 kg of TDP was measured, while in the wet year 1996 these figure were respectively 116,000 kg and 23,600 kg. [Longabucco and Rafferty, 1998]

The event-based monitoring has shown that the coefficient method used by NYCDEP in 1993 (Reckhow land use model, see Chapter 2) leads to an underestimation of P-loading to the reservoir. Monitored loads in the West Branch Delaware River, which accounts for 90-95% of the P loads were averaging 38,500 kg/y, while the NYCDEP 1993 report calculated a most-likely P-load of 23,100 kg/y. [Longabucco and Rafferty, 1998].

The timing of rainfall events is often in periods that phosphorus loading does not pose a threat to reservoir conditions. Most rainfall events occur in the period from October to May and large phosphorus loading during a short time in this period does not necessarily affect the reservoir's water quality. These phosphorus loads may be flushed out of the reservoir before the summer starts, during which algae growth is highest. The assumption that timing of phosphorus loading is important is supported by a recent simulation study. The simulations indicated that nonpoint source measures that focus on reductions of summer nutrient loads may yield greater water quality benefits. [Owens et al. 1998]

6.2 Reduction of phosphorus loads

Because of the strong influence of rainfall events, annual phosphorus loading to Cannonsville reservoir has a range from about 20,000 to 166,000 kg/y [Longabucco and Rafferty, 1998]. This makes it very difficult to estimate actual phosphorus loads without extensive (and expensive)

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[5] Hydrological year goes from October through September.

monitoring. It also makes it difficult to assess the effectiveness of measures to reduce phosphorus loads. Actual phosphorus loading reductions from nonpoint sources may be masked in a year with large rainfall events, or perceived reductions may be due to "dry" conditions, instead of effective practices.

It is assumed that on average the phosphorus loading to the reservoir is approximately 52000 kg/y. This estimation is stated in the most recent NYCDEP publication on the Phase II TMDL calculations [NYCDEP, March 1999a]. It is based on the measured annual phosphorus concentration over the years 1992 to 1996. This concentration is related to phosphorus loads by an empiric model, the Vollenweider Model [NYCDEP, March 1999a] The critical loading is based on the critical phosphorus concentration. Currently the guidance value for this critical concentration is set at 20 μg/l for total phosphorus, but this will probably be lowered to 15 μg/l [NYCDEP, March 1999b]. This would lead to a critical load of 35207 kg/y [NYCDEP, March 1999a]. The necessary reduction for meeting the proposed target load is 17161 kg for an average year. These loads are annual loads for total phosphorus, so these figures neither address the differences between particulate and dissolved phosphorus nor the effects of the timing of loads.

The Phase II TMDL calculations were only released when this project was already in its final stage and therefore other estimations for the required reductions were used in a large part of the project. The required phosphorus load reduction was at first estimated to be in between 25,000 and 35,000 kg/y. This was based on an estimated average phosphorus loading of 45,000 kg/y, based on GWLF calculations and event-based sampling [NYCDEP, January 1998 and Longabucco and Rafferty, 1998]. The critical loading for meeting a critical phosphorus concentration of 20 μg/l was estimated to be 20,000 kg/y, based on information from the publication of Longabucco and Rafferty. It was known that the critical phosphorus concentration would probably be lowered, in the worst case to 10 μg/l. This would also reduce the critical load, to approximately 10,000 kg/y, based on a linear relation between critical load and critical concentration as stated in WRI's Phase I report [WRI, December 1998].

For the largest part of this report it has been possible to incorporate the most recent reduction estimates. Where this has not been possible, or where additional analysis is required because of the most recent estimates, this has been mentioned.

In general it seems that two types of measures are necessary in order to reduce the phosphorus loading to the reservoir in a sustainable way:

- Runoff control measures to reduce the phosphorus loading during critical periods;
- Phosphorus balancing measures to prevent phosphorus leakage from saturated soils.

On the long run, both measures will be necessary to reduce the phosphorus loading to a level that ensures the required water quality in the Cannonsville reservoir. Short-term reductions will be more likely to be realized by runoff control. But if phosphorus balances are not restored in the basin, soils will become saturated and loads will most probably be rising within a few years. As most of this soil-leaked phosphorus will be dissolved, it will have a large impact on the reservoirs' eutrophic state.

7. Phosphorus reductions from agricultural sources

7.1 Agriculture in the basin

Agricultural activities account for a substantial part of the nonpoint source phosphorus loads. Before the alternatives to reduce phosphorus loads from agricultural lands will be discussed, it might be useful to get a general impression of the agriculture in the Cannonsville basin.

Agriculture plays an important role in Delaware and is dominated by dairy farming. There is a decline in this sector, both in terms of farm numbers, milk cows and corn acreage. The number of dairy farms in the county has decreased from 3,234 farms in 1950 to 237 in 1997. In the same period the number of milk cows decreased from 64,330 to 17,500 [BR&E, 1998b].

Most of the farms are relatively small businesses. Some farms hire additional workers, but most of the time this will be seasonal work for less than 150 days per year. The average farm size in 1992 was 268 acres, with most farms in between 50 and 500 acres. Most dairy farms (256 out of a total of 336 in 1992) had between 20 and 99 milk cows. There were 43 farms with 100-199 milk cows and only six farms with more than 200 milk cows. [USDA, 1992].

The total cash receipts from marketings were $51.1 million in 1996, of which $46.1 million was coming from livestock and related products [USDC, 1996]. In 1992 the receipts from livestock and related products were $46.1 million, of which $45.6 million was coming from dairy products and the sale of cattle and calves [USDA, 1992]. The production expenses in 1996 were dominated by the purchase of feed ($12.8 million) and “other” production expenses, such as repair and operation of machinery; depreciation, interest, rent and taxes ($31.3 million). The total production expenses were $55.6 million in 1996. [USDC, 1996].

The estimations of agriculture’s contribution to the total phosphorus loads entering the Cannonsville reservoir range from 46% to 50% [NYCDEP, May 1993; September 1996]. Phosphorus balances for fifteen farms show an annual surplus of phosphorus on the farms. For these farms, 72.1 tons of phosphorus is annually brought into the farms, while only 25.5 tons are taken off the farms. Purchase of feed accounted for 78% of the phosphorus brought on the farms. Fertilizer made up 20% and purchased animals 2%. [WRI, December 1998]. These balances show a phosphorus surplus of 65%. This fits well in the reported surpluses for phosphorus balances on other farms in New York, which range between 59% and 81%. [Cerosaletti et al. 1998; Chase, 1998]

Because dairy farming dominates the agricultural activities in the basin, the alternatives that are proposed in the next sections are in first instance formulated for application on dairy farms.

7.2 Animal waste management

One of the most important sources of phosphorus loads from agricultural lands is the animal waste that is produced on the farms. Traditionally manure is applied to the fields because it contains nutrients that are necessary for plant growth. When this process of manure application is not properly managed it can cause considerable environmental damage. Run-off from agricultural fields may have high concentrations of nutrients and excess amounts of nutrients may build up in the soil. A health risk of the improper management of animal waste is formed by the pathogens that it may contain; Protozoans like Giardia and Cryptosporidium pose potential health threats to humans and animals, causing recurrent diarrhea.

The manure production by dairy cows varies and is related to the size of the cow and its milk production rate. For the purpose of this study, average estimations will be used. Literature gives a daily manure production per cow ranging from 13.9 gallons [Rynk et al., 1992] to 20.1 gallons or more [Jewell et al., 1997, p.2-2]. Some typical values for the characteristics of dairy waste are given in Table 7.1.

Waste characteristic	Values Jewell[1]	Values Bartok[2]	Values USDA[3]
Biological Oxygen Demand (BOD_5)	20 g/kg		
Nitrogen (TN)	5.6 g/kg	4.5 g/kg	
Phosphorus	0.9 g/kg (P)	1.8 g/kg (P_2O_5)	2.5 g/kg (P_2O_5)
Density		993 kg/m^3	
Total Solids (TS)	14.0%	12.7%	

Table 7.1. Waste characteristics of manure as produced by dairy cows.
Sources: [1] W.J. Jewell et al. 1997; [2] J.W.Bartok 1995; [3] USDA 1992

Animal waste management comprises a wide range of tools and techniques. After an initial review of available literature, four general alternatives have been selected: composting, anaerobic digestion, transportation and management of field-application. These general alternatives may be combined in several ways to enhance their effectiveness. Besides these four, there are other alternatives, like manure treatment through a sequential batch reactor [Johnson and Montemagno, 1997], mechanical solids separation [CALS, 1998], biodrying [CALS, 1998] and wetlands [Wright, 1998]. These are not further considered either because it is estimated that they are not very applicable to the situation in the Cannonsville basin, or because research is still ongoing and not enough reliable data are currently available.

Based on available economic data, it is assumed that there is one dairy farm in the basin that has a much bigger size than the others. This farm is not included in the following descriptions, because its size is of a different order when compared to the average farm size in the watershed. It is assumed that this farm will be able to establish its own waste management systems. It might join the rest of the farms in one of the described alternatives, but the calculations for it are not included in the "average" farm estimates.

Composting

Composting is the aerobic decomposition of organic materials (such as manure, sludge, leaves, paper and food wastes) by microorganisms into a soil-like material. It is the same process that decays leaves and other organic debris in nature. Composting merely controls the conditions so that materials decompose faster. Composting on farms bring both benefits and drawbacks, as shown in Table 7.2. [Rynk et al. 1992].

Benefits of composting	Drawbacks of composting
Excellent soil conditioner	Time and money involved
Saleable product	Land required for operations
Improves manure handling	Possibility of odors during process
Improves land application	Weather may interfere with composting
Lowers risk of pollution and nuisance complaints	Marketing is necessary
Pathogen destruction	Potential loss of nitrogen in manure
Bedding substitute	Slow release of nutrients in compost
May reduce soilborne plant diseases	Risk of being considered a commercial enterprise

Table 7.2. Benefits and drawbacks of composting on farms.
(Source: Rynk et al, 1992)

During composting, microorganisms consume oxygen while feeding on organic matter. During this process, heat, CO_2 and water vapor are released into the air. Because of the water loss, the weight is reduced by 40 to 80%. Composting also leads to a volume reduction. This may range from one-quarter to more than one-half of the initial volume. The heat accumulation during composting can push temperatures well above 140°F, which will kill pathogens (official standards for killing these pathogens are set at 131°F). During the composting nitrogen losses occur, mainly through the release of ammonia. These nitrogen losses should be minimized. This reduces the bad odor of ammonia and a high nitrogen content will add value to the compost. [Rynk et al., 1992]

The phosphorus in manure is not removed by composting. Composting merely transforms manure in a material that is reduced in volume and is easier to handle due to a reduced moisture content. Compost does not smell and may have a commercial value. This may make it possible to transport (a part of) the animal waste outside the Cannonsville watershed, to areas where the compost might have an added value.

For "rapid" composting, the composting material must meet some specific conditions. The moisture content should be in between 40-65%. Usually composting will start with a raw material that had a moisture content of 65-60% and it will result in compost with a moisture content of 40%. As can be seen in Table 7.1, dairy manure usually has a moisture content of 85-90%. To get a suitable starting material, there are in general three options:

1. Add dry bulk material: for every volume of manure, one to two volumes of dry material should be added. Possible amendments are leaves, paper, finished compost, straw, wood chips, sawdust and municipal sludge. Usually these materials can be obtained for free or even a tipping fee may be received. If farmers have to pay for the amendments, composting may not be economically feasible.
2. Run the manure through a solid separator: a screw press separator will separate the manure in a solid matter (±20% of the mass) and a liquid matter (±80% of the mass). The solid matter will have a moisture content of approximately 70% and is easier to use for composting. The liquid matter has the advantage that it will be easier to apply to the fields. Small farms will not buy a screw press separator of their own, but they may share one with neighboring farms.
3. Dry up the manure through heating: forced air will be used to dry manure during the composting process. In three weeks compost with 40% dry matter will be produced. This may be recycled as bedding material on the farm, or it may be stored for other uses. This system seems promising, but is not yet implemented on farms. Results of current research will have to prove if it will be economically feasible. [Wright, November 1998]

For this study, it is assumed that dry bulk material is available at very low or no costs in the watershed. During autumn there will be a large amount of leaves and these may be stored for some period. There are also a lot of farmers in the basin that use bedding material for their cows, which also may be used as amendment. Forestry activities in the watershed may provide wood chips and sawdust.

Because most of the farms in the Cannonsville basin are of small size, it is not possible to install advanced composting systems on each farm. It seems reasonable to consider three options:

1. On-farm composting: "simple" composting on every individual farm;
2. Decentralized composting: off-farm composting facilities shared by several farms;
3. Centralized composting: one central composting facility for the whole basin.

On-farm composting

For on-farm composting, the following three methods are generally recognized: windrow composting, aerated static pile composting and in-vessel composting. For the farms in Delaware, three low-cost options will be explored: windrow composting using the available farm-equipment (infrequent turning), windrow composting using special windrow-turning equipment (frequent turning) and passively aerated windrow composting. They all require less capital investments than other methods, but are relatively more labor-intensive. [Rynk et al, 1992]

Windrow composting consists of placing the mixture of raw materials in long narrow piles or windrows, which are agitated or turned on a regular basis. Windrow turning rebuilds the windrow porosity so that a proper rate of air exchange is maintained. Passively aerated windrows do not require any turning. In this case aeration takes place through perforated pipes that are placed near the bottom of the windrows.

Usually the windrows will be situated on normal fields. This means that they are susceptible to leakage of pollutants to the soil and to loss of pollutants in run-off during rainfall events. This may well mean, that the potential benefits of composting are offset by the potential phosphorus losses by the composting piles. Thus it is necessary to provide at least adequate runoff management structures for the windrow-fields. It may even be necessary to cover the windrows under a roof of some sort. This will make on-farm composting more expensive, but it might be necessary to achieve the desired phosphorus reductions.

In the alternative using special windrow turning equipment, calculations are based on the assumption that one windrow turner will be shared among several farms. This windrow turner may either be purchased by the farmers sharing it, or it may be purchased by a third party which rents the machine to the farms.

For the on-farm composting alternatives, it is assumed that all the manure produced on the farm is being composted. Of this compost, on average 20% to 40% will be applied to the farmer's fields. The surplus is sold to buyers outside the Cannonsville basin.

Decentralized composting

For decentralized composting, five nearly identical compost sites are assumed, spread equally across the basin. The composting will be done through rectangular agitated beds [Rynk et al, 1992, p.37]. In this system, composting takes place in long narrow channels, referred to as beds. It combines controlled aeration and periodic turning. The machines work automatically without an operator.

For the decentralized composting, two options have been considered. They are related to the amount of manure that is taken to the composting facilities. In the first option, all the manure is being composted. Afterwards, a part of the compost (20-40%) will be taken back for use as fertilizer and soil conditioner on the farms. The rest will be sold to buyers outside the Cannonsville watershed. In the other option, only the surplus of the manure is taken to the composting facilities. The rest of the manure stays on the farm for application to the fields. All the compost from the composting facilities will be sold to buyers outside the watershed. The advantage of this option is that there is no unnecessary transportation of manure and compost. The advantage of the first option is that all the fertilizer used by the farmers will be of relatively high quality and will be free of potentially harmful pathogens.

Centralized composting

One composting facility for the entire basin is assumed, located on a central position. The system used will be the rectangular agitated bed system as described above. For centralized composting the same options as for decentralized composting will be considered: composting all of the manure or composting only the surplus of the manure.

Bulk prices for compost range from $7.50 to $75 per m^3, the average being $15 per m^3 [Rynk et al, 1992]. This means that all composting options can produce compost at competitive costs as long as the markets are not located too far away. It must be feared however that the compost will have to be transported a considerable distance before it reaches interested buyers. If the compost is of good quality, it will still be marketable, but low quality compost will not be.

Anaerobic digestion

Anaerobic digestion is a biological fermentation process that can be used to treat manure. This process results in an odorless liquid matter that still has the nutrient characteristics of the raw manure. During the anaerobic digestion biogas is produced. This can be converted into electricity and heat by cogeneration. The heat can be applied to keep the temperature of the digester on the required level. The electricity can be either used on the farms or sold to the utility. [Jewell et al. 1997]

Anaerobic digestion requires skilled operation and management and a high capital investment. The minimum size for an economically feasible operation is around 500 cows. [Wright and Perschke, 1998]. Therefore, on-farm anaerobic digestion has not been considered. The options considered here are five decentralized digestion facilities or one central facility, analogous to the off-farm composting options.

The digester type considered most appropriate here is a plug flow digester. This is a reactor that treats independent slugs of material that move linearly throughout the unit without mixing. It is the most efficient biochemical conversion process and it has relatively low costs. The plug flow reactor is not suitable for dilute mixtures, so adding other wastes to manure must be done with care. [Jewell et al. 1997]. The digester must be maintained at a nearly constant temperature, either 35°C for mesophilic units or 55°C for thermophilic processes. [Jewell et al. 1997]. A small mass reduction will occur because biodegradable organic matter is converted to methane. This mass reduction is typically around 5%. The dry matter content of the effluent may vary between 5 to 9% total solids. [Jewell et al. 1997].

A study after anaerobic digestion options for dairy farms in New York showed that the system might well be economically attractive, as long as the generated electricity can be sold for a reasonable price [Jewell et al. 1997]. However the study recognized that utilities are often not willing to pay a competitive price for electricity that is generated by small independent producers. Independent generation is less reliable and most utilities still have excess supply facilities. The purchase of independent electricity means they have less use for their own "cheap" base-load generators. During peak hours they will have to run more of their expensive smaller peaking plants, which makes their own electricity production costs higher. Perhaps electricity generation from biogas may qualify for some financial government support, since biogas is a renewable resource.

Use of the generated electricity directly on the farms will require independent transmission lines. The costs of such infrastructure will be high and it might be difficult to obtain permission of all of the landowners for a private transmission line. Furthermore the utility will probably not be willing to interconnect with a competitor. This means that all the electricity demands will have to be met by electricity generated by the anaerobic digestion plant. Because of these difficulties the option of selling the generated electricity back to the farms has not been further explored.

The treated manure will still contain the original amounts of phosphorus. [Wright and Perschke, 1998]. Because of the reduced odors and the elimination of pathogens, it may be possible to sell it to buyers outside of the basin. Since the product is liquid, it will be easier to handle for farmers, who can pump it onto their fields. For regular consumers it will be less attractive.

A part of the costs for anaerobic digestion may be compensated by the electricity benefits. If it is assumed that the generated electricity can be sold for $0.09 per kWh, than these benefits equal $4.65 per m^3 of digested material. If a low (and perhaps more realistic) price of $0.025 per kWh is assumed, benefits are $1.29 per m^3.

In addition to the electricity benefits, also other benefits may be generated. After digestion, the produced liquid may be used to recover bedding fiber of 50-60% moisture content. This can be done with a screw press separator and additional drying. If a thermophilic digester has been used, the bacteria content should be largely reduced and the bedding fiber can be used on farms. Cost of production are estimated by Jewell et al. to be around $4 per cubic yard. Current bedding costs for farmers are around $6 per cubic yard. [Jewell et al. 1997]. The economic profitability for bedding fiber recovery thus depends on the transportation costs. These are estimated to vary between $2 and $5, so currently fiber recovery does not result in any economic benefits for farmers in Delaware.

Transportation

Both composting and anaerobic digestion are transforming the raw manure into a product that might be easier to market outside the Cannonsville basin. However, it is also possible that there is no market for such products, or that farmers outside the basin will be willing to buy raw manure if this is cheaper. Therefore the option of transporting raw manure to farms outside the basin has been considered. It has been assumed that the phosphorus balance allows farms to apply only a small part of the manure to their fields. This means that the surplus (presumably 60 to 80%) of the manure has to be transported to other destinations.

Management of field-application
If manure is spread on the fields, proper nutrient management can prevent unnecessary phosphorus losses. The time and rate of manure application can be adjusted to the crop requirements and the potential for nutrient uptake. Also the method of manure application can be adjusted to enhance the effectiveness. Most of those measures are already incorporated in the Whole Farms Plans that have been developed by the Watershed Agricultural Program. Management of field-application is included in the Best Management Practices described in paragraph 7.4.

7.3 Animal nutrition management

As described in paragraph 7.2, animal waste is an important source of phosphorus pollution. The phosphorus concentration of manure can be lowered by balanced diets for the animals. Because by far the largest amount of animal phosphorus is produced by dairy cows in the basin, they will be the subjects of this section. The phosphorus in diets of dairy cattle is not easy to reduce, as it is part of a complex feeding system. In order get some understanding of the basic concepts of animal nutrition, Appendix B contains a general introduction to the subject.

The phosphorus balances for fifteen farms in the Cannonsville basin show that almost 80% of the phosphorus that is brought onto the farm, is used for feeding [WRI, December 1998]. This is consistent with other research where these percentages ranged from 59 to 85% [Chase, 1998]. Generally phosphorus levels in the feeding are higher than the phosphorus requirements per cow. Table 7.3 shows that the prescribed requirements vary a little per country. For U.S. farms, the data from the National Research Council (NRC) are usually used.

Milk (lb.)	**Country**	**P Requirement (grams)**			**Assumed**
(4% FCM)		**Maintenance**	**Milk**	**Total**	**Availability (%)**
50	U.S.	17.5	44.9	62.4	50
	Netherlands	25.7	34.0	59.7	60
	U.K.	12.7	35.4	48.1	58
100	U.S.	17.5	89.8	107.3	60
	Netherlands	25.7	68.0	93.7	60
	U.K.	12.7	70.8	83.5	58

Table 7.3. Daily phosphorus requirements for dairy cattle.
Data are for a 1350 lb. cow. (Source: Chase, 1998, Table1)

The phosphorus requirements are expressed in grams. This means that rations should be formulated based on the grams of phosphorus rather than as a percentage of dry matter. Most farmers will add a safety margin to the NRC-requirements. This is necessary because the actual dry matter intake and the feed's mineral compositions may show some variation.

Some farmers favor excess phosphorus intake, because they believe it might enhance the reproduction performance and the milk production. Past studies after these hypotheses have shown no significant evidence to support them [Chase, 1998]. However for both reproduction and milk production more research is needed to examine the relation with phosphorus intake more closely. For now it is assumed that excess phosphorus intake will not have significant nutritional benefits.

A balanced diet using the feeds currently available will be able to reduce phosphorus levels and to decrease the surplus in farm phosphorus balances. Most protein supplements have high levels of phosphorus. Fine-tuning of protein nutrition can therefore play an important role in this regard. There already is a system that can be used to evaluate diets for dairy cows, the Cornell Net Carbohydrate and Protein System (CNCPS). Ration formulation with this system has decreased nitrogen excretion by about 30% with a similar reduction of P excretion of about 20%. During the same period, milk production has increased. [Chase, 1998]. Application of this system in pasture-based dairy farms has resulted in reductions in N and P remaining on the farm of 5% and 18% respectively [Cerosaletti et al. 1998]. Some of the results of this study are shown in Table 7.4.

	Production group			
	<50 lb. milk	**50-70 lb. milk**	**70-90 lb. milk**	**>90 lb. milk**
P intake				
Original, g/d	89	105	123	137
Balanced, g/d	67	80	99	115
Reduction, g	22	25	25	22
Reduction, %	24.7	23.8	19.9	16.1
NRC requirements*, g/d	50	70	91	114
P excretion, fecal + urinary				
Original, g/d	74	82	92	98
Balanced, g/d	53	58	70	80
Reduction, g	21	24	22	18
Reduction, %	28.4	29.3	23.9	18.4
Efficiency, balanced (g excreted per kg milk)	2.96	2.16	1.95	1.75

Table 7.4. Effects of CNPCPS-balanced rations on phosphorus intake and excretion.
(source: Cerosaletti et al. 1998, Table 4)
**NRC requirements based on 1300 lb. body weight, 4.0% butterfat, 100% dry matter intake and milk levels of 40, 60, 80 and 100 lb.*

In the study by Cerosaletti et al., the phosphorus intake in the original diets averaged 46% over NRC requirements, while the balanced diets averaged only 14% over the same requirements. For the balanced diets, the used P-requirements exceeded the NRC levels by 10%, as a safety factor for the reasons discussed above. [Cerosaletti et al. 1998].

Balancing diets with CNCPS will probably not lead to increased feeding costs. It may very well lead to an actual reduction in feeding costs and an increase in milk production. It does require additional labor however. This includes the time and effort necessary to gather and enter CNCPS inputs, as well as balancing the rations. Another major cost associated with using the CNCPS is the cost of forage analysis to obtain necessary feed composition inputs. [Cerosaletti et al. 1998] These costs will vary from farm to farm. It seems most appropriate forthe Delaware farms to hire some professional expertise to assist in these activities. A very rough estimation of these costs is thought to be $250 to $500 monthly per farm (see Appendix C). A pilot study on two farms on nutrient management including the balancing of diets showed actual benefits. On the first farm the increase in milk production and decrease in feed expenses resulted in a small projected net benefit of nutrient management of $1,350. On the other farm the positive impact of nutrient management was higher, estimated to be $16,000. [Barry et al. 1996]

7.4 Traditional Best Management Practices

The Watershed Agricultural Program has already implemented a lot of measures on farms to improve farm operations. For the participating farms, Whole Farm Plans have been developed, that tailored the needs of the individual farm. Often one or more Best Management Practices (BMPs) were included in those plans. BMPs are measures to reduce nonpoint source pollution that are recognized by government agencies [EPA, January 1993 and NYS-NPSMP, 1996]. The BMPs that have been implemented on farms in the Cannonsville basin are mostly aiming at keeping the phosphorus on the lands and minimizing the run-off losses. Practices that address the phosphorus balances on farms have not received special attention so far, which is why they have been discussed in more detail in the previous sections.

Because of the existing uncertainties related to the assessment of phosphorus loads (see Chapter 6), it is very well possible that the current practices are also effective on the long term. The BMPs that aim at storing the phosphorus in the soil and minimizing run-off losses are described in Appendix D. They include practices to reduce pollution from animal waste, fertilizer and erosion. From the Watershed Agricultural Program some cost estimates have been derived [WRI, December 1998]:

Category	**# farms with BMPs**	**# of BMPs recommended**	**Total planned costs* ($)**
Storage of manure, fertilizer	13	17	221,864
Concentrated nutrient sources			
Barnyard	82	241	3,093,068
Feed/silage leachate	6	8	117,739
Milkhouse	21	24	130,279
Nutrient management (Manure handling equipment, subsurface drainage, other structural practices)	76		2,004,627
Diffuse sediment sources (Pasture and hayland management, diversions, conservative cropping practices)	54		572,223
Concentrated sediment sources (Access road improvement, critical area protection and fencing)	46	78	336,511

Table 7.5. BMPs recommended in Whole Farm Management Plans for pollutant categories that are related to phosphorus sources.
(Source: NYSWRI, 1998)
**Costs are a lower bound.*

The potential phosphorus reduction is estimated based on available literature sources. Because the Whole Farm Plans have been implemented on 94 farms already, the potential for additional future agricultural BMPs is somewhat reduced. The potential for future BMPs on other farms is estimated to lead to improvements for 50 to 75% of the agriculture in the basin.

8. Phosphorus reductions from wastewater treatment plants' effluent

8.1 Wastewater treatment plants in the Cannonsville basin

The wastewater treatment plants (WWTPs) in the Cannonsville basin are the only regulated point sources of phosphorus pollution. Their contribution to phosphorus loads is estimated in different reports to be in between 9% and 35% of the total phosphorus loads entering the Cannonsville reservoir. The estimations of the actual loads from WWTPs range from 4,300 kg/y [NYCDEP, January 1998] to 12,682 kg/y [NYCDEP, May 1993]. This difference may be caused by the different methods used to estimate phosphorus loads and by variation in discharge and effluent concentrations from WWTPs in different periods. In 1992 one of the plants was upgraded which resulted in much lower phosphorus concentrations in the effluent [Longabucco and Rafferty, 1998]. This might partly account for lower estimations of WWTPs for the more recent years.

Currently there are eleven WWTPs with a discharge permit in the basin. Four of these are municipal and seven are privately operated. The focus in this report will be on the municipal WWTPs because they account for the majority of the phosphorus loads. [NYCDEP, March 1999a]

Municipal WWTPs	Permit flow (m^3/day)	Average flow (m^3/day)	Avg P-conc effluent (mg/l)	P-load (kg/y)	P-load 1995 (kg/y) (DEP)[1]
Delhi	1949	1628	3.0	1782	1376
Hobart	284	114	3.6	149	195
Stamford	1893	1514	1.7	940	182
Walton	4429	5678	1.0	2073	3192
Total municipal plants				**4944**	**4945**

Table 8.1. Selected characteristics of municipal wastewater treatment plants

Source: Delaware Engineering (Delhi, Stamford, Walton) and LVDV Engineering (Hobart), March 1999;

[1] source: NYCDEP March 1999, Table 3.5.

Table 8.1 shows some characteristics of the four municipal plants in the basin. The data shown in the table concern the period from March 1998 to March 1999 and they were obtained from the companies that operate these plants. These data are compared with NYCDEP estimates for the loads in 1995. There some differences in the loads from the individual plants. These differences may be caused by different flows in the different years or by changes in the operation of the plants over the years. In the remainder of this report, the estimates from the engineering companies will be used.

8.2 Planned upgrades

To decrease the phosphorus loads, plans and funds for upgrades of the current systems have already been included in the Watershed Agreement [MOA, 1997]. These upgrades should result in the use of best treatment technologies at the plants in order to meet the phosphorus limits shown in Table 8.2.

Permit flow (gal/d)	Permit flow (m^3/d)	TP limit (mg/l)
<50,000	<189	1.0
>50,000 and <500,000	>189 and <1893	0.5
>500,000	>1893	0.2

Table 8.2. Phosphorus limits for effluent after upgrades.

(Source: NYCDEP, March 1995, p.10)

Most of the planned upgrades will also have a positive impact on the biochemical oxygen demand (BOD), suspended solids (SS) and coliform levels in the effluent. Ammonia will probably not be reduced very much. All the upgrades are to be finished and operational by May 1, 2002. [Delaware Engineering, December 1998]

Currently the plans for upgrading are being developed. New York City provides the funding for these upgrades as part of the Watershed Agreement. However it is expected that the funds reserved by New York City are less than half of the total funds needed. The total costs for the upgrade of the four municipal WWTPs at Walton, Delhi, Stamford and Hobart are estimated to be around $35 million instead of the expected $13-15 million [Delaware Eng., LVDV Eng, March 1999].

The higher costs for the upgrades are probably partly explained by the fact that the upgraded plants are designed to meet very low phosphorus effluent concentrations, even lower than is required under the MOA (see tables 8.2 and E.3). The upgrade costs will probably be lower if the upgrades are designed to meet just the MOA-requirements.

9. Phosphorus reductions from septic systems

9.1 Failing systems

Description of septic systems
A septic system is an on-site wastewater treatment system for the treatment of domestic wastewater. Besides this system there are also other on-site wastewater treatment systems, but the septic system is most common in the Cannonsville basin. The septic system consists of a watertight chamber, followed by an absorption field. The septic tanks are buried and they are designed to provide 24 to 36 hours of quiescent detention time for the wastewater. Sewage bacteria break up some solids in the tank and heavy solids sink to the bottom as sludge. Grease and light particles float to the top as scum. After the septic tank, liquid flows through a distribution box that diverts flow equally to two or more perforated pipes laid in gravel trenches within natural, undisturbed soil. Bacteria and oxygen in the soil help purify the liquid. The sludge and scum in the tank is pumped out periodically. [NYS NPSMP, 1994].

Characteristics of typical residential wastewater are shown in Table 9.1, followed by some characteristics of pollutant removal by and costs of septic systems in Table 9.2

Parameter	Mass Loading (g/cap/d)	Concentration (mg/l)
Total Solids (TS)	115 – 170	680 – 1000
Suspended Solids (SS)	35 – 50	200 – 290
Biological Oxygen Demand (BOD_5)	35 – 50	200 – 290
Chemical Oxygen Demand (COD)	115 – 125	680 – 730
Total Nitrogen (TN)	6 – 17	35 – 100
Total Phosphorus (TP)	3 – 5	18 – 29
Total Coliforms	-	$10^{10} – 10^{12}$ *

Table 9.1. Characteristics of typical residential wastewater
(Source: USEPA, 1980, Table 4-3)
**Concentration presented in organisms per liter*

	TSS (%)	BOD (%)	TN (%)	TP (%)	Path. (Logs)*	Cap. Cost ($1,000)	Maint. Cost ($/y)
Average	72	45	28	57	3.5	4.5	70
Probable range	60-70	40-55	10-45	30-80	3-4	2.0-8.0	50-100
Observed Range	54-83	30-60	0-58	9-95	3-4	2.0-10.0	25-110
# Values Considered	7	7	13	12	2	8	4

Table 9.2. Amounts of pollutants removed and cost for conventional septic systems
*(Source: USEPA, January 1993) *Pathogen organism removal measured in powers of ten: entry of 3 represents a 1,000 fold reduction in pathogens.*

The costs for septic systems may be higher for non-conventional systems. Sometimes a different septic system is required, for example a raised system may be necessary due to soil conditions. Costs for such systems are usually higher.

Failing systems in the Cannonsville basin
Some septic systems may be failing, which means that some of the wastewater is not properly treated and may still be polluted when it leaves the system. Failure might be due to wear out or improper design. The extent to which a failure affects pollutant removal depends on the type of failure and the site characteristics.

A 1993 estimation by NYCDEP of the total number of septic systems in Delaware County was 10,820, of which 1% would be failing [SWCD memo, 1998]. More recent estimations are that 50% of the septic systems is failing [SWCD and CWC, November 1998]. This high percentage of failure is in large due to the way in which systems were designed before 1990.

In order for the soil treatment of conventional septic systems to be effective, the soil has to be well drained, must have no hardpan subsoils and must have slopes of less than 15%. A SWCD survey of 1998 GIS data shows that only 5.2% of the soils in Delaware County meet these requirements. It is likely that only 5-7% of the sites supports conventional leach fields. Almost all of the systems designed before 1990 are conventional systems in which carefully determined soil conditions were not included. [SWCD memo, 1998].

In large parts of Delaware there is an impervious layer at a depth of 3-4 feet. Conventional leach fields in these soils do not allow the water to infiltrate deep enough. The soil will be saturated sooner over the entire depth. This causes a lack of air, which disturbs the aerobic treatment processes. It also causes lateral flows during rainfall events, which means that the wastewater is flowing out of the system without a proper soil treatment. The impact of such failures is in large dependent on the distance of the septic system to a watercourse and the characteristics of the land areas the water will flow through before it reaches the watercourse.

The contribution of septic systems to the phosphorus load in the Cannonsville basin has been estimated at 1100 kg/y [NYCDEP, January 1998] and 1298 kg/y [NYCDEP, September 1996]. This accounted for 2.4% respectively 4.3% of the estimated total phosphorus load. Based on the above-described failure of 50% of the systems, the actual figures may be much higher.

9.2 Possibilities for upgrades and rehabilitation

Under the Watershed Agreement (MOA) there is a fund of $13.6 million available for the upgrade and rehabilitation of septic systems. This fund is administered by the Catskill Watershed Corporation (CWC) and is to be used for the entire New York City Watershed (see Appendix A). Owners of failing systems get a Notice of Violation from NYCDEP. Only systems for which such a Notice has been given can make a request with the CWC for the upgrade funds. The design of the upgrades is reviewed by New York City inspectors.

When the fund was established, costs for rehabilitation were expected to be much lower than they now appear to be. Partly due to the soil conditions described above, most septic systems need a more expensive design than the current conventional one. Recent estimations of the CWC, based on the funds they already have disbursed, are that the rehabilitation costs are about $10,000 per system [CWC, November 1998]. This means that the funds will be sufficient for the upgrade and rehabilitation of roughly 1360 systems.

The number of septic systems in the NYC Watershed is approximately 25,000 [CWC, November 1998]. Combined with the above mentioned estimated failure of about 50% of these systems, this means that the Septic Program Funds of $13.6 million are not enough to address all the failing septic systems, but that some $125 million would be needed.

Funds are disbursed by the CWC on a first come first served base and currently there are about 350 systems identified by CWC in Delaware County. For the total NY City Watershed 1044 systems have been identified, based on NYC DEP notices of failure. In Delaware County already some 100 systems have been repaired and in the total Watershed this number is 286. [CWC, November 1998]. When all the identified failing septic systems have been addressed, only some $4 million will be left for all the other systems that might be failing. This means that there might be a couple of thousand of failing systems in Delaware County, for which no upgrade funds are available.

10. Phosphorus reductions not included in the project

Besides the possible phosphorus reductions from the practices described in the previous chapters, there are several other possibilities for reductions. These have not been included in this project because of the limited time that was available to obtain the necessary data. However it is thought that the most promising and important practices have been included. The most important ones among the excluded practices are the practices focusing on phosphorus loads from forests and urban areas.

Forests contribute a significant amount of phosphorus to the total loads in the basin. The estimation range from 12% to 22% of the total loading [NYCDEP 1993, 1996, 1998]. This is mostly due to the fact that over 60% of the watershed's area is covered by forests. The loading per acre is relatively small, and it will be very difficult to reduce these loads any further. [WRI, December 1998]

The urban areas account for 2% to 4% of the phosphorus loads in the basin [NYCDEP, 1993, 1996, 1998]. Unlike the forests, it is expected that it is very well possible to reduce these loads. But because of their relatively small contribution, they have not received the same priority as the other phosphorus sources.

Part IV: Model formulation

11. Structural model

The structural model is a conceptual model that structures and integrates the information that is contained in the Chapters 1 to 10. The approach used to construct this structural model is taken from the book 'Decision Modeling in Policy Management' [Beroggi, 1999]. In this approach, several elements of decision modeling are identified. These elements and their relations are visualized in a diagram that forms the actual structural model. The elements that constitute the structural model are: decision makers, decision variables, criteria, scenarios, content goals, and structural goals. These elements will be defined and discussed for this particular case and then the structural model will be depicted.

11.1 Elements of the structural model

Decision makers

There are several actors that play an important role in Delaware's phosphorus management problems, as described in Chapter 5. The most central actors here are Delaware County and its County Phosphorus Study Committee. This Committee is formed by representatives of the following groups:

- Delaware County government and businesses
- NYC Watershed organizations (Watershed Ag Program and Catskill Watershed Corp)
- NY City government (NYCDEP)
- NY State government

All these groups will have a say in the decisions regarding the formulation and implementation of phosphorus management strategies. The main objective of the County Phosphorus Study Committee is to identify ways to reduce the phosphorus loads to the Cannonsville reservoir without restricting the economic growth in Delaware County.

Decision variables

In Part III of this report, several promising alternatives have been identified. They are related to agricultural waste management (composting, anaerobic digestion and transportation of manure), to nutrition management and traditional BMPs on farms and to the treatment of residential and urban wastewater. These alternatives are the decision variables of the structural model. The decision makers can decide if and how they want to implement these alternatives.

Criteria

The model's criteria are used to evaluate the effects of the decision variables. They are used to measure the contribution of alternatives to a solution for the phosphorus problems of the Cannonsville reservoir. The identified criteria can be divided in three categories: physical criteria, economic criteria and socio-political criteria. Each of the considered criteria will be discussed below.

Physical criteria: Phosphorus reduction

Phosphorus reduction is the first and most obvious of the criteria to be included. It would be preferable to make a distinction between dissolved phosphorus and particulate phosphorus because of their differences in bio-availability (Chapter 6). However such a distinction is not made by the official regulations that are applicable to Delaware's situation. Both the official criteria to determine whether or not a basin is phosphorus restricted and the TMDLs are based on total phosphorus. The same goes for the critical concentration for the reservoir. To comply with the legal standards, annual loads of total phosphorus will be used to measure reductions.

Reductions will be needed on a short-term to obtain and retain the necessary support for the phosphorus management activities. In 2002 EPA will evaluate the effectiveness of the phosphorus reduction efforts for the Filtration Avoidance Determination and the MOA will also be evaluated in that year. Short-term results are needed to lighten the burden that is posed on Delaware County because of the fact that the Cannonsville basin is phosphorus restricted. Erosion and rainwater runoff control measures are likely to have short-term benefits. The short-term effects will be expressed as total phosphorus stored in soils that have a low potential for runoff losses.

To make sure that short-term reductions are sustainable on the long term, phosphorus loads will need to be balanced. Soils have a limited capacity to adsorb phosphorus. When the soil is saturated, phosphorus will be leaking easily. This will cause an increase in phosphorus loading to the reservoir, which will diminish the effects of previous reduction measures. Once this saturation point is reached it will take a long time before the soil conditions are restored. To prevent reaching this point, it is necessary to balance the phosphorus loads. Long-term effects will be expressed as the amount of total phosphorus that is prevented from entering the soil.

Physical criteria: Pathogen reduction
Besides phosphorus, there are also other important pollutants that need to be controlled. One of them is the control of pathogens from wastewater, particularly Giardia and Cryptosporidium [WAC, December 1997]. Phosphorus control measures that also lead to a reduction of pathogens will be beneficial to Delaware County, because this will save them money and efforts to implement separate measures to control the pathogens. It is not possible to quantify the exact reduction in pathogens from farms, so only the reductions that are related to the treatment or removal of manure will be used here.

Physical criteria: Nitrogen reduction
Just as for pathogens, also a nitrogen reduction would be beneficial to Delaware County. However this criteria is not operationalized here for two reasons. The first reason is that in the Cannonsville basin nitrogen loads are of less concern than phosphorus loads and pathogens, as can be seen from the pollution prevention priorities of the Watershed Agricultural Program [WAC, 1997]. The other reason is that not enough reliable data have been obtained to quantify the effects of all the alternatives regarding nitrogen loads.

Economic criteria: Costs
The measures to reduce phosphorus loads will bring financial costs and perhaps some financial benefits. The costs might be capital costs that only have to be made once, or operational costs that will have to be accounted for periodically as long as the practice is in use. To be able to compare all the costs, they have been annualized using a discount rate of 10%. Costs are expressed in 1997 US dollars. Costs from other years have been corrected based on the Consumer Price Index.

Socio-political criteria: Distribution of costs
Different measures address different sources of phosphorus loading and will bring costs for different groups. Some costs might be recovered from funds outside Delaware County, such as funding for the programs under the MOA. These costs will be preferred above costs that will have to be paid for by groups within Delaware County. Furthermore it will probably not be acceptable nor desirable to let one group pay all the costs for the entire phosphorus reduction efforts. Therefore strategies that promote an equal distribution of costs are preferred. Unevenly distributed costs may need to be redistributed through local tax measures. An indication for the distribution of costs is the division between capital (fixed) and operational (variable) costs. In general it is likely that capital costs can be funded at least partly by existing State funds or funds from the Watershed Agreement. Actors within Delaware County will probably have to pay for most of the operational costs.

Scenarios
Scenarios are part of the structural model to be able to cope with occurring uncertainties. A scenario in this context is a statement of the assumptions about the operating environment in the Cannonsville basin. Scenarios are often used to deal with the uncertainties that are related to the future developments [Schwarz, 1988]. In the model used here, the uncertainties are not only related to future developments, but also to a lack of knowledge about the current situation. This caused by the fact that information on the alternatives and their characteristics has been obtained from various sources. For

most characteristics different estimates have been found. These differences in estimates are an important source of uncertainties in the model.

Scenarios can be used to delimit the uncertainty space that needs to be taken into account. A set of scenarios can be selected by varying one or several parameters. For practical reasons, the number of scenarios - and consequently the number of parameters to be varied - must be kept down. As few as one or two parameters and three to six scenarios is usual in most projects. The choice of parameters is thus of crucial importance. If the chosen parameter(s) are not the most important ones, than the scenarios will be of less value [Schwarz, 1988].

Appendix E and F contain information about the specific uncertainties for information used in this model. As can be seen, all of the identified uncertainties are related to either the costs or the effectiveness of the alternatives. Therefore costs and effectiveness will be used as the parameters to design scenarios.

Content goals

The content goals are the goals that state in terms of the criteria what a good action or strategy should achieve. They refer to the criteria and (part of) the criteria can be used to see if the content goals are achieved by a certain strategy. The following content goals have been identified:

- Minimize the total costs
- Realize a target reduction of short term phosphorus loads
- Realize a target reduction of long term phosphorus loads
- Realize a target reduction of pathogens from farms
- Realize an acceptable distribution of costs among different actors

Structural goals

The structural goals are goals that refer to the structure or form of decision options. Structural goals are also referred to as constraints. They state how alternatives can be combined to form strategies. Most of the alternatives can be combined quite straightforwardly. Their individual effects can usually be summed to determine the strategy's consequences. However there are some exceptions:

At most one waste management alternative at the time can be implemented

On farms where the manure is composted on the farm, the manure cannot be digested at the same time. In theory it would be possible to have digestion for some part of the basin and composting for another part. In practice however, one of those options will be better than the other for a certain scenario and this option will be selected by the model.

Actions are taken for a specified unit, and can not exceed the maximum number of units

Nutrition and waste management cannot exceed the total number of dairy farms, septic system rehabilitation cannot exceed the number of failing systems in the watershed, agricultural BMPs cannot exceed the number of farms and WWTP ugrading is only possible for existing WWTPs.

Waste management alternatives must always be combined with agricultural BMPs

When waste management alternative are implemented, the surplus phosphorus is no longer applied to the farmlands. This means that phosphorus losses from the lands must be minimized or else the crop growth will be limited due to phosphorus shortages. The phosphorus uptake by the crops can be optimized by traditional agricultural BMPs.

Additivity of consequences does not hold for waste management, nutrition management and BMPs

When less phosphorus is applied to the lands, this will affect the impacts of the BMPs. And less phosphorus in manure due to nutrition management may lead to a lower amount of surplus manure. This will have consequences for the implementation of waste management alternatives.

The background of the last two structural goals may be clarified by the schematic in Figure 11.2. This figure shows the phosphorus flows in (agricultural) soils. Phosphorus enters the soil as part of the manure, fertilizers or rain. A part of the phosphorus will remain on the soil surface and this will leave the lands with the surface water runoff. Another part of the phosphorus remains in the soil just below the surface. These parts of the soil can erode, for example during rainfall events. When sediments are washed out during rainfall events, the phosphorus contained in this sediment is also lost. Some of the phosphorus will be used as nutrient by the crops. A large part of the phosphorus will be bound by soil particles, as described in Chapter 6. The amount of phosphorus that leaves the soil with ground water flows is very small, but this amount increases as the soil gets saturated.

The BMPs aim at reducing the surface runoff and the soil erosion, while increasing the efficiency of phosphorus uptake by the crops. The waste management and nutrition management alternatives aim at reducing the amount of phosphorus that enters the soil. The purpose of these alternatives is to apply only as much phosphorus to the soil as is necessary for crop uptake. This is only possible when eventually all the other flows disappear almost completely (else the crops will have a phosphorus shortage). This makes it necessary to implement BMPs that enhance the efficiency of phosphorus uptake by crops and that reduce the phosphorus losses from erosion and surface runoff.

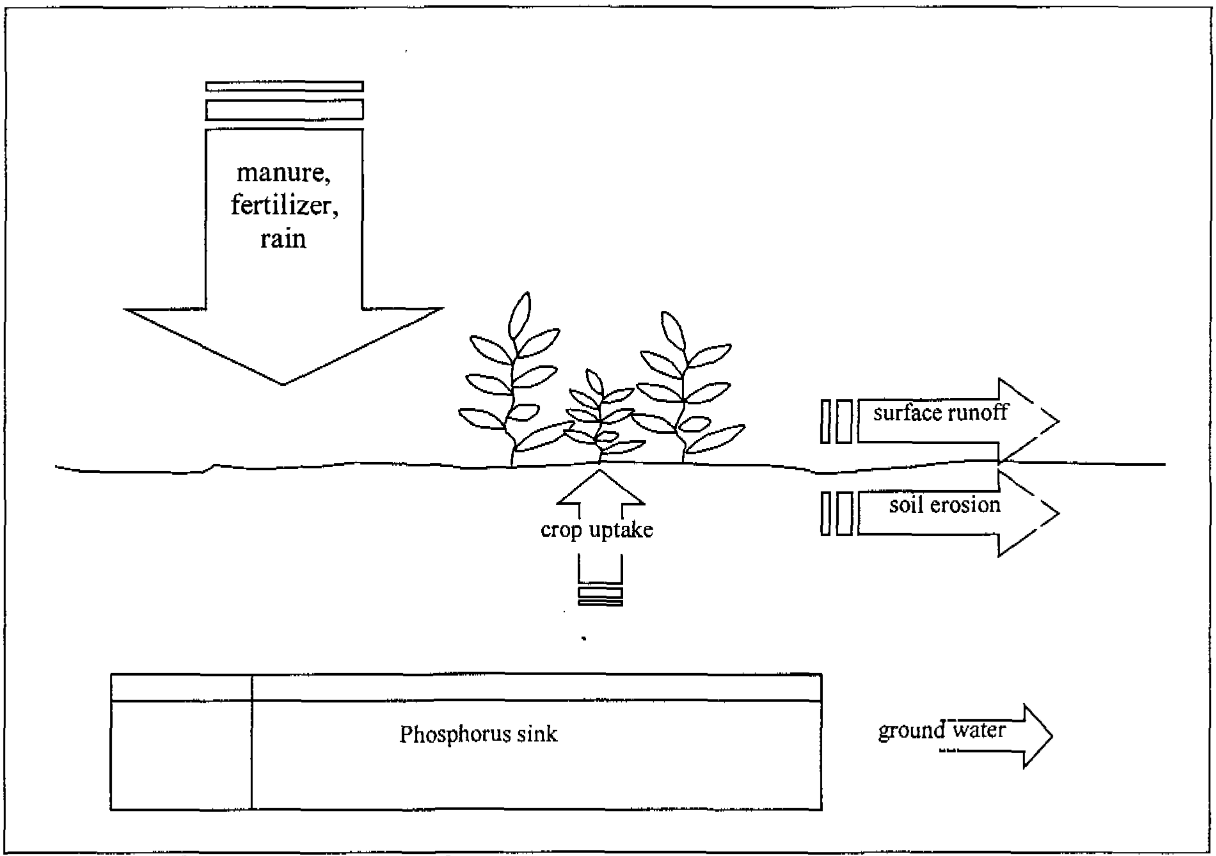

Figure 11.1. Phosphorus flows in soils

11.2 Visualization of the structural model

The described elements of the structural model can be summarized and visualized in a diagram that forms the actual structural model. This diagram is shown in Figure 11.2. The elements of the structural model have different shapes, to visualize that each element has characteristics that differ from the others [Beroggi, 1999].

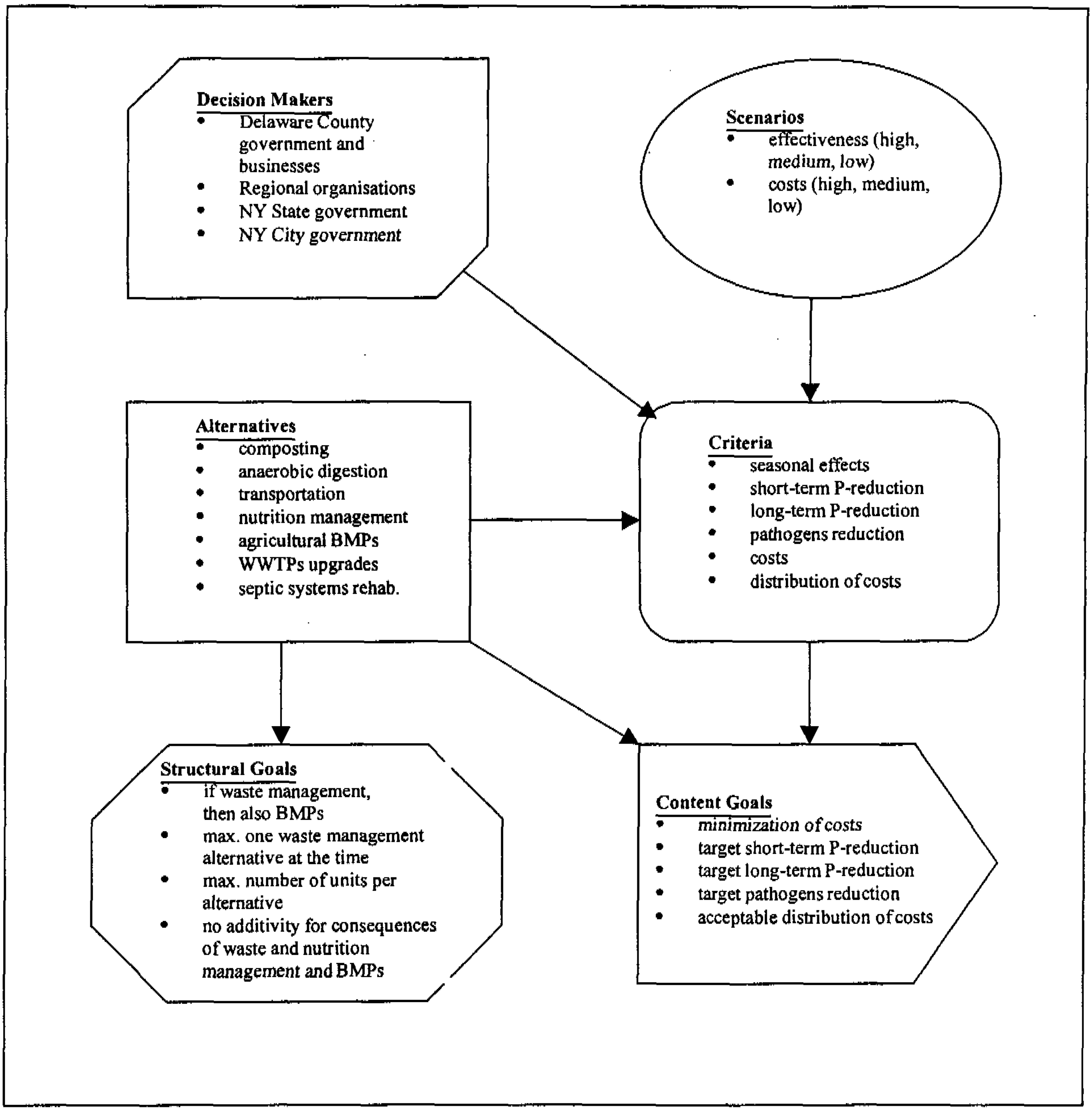

Figure 11.2: Structural model for Cannonsville phosphorus reductions

Excluded from the model

This formulation of the structural model means that the model does not include the aspects of seasonal impact or of dissolved vs. particulate phosphorus. These aspects have been excluded because the current legal procedures also do not take them into account and because there still is a lot of uncertainty concerning these issues, which makes it difficult to quantify them.

Another aspect that might be of importance but that is not included in the model is the regional economic impact of manure treatment industries for composting or anaerobic digestion. A large composting plant may create jobs and be beneficial to the local economy.

Also there are no alternatives included that address loads from forests and impervious surfaces/urban runoff, for reasons stated in Chapter 10.

These 'omissions' clearly show that the model in no way replaces reality itself. It is merely a tool to gain a little more insight in the alternatives and their effects.

12. Formal model

The problem as described in the structural model can be formalized in a formal model. This means that the elements and relations of the structural are translated into mathematical expressions. This will be done based on the same elements that were introduced in the previous chapter.

In this formalization, some simplifications of the real situation will be made. An important simplification is that the dimension of time will be neglected. In reality, time aspects play an important role. For example, when alternatives are implemented, it will take time before the phosphorus concentrations in the reservoir will be affected. The time aspects have been neglected to keep the model manageable and because not enough is known about the behavior of phosphorus in the soils to incorporate the dynamics in a responsible way. This simplification can be justified because the purpose of the model is not to make a perfect simulation of real world dynamics, but to be able to make a rough screening of different alternatives.

Another simplification is that the model will mostly use linear expression to describe the relations between the elements. These linear expressions are considered to be a suitable approximation, also because the real world dynamics are excluded.

12.1 Decision variables

Decision variables related to waste management activities

C_{onf}: Number of units engaging in on-farm composting. Each unit consists of five dairy farms that share some of the necessary capital equipment.

C_{all}: Number of units engaging in decentralized composting where *all* of the manure is composted in one of the off-farm compost facilities in the basin. Each unit represents one compost facility that processes manure of thirty-two dairy farms

C_{sur}: Number of units engaging in decentralized composting where *only the surplus* of the manure is composted in one of the off-farm compost facilities in the basin. Each unit represents one compost facility that processes manure of thirty-two dairy farms

D_{all}: Number of units engaging in decentralized anaerobic digestion where *all* of the manure is digested in one of the off-farm digestion facilities in the basin. Each unit represents one digestion facility that processes manure of thirty-two dairy farms

D_{sur}: Number of units engaging in decentralized anaerobic digestion where *only the surplus* of the manure is digested in one of the off-farm digestion facilities in the basin. Each unit represents one digestion facility that processes manure of thirty-two dairy farms

T: Number of units engaging in the transportation of the raw surplus manure to locations outside the basin. Each unit consists of five dairy farms that share some of the necessary capital equipment.

As can be seen, the alternatives regarding the centralized composting and anaerobic digestion of manure in one central facility for the entire basin have not been translated for the formal model. These alternatives have been excluded because quantification of effects showed that these centralized alternatives are inferior to the decentralized off-farm manure processing alternatives. This is probably caused by the fact that manure has to be transported over larger distances to reach the one central facility, which increases the production costs.

Decision variables related to nutrition management activities

$N_{no\text{-}wm}$: Number of units engaging in nutrition management without waste management activities. Each unit represents one dairy farm.

$N_{C\text{-}onf}$: Number of dairy farms engaging in nutrition management together with on-farm composting

$N_{C\text{-}all}$: Number of dairy farms engaging in nutrition management together with decentralized composting of all manure

$N_{C\text{-}sur}$: Number of dairy farms engaging in nutrition management together with decentralized composting of surplus manure

$N_{D\text{-}all}$: Number of dairy farms engaging in nutrition management together with decentralized digestion of all manure

$N_{D\text{-}sur}$: Number of dairy farms engaging in nutrition management together with decentralized digestion of surplus manure

N_T: Number of dairy farms engaging in nutrition management together with transportation of surplus manure

Decision variables related to agricultural BMPs

$B_{no\text{-}n}$: Number of units implementing traditional agricultural BMPs without nutrition management activities. Each unit consists of one dairy farm

B_{nutr}: Number of dairy farms implementing traditional agricultural BMPs together with nutrition management

Decision variable related to septic systems

S: Number of units engaging in septic system rehabilitation or upgrading. Each unit consists of one mall-functioning septic system

Decision variables related to WWTPs

W_W: Upgrading of the Walton WWTP
W_D: Upgrading of the Delhi WWTP
W_S: Upgrading of the Stamford WWTP
W_H: Upgrading of the Hobart WWTP

12.2 Content goals and criteria

Minimization of costs

The total costs for the implementation of alternatives should be minimized:

$$\text{Min } Z = c_1 C_{onf} + c_2 C_{all} + \ldots + c_{20} W_H$$

In this expression, Z represents the annualized costs for the implementation of phosphorus management activities; c_j represents the cost per unit of activity (decision variable)

Short-term phosphorus reduction

A target reduction in P-load should be achieved on the short-term:

$$a_{1,1} C_{onf} + a_{1,2} C_{all} + \ldots + a_{1,20} W_H \geq target_{\text{short-term}}$$

In this expression, a_{1j} represents the short-term reduction (in kg/y) that is achieved when one unit of activity j (decision variable) is implemented. The value for the target is determined by political decisions and health considerations.

Long-term phosphorus reduction/balancing of phosphorus

A target for long-term P-reductions should be realized by balancing phosphorus loads in the basin:

$$a_{2,1} C_{onf} + a_{2,2} C_{all} + \ldots + a_{2,20} W_H \geq target_{\text{long-term}}$$

a_{2j} represents the long-term reduction (in kg/y) that is achieved when one unit of activity j (decision variable) is implemented. The value for the target is determined partly by soil conditions.

Pathogens reduction

A target reduction for pathogens from dairy farms may be specified:

$$a_{3,1}C_{onf} + a_{3,2}C_{all} + \ldots + a_{3,20}W_H \geq target_{\text{pathogens}}$$

$a_{3,j}$ represents the pathogen reduction (as a percentage of the original pathogens) that is achieved when per unit of activity j. The value for the target is determined partly by political decisions and health considerations.

Acceptable distribution of costs

The practical feasibility of a certain strategy is related to the distribution of costs. This distribution of costs may be constrained e.g. there may be limits on the costs per group:

$$c_1C_{onfarm} + c_2C_{all} + \ldots + c_{15}B_{nutr} \leq Cost_{\text{farms}}$$
$$c_{16}S \leq Cost_{\text{septics}}$$
$$c_{17}W_W + c_{18}W_D + c_{19}W_S + c_{20}W_H \leq Cost_{\text{WWTPs}}$$

The c_j's in these functions are the same as in the objective function. The limits on the costs per group are not predetermined, but most probably it is desirable that the values for the three limits are in the same order of magnitude.

12.3 Structural goals

Waste management activities must be combined with BMPs

$$B_{no\text{-}nutr} + B_{nutr} \geq 5C_{onfarm} + 32C_{all} + 32C_{surplus} + 32D_{all} + 32D_{surplus} + 5T$$

At most one waste management activity at the time can be implemented

$$\begin{aligned} C_{onf} &\leq \mathrm{M}y_{C\text{-}onf} \\ C_{all} &\leq \mathrm{M}y_{C\text{-}all} \\ C_{sur} &\leq \mathrm{M}y_{C\text{-}sur} \\ D_{all} &\leq \mathrm{M}y_{D\text{-}all} \\ D_{sur} &\leq \mathrm{M}y_{D\text{-}sur} \\ T &\leq \mathrm{M}y_T \end{aligned}$$
$$y_{C\text{-}onf} + y_{C\text{-}all} + y_{C\text{-}sur} + y_{D\text{-}all} + y_{D\text{-}sur} + y_T \leq 1$$

In this expression M represents a very large positive value and y_i a binary variable

Values of decision variables can not exceed the maximum number of units

The number of units for BMPs can not exceed the total number of dairy farms:

$$B_{no\text{-}nutr} + B_{nutr} \leq 160$$

Number of units for nutrition management activities can not exceed the total number of dairy farms:

$$5C_{onf} + 32C_{all} + 32C_{sur} + 32D_{all} + 32D_{sur} + 5T + N_{no\text{-}wm} \leq 160$$

Number of units for on-farm composting or manure transportation cannot exceed the total number of dairy farms divided by five (five farms consist one unit):

$$C_{onfarm}, T \leq 32$$

Number of units for off-farm composting or anaerobic digestion cannot exceed the total number of dairy farms divided by thirty-two (there are thirty-two farms served by one facility):

$$C_{all}, C_{surplus}, D_{all}, D_{surplus} \leq 5$$

Number of units for rehabilitation of septic systems cannot exceed the total number of failing systems:

$$S \leq 2500$$

A wastewater treatment plant can only be upgraded once:

W_W, W_D, W_S, W_H are binary variables (either 0 or 1: on or off)

12.4 Additional constraints for model formulation

Nutrition management on farms with or without waste management must be divided correctly
(NB: units are not single farms for all the activities)

$$\begin{aligned} N_{C\text{-}onf} &\leq 5C_{onf} \\ N_{C\text{-}all} &\leq 32C_{all} \\ N_{C\text{-}sur} &\leq 32C_{sur} \\ N_{D\text{-}all} &\leq 32D_{all} \\ N_{D\text{-}sur} &\leq 32D_{sur} \\ N_T &\leq 5T \end{aligned}$$

BMPs must be properly combined with nutrition management

$$B_{nutr} \geq N_{C\text{-}onf} + N_{C\text{-}all} + N_{C\text{-}sur} + N_{D\text{-}all} + N_{D\text{-}sur} + N_T$$
$$B_{nutr} \leq N_{no\text{-}wm} + N_{C\text{-}onf} + N_{C\text{-}all} + N_{C\text{-}sur} + N_{D\text{-}all} + N_{D\text{-}sur} + N_T$$
$$N_{no\text{-}wm} + N_{no\text{-}wm} + N_{C\text{-}onf} + N_{C\text{-}all} + N_{C\text{-}sur} + N_{D\text{-}all} + N_{D\text{-}sur} + N_T + B_{no\text{-}n} \leq 160$$

Constraints regarding the individual decision variables:

$C_{onf}, C_{all}, C_{sur}, D_{all}, D_{sur}, T, N_{no\text{-}wm}, N_{C\text{-}onf}, N_{C\text{-}all}, N_{C\text{-}sur}, N_{D\text{-}all}, N_{D\text{-}sur}, N_T, B_{no\text{-}n}, B_{nutr} \geq 0$ and integer

y_i is binary for all i

12.5 Scenarios

Costs and effectiveness of the decision variables have been identified as scenario parameters. Variation of these two parameters makes it possible to formulate five different scenarios. For these scenarios the formal model will have to solved and analyzed.

The identified scenarios are summarized in Table 12.1. The first three scenarios are based on respectively the most optimistic, the most pessimistic and the average estimations of the effectiveness and costs of alternatives. The last two scenarios are related to the situation where either agricultural or wastewater treatment (septic systems and WWTPs) alternatives are relatively promising.

Scenario	Effectiveness Ag Alternatives	Effectiveness Wastewater Alt.	Costs Ag Alternatives	Costs Wastewater Alternatives
Optimistic	High	High	Low	Low
Pessimistic	Low	Low	High	High
Average	Average	Average	Average	Average
Agriculture	High	Average	Low	Average
Wastewater tr.	Average	High	Average	Low

Table 12.1. Scenarios in the formal model

13. Resolution model

The various elements of the formal model have been described in the previous chapter. These elements should be combined in a way that makes it possible to solve the formal model. If the formal model fits a certain form, than a suitable resolution algorithms may be available. The formal model and the resolution algorithm constitute the resolution model.

13.1 Selection of a resolution approach

The expressions of the formal model fit the model form that is generally used for integer programming [Hillier and Lieberman, 1995]. Integer programming (IP) models can be solved with the branch-and-bound algorithm, which is programmed in most generally available software packages. This makes it possible to optimize the model quickly so that a relatively large number of scenarios can be investigated. Integer programming seems to be the most suitable approach for this problem. It fits the formal model because it uses linear expressions and because the model has no dynamic aspects.

The integer programming approach will be combined with the use of scorecards. Scorecards can present useful information about the alternatives, but in themselves they do not suggest specific combinations of alternatives. Values that are contained in scorecards will function as the input for an IP-model, based on which strategies can be identified. So scorecards are not used as a 'final product', but to support the IP-model.

In general, it would also be possible to combine integer programming with other decision modeling tools, for example with utility theory. For this case however, utility theory is not very applicable, because it requires knowledge about the decision makers' preferences and the probability of the occurrence of various events [Beroggi, 1999]. This knowledge is at this moment not available for Delaware's phosphorus management problems.

13.2 Formulation of integer programming model

An integer programming model uses related linear expressions to optimize a goal variable. This is done by calculating the optimal set of values for the decision variables. The goal variable for the phosphorus management problem will be the total costs for implementation of alternatives (Z). This variable should be minimized, while meeting the constraints posed by the content and structural goals.

Integer programming model

Minimize

$$Z = c_1 C_{onfarm} + c_2 C_{all} + \ldots. + c_{20} W_H$$

subject to

$$
\begin{aligned}
a_{11} C_{onfarm} + a_{12} C_{all} + \ldots. + a_{120} W_H &\geq \mathit{target}_{\text{short-term}} \\
a_{21} C_{onfarm} + a_{22} C_{all} + \ldots. + a_{220} W_H &\geq \mathit{target}_{\text{long-term}} \\
a_{31} C_{onfarm} + a_{32} C_{all} + \ldots. + a_{320} W_H &\geq \mathit{target}_{\text{pathogens}} \\
c_1 C_{onfarm} + c_2 C_{all} + \ldots. + c_{15} B_{nutr} &\leq \mathit{Cost}_{\text{farms}} \\
c_{16} S &\leq \mathit{Cost}_{\text{septics}} \\
c_{17} W_W + c_{18} W_D + c_{19} W_S + c_{20} W_H &\leq \mathit{Cost}_{\text{WWTPs}} \\
C_{onfarm} - \mathrm{M} y_{C\text{-}onfarm} &\leq 0 \\
C_{all} - \mathrm{M} y_{C\text{-}all} &\leq 0 \\
C_{surplus} - \mathrm{M} y_{C\text{-}surplus} &\leq 0 \\
D_{all} - \mathrm{M} y_{D\text{-}all} &\leq 0 \\
D_{surplus} - \mathrm{M} y_{D\text{-}surplus} &\leq 0 \\
T - \mathrm{M} y_T &\leq 0 \\
y_{C\text{-}onfarm} + y_{C\text{-}all} + y_{C\text{-}surplus} + y_{D\text{-}all} + y_{D\text{-}surplus} + y_T &\leq 1 \\
5C_{onfarm} + 32C_{all} + 32C_{surplus} + 32D_{all} + 32D_{surplus} + 5T + N_{no\text{-}wm} &\leq 160 \\
N_{C\text{-}onfarm} - 5C_{onfarm} &\leq 0 \\
N_{C\text{-}all} - 32C_{all} &\leq 0 \\
N_{C\text{-}surplus} - 32C_{surplus} &\leq 0 \\
N_{D\text{-}all} - 32D_{all} &\leq 0 \\
N_{D\text{-}surplus} - 32D_{surplus} &\leq 0 \\
N_T - 5T &\leq 0 \\
B_{no\text{-}nutr} + B_{nutr} - 5C_{onfarm} - 32C_{all} - 32C_{surplus} - 32D_{all} - 32D_{surplus} - 5T &\geq 0 \\
B_{nutr} - N_{C\text{-}onfarm} - N_{C\text{-}all} - N_{C\text{-}surplus} - N_{D\text{-}all} - N_{D\text{-}surplus} - N_T &\geq 0 \\
B_{no\text{-}nutr} + B_{nutr} &\leq 160 \\
B_{nutr} - N_{no\text{-}wm} - N_{C\text{-}onfarm} - N_{C\text{-}all} - N_{C\text{-}surplus} - N_{D\text{-}all} - N_{D\text{-}surplus} - N_T &\leq 0 \\
N_{no\text{-}wm} + N_{no\text{-}wm} + N_{C\text{-}onfarm} + N_{C\text{-}all} + N_{C\text{-}surplus} + N_{D\text{-}all} + N_{D\text{-}surplus} + N_T + B_{no\text{-}nutr} &\leq 160 \\
C_{onfarm} &\leq 32 \\
T &\leq 32 \\
C_{all} &\leq 5 \\
C_{surplus} &\leq 5 \\
D_{all} &\leq 5 \\
D_{surplus} &\leq 5 \\
S &\leq 2500
\end{aligned}
$$

All decision variables ≥ 0
All decision variables integer, except for
W_W, W_D, W_S, W_H which are binary,
y_i is binary for all i

13.2 Values of model parameters for the different scenarios

As can be seen, the IP-model contains all the expressions that were formulated as part of the formal model. The values of the model's parameter-vectors ***a***, and **c**, are known, although they may vary for different scenarios. These values are based on input variables that might differ for the five identified scenarios. The values of the input variables that are subject to changes are stated in the next two tables. An explanation of these values can be found in Appendix E, together with information on the way in which the values for the model parameters have been calculated.

Input variable	Optimistic	Pessimistic	Most likely
Manure Surplus	80%	60%	60%
Price on-farm compost	\$20 m^{-3}	\$10 m^{-3}	\$15 m^{-3}
Price central compost	\$25 m^{-3}	\$12 m^{-3}	\$17 m^{-3}
Price digested manure	\$4.00 m^{-3}	\$1.60 m^{-3}	\$2.60 m^{-3}
Price raw manure	\$2.60 m^{-3} (\$0.01 gal^{-1})	\$0.70 m^{-3} (\$0.003 gal^{-1})	\$1.60 m^{-3} (\$0.006 gal^{-1})
Distance to markets	64 km (40 miles)	322 km (200 miles)	193 km (120 miles)
On-farm composting method	frequent turning	infrequent turning	frequent turning
P-content manure	1.1 g/kg	0.9 g/kg	1.0 g/kg
Short term effects BMPs	53.2 kg/farm/y (or 90% reduction)	7.7 kg/farm/y (or 35% reduction)	21.7 kg/farm/y (avg. 'successive forests method'; 60% reduction)
P-reductions in manure from nutrition man.	24 g/cow/day (438 kg/farm/y) - 29,3%	18 g/cow/day (329 kg/farm/y) - 18,4%	22 g/cow/day (402 kg/farm/y) - 23,9%
Pathogens reduction BMPs	90%	50%	70%
Manure surplus when nutrition is combined with waste man.	less: 72%	less: 51% (less P in excretion)	less: 47%
BMPs with balancing (short term)	higher (10% ratio)	higher (65% of surplus/loads ratio)	higher (40% ratio)
Costs nutrition management	\$3,000 per year	\$6,100 per year	\$4,500 per year
Short term effects nutrition	13.6 kg/farm/y	4.3 kg/farm/y	8.8 kg/farm/y

Table 13.1. Effectiveness and efficiency of agricultural alternatives

Input variable	Optimistic	Pessimistic	Most likely
Cost WWTP Upgrades			
Walton	\$12 million	\$16 million	\$16 million
Delhi	\$7 million	\$10.8 million	\$10.8 million
Stamford	\$6 million	\$7 million	\$7 million
Hobart	\$1.5 million	\$1.8 million	\$1.8 million
TP conc. after upgrade			
Walton	0.05 mg/l	0.2 mg/l	0.05 mg/l
Delhi	0.05 mg/l	0.2 mg/l	0.05 mg/l
Stamford	0.02 mg/l	0.2 mg/l	0.02 mg/l
Hobart	0.05 mg/l	0.5 mg/l	0.05 mg/l
Effect septic systems	4.4 kg/system/y	0.7 kg/system/y	2.6 kg/system/y

Table 13.2. Effectiveness and efficiency of wastewater treatment alternatives

Besides the changing input variables, there are also other input variables whose values are subject to uncertainties. However their values remain the same in the different scenarios. The assumptions that are made for these values can be found in Appendix C.

For each of the five scenarios, specific parameter values have been calculated. The values for the optimistic, pessimistic and most likely variant are shown on the following page. The values for scenario 4 and 5 (agriculture and wastewater treatment) can also be derived from these tables. Details on the calculation of these parameter values can be found in Appendices C, D and E.

Decision variable	Unit	Short-term P-reduction (kg/y)	Long-term P-reduction (kg/y)	Pathogens (# farms)	Fixed costs (1,000$/y)	Variable costs (1,000$/y)
C_{onf}	5 farms	16	5096	0.5	18.1	-81.9
C_{all}	32 farms	102.4	32614	3.2	606.0	-879.3
C_{sur}	32 farms	102.4	32614	2.6	416.5	-832.2
D_{all}	32 farms	102.4	32614	3.2	166.5	136.9
D_{sur}	32 farms	102.4	32614	2.6	151.0	123.9
T	5 farms	16	5096	0.4	9.7	17.5
$N_{no\text{-}wm}$	farm	13.6	438	0	0.0	3.0
$N_{C\text{-}onf}$	farm	0	0	0	-0.5	5.4
$N_{C\text{-}all}$	farm	0	0	0	-6.5	12.4
$N_{C\text{-}sur}$	farm	0	0	0	-1.7	6.3
$N_{D\text{-}all}$	farm	0	0	0	-0.2	2.9
$N_{D\text{-}sur}$	farm	0	0	0	-0.6	2.5
N_T	farm	0	0	0	-0.2	2.7
$B_{no\text{-}n}$	farm	53.2	0	0.9	9	0
B_{nutr}	farm	41.0	0	0.9	9	0
S	system	1.1	4.4	0	1.1	0
W_W	plant	1969	0	0	1322.4	0
W_D	plant	1753	0	0	771.4	0
W_S	plant	928	0	0	661.2	0
W_H	plant	147	0	0	165.3	0

Table 13.3. Model parameter values for the optimistic scenario

Decision variable	Unit	Short-term P-reduction (kg/y)	Long-term P-reduction (kg/y)	Pathogens (# farms)	Fixed costs (1,000$/y)	Variable costs (1,000$/y)
C_{onf}	5 farms	26.5	3150	2.5	27.8	130.3
C_{all}	32 farms	169.6	20160	16	509.5	551.3
C_{sur}	32 farms	169.6	20160	9.6	362.2	455.2
D_{all}	32 farms	169.6	20160	16.0	224.3	637.9
D_{sur}	32 farms	169.6	20160	9.6	178.0	611.8
T	5 farms	26.5	3150	1.5	18.8	91.8
$N_{no\text{-}wm}$	farm	4.3	329	0	0.0	6.1
$N_{C\text{-}onf}$	farm	0	0	0	-0.5	3.9
$N_{C\text{-}all}$	farm	0	0	0	-1.0	5.1
$N_{C\text{-}sur}$	farm	0	0	0	-1.5	4.2
$N_{D\text{-}all}$	farm	0	0	0	-0.8	3.8
$N_{D\text{-}sur}$	farm	0	0	0	-0.8	3.4
N_T	farm	0	0	0	-0.5	3.5
$B_{no\text{-}n}$	farm	7.7	0	0.5	9	0
B_{nutr}	farm	6.2	0	0.5	9	0
S	system	0.18	0.7	0	1.1	0
W_W	plant	1658	0	0	1763.2	0
W_D	plant	1664	0	0	1190.2	0
W_S	plant	829	0	0	771.4	0
W_H	plant	128	0	0	198.36	0

Table 13.4. Model parameter values for the pessimistic scenario

Decision variable	Unit	Short-term P-reduction (kg/y)	Long-term P-reduction (kg/y)	Pathogens (# farms)	Fixed costs (1,000$/y)	Variable costs (1,000$/y)
C_{onf}	5 farms	31	3501	1.5	10.1	27.5
C_{all}	32 farms	198.4	22406	9.6	448.3	112.5
C_{sur}	32 farms	198.4	22406	5.8	299.0	18.5
D_{all}	32 farms	198.4	22406	9.6	190.9	383.0
D_{sur}	32 farms	198.4	22406	5.8	144.6	356.9
T	5 farms	31	3501	0.9	13.6	52.9
$N_{no\text{-}wm}$	farm	8.8	402	0	0.0	4.5
$N_{C\text{-}onf}$	farm	0	0	0	-0.1	4.2
$N_{C\text{-}all}$	farm	0	0	0	0.7	4.7
$N_{C\text{-}sur}$	farm	0	0	0	-1.6	4.4
$N_{D\text{-}all}$	farm	0	0	0	-0.8	2.8
$N_{D\text{-}sur}$	farm	0	0	0	-0.9	2.3
N_T	farm	0	0	0	-0.5	2.4
$B_{no\text{-}n}$	farm	21.7	0	0.7	9	0
B_{nutr}	farm	16.4	0	0.7	9	0
S	system	0.675	2.6	0	1.1	0
W_W	plant	1969	0	0	1763.2	0
W_D	plant	1753	0	0	1190.2	0
W_S	plant	928	0	0	771.4	0
W_H	plant	147	0	0	198.36	0

Table 13.5. Model parameter values for the most likely scenario

The parameter values of the above tables are used to describe specific models for the five different scenarios. These models can be solved using the 'Solver' in MS Excel. This software has been selected because it is generally available. This will make it easy to reproduce the results and to adapt the model in the future if new information requires a change in some parts of the model. The last step to be taken before the model can actually be solved, is to determine realistic values for the content goals. This will be done in the next paragraph.

13.3 Values of content goals within scenarios

The values for the ***target*** and ***Cost*** vectors in the IP model are the uncertain outcomes of a political decision process. Different values for these vectors will be used to explore possible situations within the scenarios.

Target for short-term phosphorus reduction

The short-term reduction of phosphorus is the most important content goal. If this goal is not met, the critical loads will still be exceeded in the near future. This means that the Cannonsville basin will remain phosphorus restricted and that NYCDEP will most probably not be granted filtration avoidance by the EPA in 2002.

In accordance with the official procedures, the average loading is used here. The average loading is estimated to be approximately 52,000 kg/y. The necessary reduction for meeting the proposed future target is approximately 17,000 kg/y. (Paragraph 6.2)

Target for long-term phosphorus reduction

On the long-term, the phosphorus that is brought onto agricultural lands should be more in balance with the phosphorus that is used by the crops. This means a substantial reduction of the current amount of phosphorus that is brought on the lands. However it is not known when this reduction should be reached, because it is not known what the capacity for P-uptake of the soil is. To balance the phosphorus, 60% to 80% reductions seem necessary. This means a reduction of 100,800 to 163,072 kg/y of total phosphorus on the 160 dairy farms.

Target for reduction of pathogens from farms

The reduction of pathogens from farms will be beneficial to Delaware County. But pathogen reductions will be of less importance than phosphorus reductions, so they will only be used to distinguish between strategies that are equally fit from a phosphorus reduction point of view.

Acceptable distribution of costs

As for pathogen reductions, no thresholds will be set for this content goal. The optimal model solutions will be analyzed to see if this content goal is met sufficiently. If this is not the case, it will be necessary to see if the optimal solution has to be rejected or if socio-political measures could help to overcome the problems.

Minimization of costs

For this content goal, no target needs to be set, because the model will determine the strategy with the least costs that meets all the modeled constraints.

Part V: Model results

14. Analysis of model results

14.1 Presentation of model results

The resolution model described in Chapter 13 can be solved for the different scenarios. Within each scenario, different combinations of target values for content goals can be used. For the first analysis, only short-term phosphorus reductions and costs have been varied, because these two were considered to be the most important content goals. This analysis showed that unfortunately the short-term reduction targets were not met in any of the identified scenarios, i.e. there is no feasible solution to the model. Therefore it has not been possible to identify different strategies that meet the short-term reduction targets. Consequently also no trade-offs between secondary criteria such as pathogen reduction and variable costs could be identified.

Information in DEP's Phase II TMDL calculations shows that there might be feasible solutions to the model if a target concentration of 20 $\mu g\ l^{-1}$ is applied instead of the proposed target concentration of 15 $\mu g\ l^{-1}$ [NYCDEP, March 1999a]. Unfortunately this information only became available after most of the analysis already had been completed. However the performed analysis is still considered to be valid, because it is most likely that the proposed target concentration will be effected. If, however, in the future the guidance value is changed to a value between 15 and 20 $\mu g\ l^{-1}$, then additional analysis is probably useful to identify trade-offs between different criteria.

To represent the relation between costs and the level of short-term target reductions, graphs have been used. On one axis the achieved reduction is represented, while on the other axis the minimal costs are shown. The result is a plot of the minimal costs associated with meeting certain targets. The elements of the plot are formed by the IP-model solutions (as different combinations of activities). These types of graphs might also give some useful insights in the activities that should certainly be implemented and activities for which the choice of implementation is more complex. The use of such graphs has proven to be useful in the past, for example in the policy analysis study after freight options in the Netherlands [Hillestad et al., 1996].

The graphs for cost-effectiveness of optimal strategies are depicted in the figures 14.1 to 14.5. Each point in these graphs represents a strategy, consisting of a certain combination of alternatives. The strategies in the graphs from left to right result in increasing phosphorus reductions. They correspond with the combinations shown from the bottom to the top in the tables that are shown directly below the graphs, starting with Table 14.1.

As can be seen from the results, waste management (composting or transportation) is included in most strategies. It is not certain however that there is indeed a market for compost or manure. Therefore also model results have been depicted for the case that waste management alternatives cannot be implemented because there is no market. Results for both situations are shown in the same figures (Figures 14.1 to 14.5). In these graphs, strategies with nutrition management are depicted by triangles, strategies with waste management are represented by bullets.

Except for a graph and a table that state the effects of the most promising strategies for each scenario, also tables are shown that describe the relevant scores of individual alternatives. These tables, starting with Table 14.2, are drawn up as if the alternatives were implemented for the maximum number of units possible in the Cannonsville basin. The alternatives in these tables are ranked according to their cost-effectiveness with regard to short-term phosphorus reduction. The waste management alternatives are only shown in combination with agricultural BMPs, because of the model's structural goals (see Part IV).

Results for scenario 1, optimistic estimations

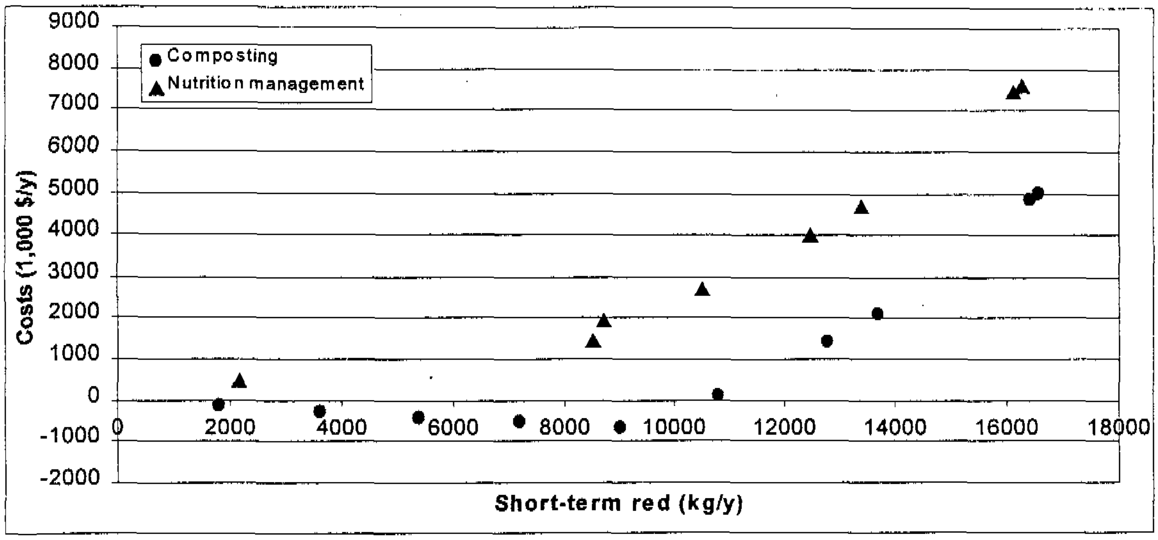

Figure 14.1: Cost-effectiveness of strategies for scenario 1

Strategies with waste management	Short-term reduction (kg/y)	Costs (1,000 $/y)	Strategies without waste management	Short-term reduction (kg/y)	Costs (1,000 $/y)
$C_{sur}+B_{no\text{-}n}+S+W_{W,D,S,H}$	16571	5037	$N_{no\text{-}wm}+B_{nutr}+S+W_{W,D,S,H}$	16277	7595
$C_{sur}+B_{no\text{-}n}+S+W_{W,D,S}$	16424	4871	$N_{no\text{-}wm}+B_{nutr}+S+W_{W,D,S}$	16130	7430
$C_{sur}+B_{no\text{-}n}+W_{W,D,S}$	13674	2116	$N_{no\text{-}wm}+B_{nutr}+W_{W,D,S}$	13380	4675
$C_{sur}+B_{no\text{-}n}+W_{W,D}$	12746	1455	$N_{no\text{-}wm}+B_{nutr}+W_{W,D}$	12452	4014
$C_{sur}+B_{no\text{-}n}+W_{D}$	10777	133	$N_{no\text{-}wm}+B_{nutr}+W_{D}$	10483	2691
$C_{sur}+B_{no\text{-}n}$	9024	-639	$N_{no\text{-}wm}+B_{nutr}$	8730	1920
$C_{sur}(4)+B_{no\text{-}n}(128)$	7219	-511	$B_{no\text{-}n}$	8512	1440
$C_{sur}(3)+B_{no\text{-}n}(96)$	**5414**	**-383**	**$N_{no\text{-}wm}$**	**2176**	**480**
$C_{sur}(2)+B_{no\text{-}n}(64)$	3610	-255			
$C_{sur}(1)+B_{no\text{-}n}(32)$	1805	-128			

Table 14.1. Combinations of alternatives that compose strategies for scenario 1
*(strategies in **bold** are sub-optimal, figures in brackets refer to units; no brackets means max. number of units)*

Alternative	Costs short-term P red (1,000$/kg/y)	Shortterm P-red (kg/y)	Longterm P-red (kg/y)	Pathogens (% dairy farms)	Fixed costs (1,000$/y)	Variable costs (1,000$/y)
$C_{sur}+B_{no\text{-}n}$	-0.071	9024	163072	98%	3522	-4161
$C_{onf}+B_{no\text{-}n}$	-0.067	9024	163072	100%	2018	-2622
$C_{all}+B_{no\text{-}n}$	0.008	9024	163072	100%	4470	-4397
$B_{no\text{-}n}$	0.169	8512	0	90%	1440	0
B_{nutr}	0.220	6554	0	90%	1440	0
$N_{no\text{-}wm}$	0.221	2176	70080	0%	0	480
$T+B_{no\text{-}n}$	0.256	9024	163072	98%	1752	561
$D_{sur}+B_{no\text{-}n}$	0.312	9024	163072	98%	2195	619
$D_{all}+B_{no\text{-}n}$	0.328	9024	163072	100%	2273	685
W_D	0.440	1753	0	0%	771	0
W_W	0.672	1969	0	0%	1322	0
W_S	0.713	928	0	0%	661	0
S	1.002	2750	11000	0%	2755	0
W_H	1.124	147	0	0%	165	0

Table 14.2. Values for individual alternatives, scenario 1 (ranked for costs)

Results for scenario 2, pessimistic estimations

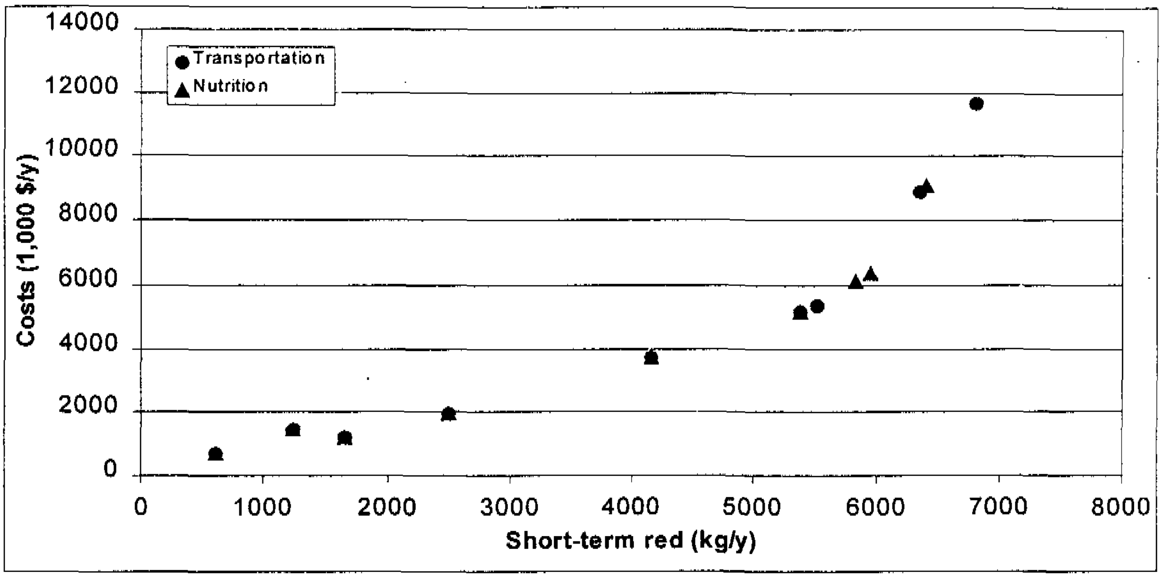

Figure 14.2. Cost-effectiveness of strategies for scenario 2

Strategies with waste management (sub-optimal)	Short-term reduction (kg/y)	Costs (1,000 $/y)	Strategies without waste management (optimal)	Short-term reduction (kg/y)	Costs (1,000 $/y)
$T+B_{no-n}+S+W_{W,D,S,H}$	6809	11657	$N_{no-wm}+B_{nutr}+S+W_{W,D,S,H}$	6408	9094
$T+B_{no-n}+W_{W,D,S,H}$	6359	8902	$N_{no-wm}+B_{nutr}+W_{W,D,S,H}$	5958	6339
$B_{no-n}+W_{W,D,S,H}$	5511	5363	$N_{no-wm}+B_{nutr}+W_{W,D,S}$	5830	6141
$B_{no-n}+W_{W,D,S}$	5383	5165	$B_{nutr}+W_{W,D,S}$	5383	5165
$W_{W,D,S}$	4151	3725	$W_{W,D,S}$	4151	3725
$W_{D,S}$	2493	1962	$W_{D,S}$	2493	1962
W_D	1664	1190	W_D	1664	1190
B_{no-n}	**1232**	**1440**	**B_{no-n}**	**1232**	**1440**
$B_{no-n}(80)$	**616**	**720**	**$B_{no-n}(80)$**	**616**	**720**

Table 14.3: Combinations of alternatives that compose strategies for scenario 2
*(strategies in **bold** are sub-optimal, figures in brackets refer to units; no brackets means max. number of units)*

Alternative	Costs short-term P red (1,000$/kg/y)	Shortterm P-red (kg/y)	Longterm P-red (kg/y)	Pathogens (% dairy farms)	Fixed costs (1,000$/y)	Variable costs (1,000$/y)
W_D	0.72	1664	0	0%	1190	0
W_S	0.93	829	0	0%	771	0
W_W	1.06	1658	0	0%	1763	0
B_{no-n}	1.17	1232	0	50%	1440	0
N_{no-wm}	1.42	688	52640	0%	0	976
B_{nutr}	1.45	991	0	50%	1440	0
W_H	1.55	128	0	0%	198	0
$T+B_{no-n}$	2.39	2080	100800	80%	2041	2938
$D_{sur}+B_{no-n}$	2.59	2080	100800	80%	2330	3059
$C_{sur}+B_{no-n}$	2.66	2080	100800	80%	3251	2276
$D_{all}+B_{no-n}$	2.76	2080	100800	100%	2561	3190
$C_{onf}+B_{no-n}$	3.13	2080	100800	100%	2331	4171
$C_{all}+B_{no-n}$	3.24	2080	100800	100%	3988	2757
S	6.12	450	1750	0%	2755	0

Table 14.4. Values for individual alternatives, scenario 2 (ranked for costs)

Results for scenario 3, most likely estimations

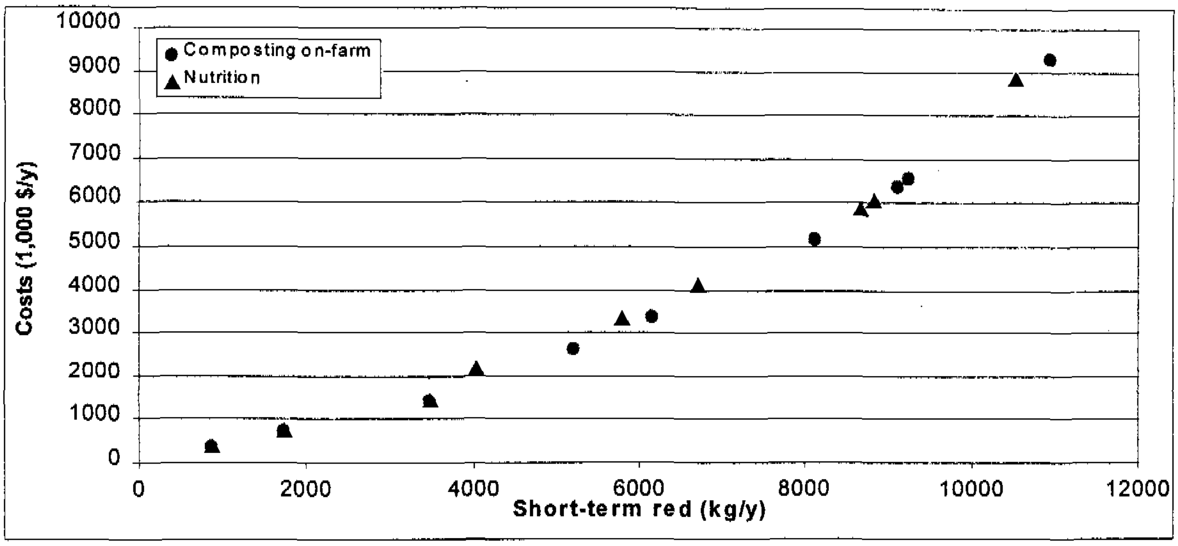

Figure 14.3. Cost-effectiveness of strategies for scenario 3

Strategies with waste management	Short-term reduction (kg/y)	Costs (1,000 $/y)	Strategies without waste management	Short-term reduction (kg/y)	Costs (1,000 $/y)
$C_{onf}+B_{no-n}+S+W_{W,D,S,H}$	10949	9324	$N_{no-wm}+B_{nutr}+S+W_{D,S,W,H}$	10520	8838
$C_{onf}+B_{no-n}+W_{W,D,S,H}$	9261	6569	$N_{no-wm}+B_{nutr}+W_{D,S,W,H}$	8832	6083
$C_{onf}+B_{no-n}+W_{W,D,S}$	9114	6370	$N_{no-wm}+B_{nutr}+W_{D,S,W}$	8685	5885
$B_{no-n}+W_{W,D,S}$	8122	5165	$N_{no-wm}+B_{nutr}+W_{D,S}$	6716	4122
$B_{no-n}+W_{D,S}$	6153	3402	$N_{no-wm}+B_{nutr}+W_{D}$	5788	3350
$B_{no-n}+W_{D}$	5225	2630	$N_{no-wm}+B_{nutr}$	4035	2160
B_{no-n}	3472	1440	B_{no-n}	3472	1440
$B_{no-n}(80)$	1736	720	$B_{no-n}(80)$	1736	720
$B_{no-n}(40)$	868	360	$B_{no-n}(40)$	868	360

Table 14.5. Combinations of alternatives that compose strategies for scenario 3
(figures in brackets refer to units; no brackets means max. number of units)

Alternative	Costs short-term P red (1,000$/kg/y)	Shortterm P-red (kg/y)	Longterm P-red (kg/y)	Pathogens (% dairy farms)	Fixed costs (1,000$/y)	Variable costs (1,000$/y)
B_{no-n}	0.41	3472	0	70%	1440	0
N_{no-wm}	0.51	1408	64320	0%	0	720
B_{nutr}	0.55	2627	0	70%	1440	0
$C_{onf}+B_{no-n}$	0.59	4464	112032	100%	1764	881
$C_{sur}+B_{no-n}$	0.68	4464	112032	88%	2935	92
W_D	0.68	1753	0	0%	1190	0
$T+B_{no-n}$	0.80	4464	112032	88%	1876	1692
W_S	0.83	928	0	0%	771	0
$D_{sur}+B_{no-n}$	0.88	4464	112032	88%	2163	1784
W_W	0.90	1969	0	0%	1763	0
$C_{all}+B_{no-n}$	0.95	4464	112032	100%	3682	563
$D_{all}+B_{no-n}$	0.97	4464	112032	100%	2394	1915
W_H	1.35	147	0	0%	198	0
S	1.63	1688	6500	0%	2755	0

Table 14.6. Values for individual alternatives, scenario 3 (ranked for costs)

Results for scenario 4, optimistic estimations for agriculture

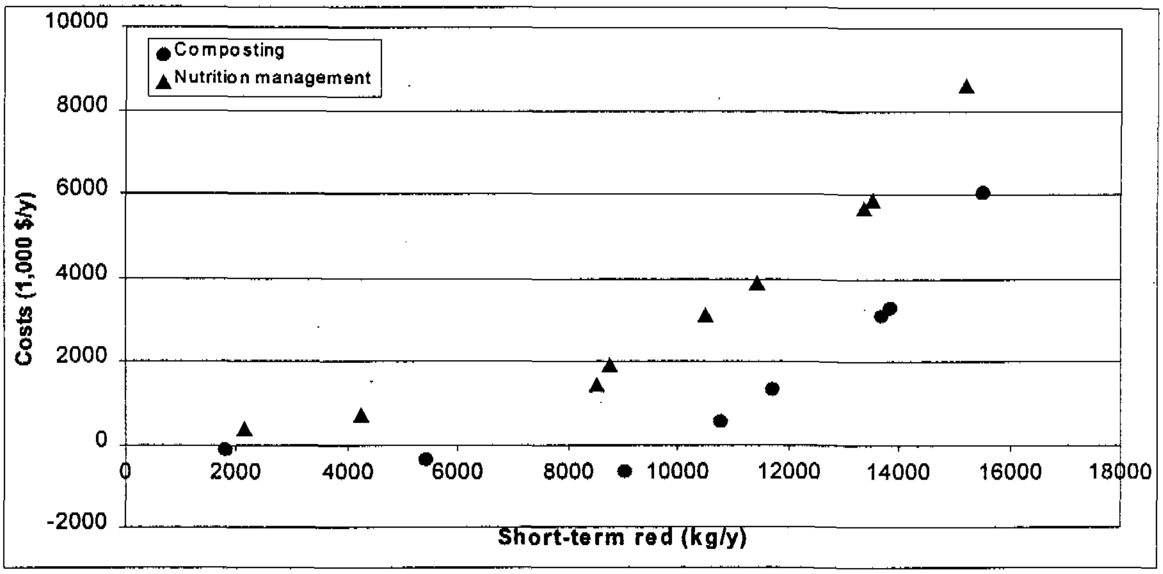

Figure 14.4. Cost-effectiveness of strategies for scenario 4

Strategies with waste management	Short-term reduction (kg/y)	Costs (1,000 $/y)	Strategies without waste management	Short-term reduction (kg/y)	Costs (1,000 $/y)
$C_{sur}+B_{no\text{-}n}+S+W_{W,D,S,H}$	15509	6040	$N_{no\text{-}wm}+B_{nutr}+S+W_{W,D,S,H}$	15214	8598
$C_{sur}+B_{no\text{-}n}+W_{W,D,S,H}$	13821	3285	$N_{no\text{-}wm}+B_{nutr}+W_{W,D,S,H}$	13527	5843
$C_{sur}+B_{no\text{-}n}+W_{W,D,S}$	13674	3086	$N_{no\text{-}wm}+B_{nutr}+W_{W,D,S}$	13380	5645
$C_{sur}+B_{no\text{-}n}+W_{D,S}$	11705	1323	$N_{no\text{-}wm}+B_{nutr}+W_{D,S}$	11411	3882
$C_{sur}+B_{no\text{-}n}+W_{D}$	10777	552	$N_{no\text{-}wm}+B_{nutr}+W_{D}$	10483	3110
$C_{sur}+B_{no\text{-}n}$	9024	-639	$N_{no\text{-}wm}+B_{nutr}$	8730	1920
$C_{sur}(3)+B_{no\text{-}n}(96)$	5414	-383	$B_{no\text{-}n}$	8512	1440
$C_{sur}(1)+B_{no\text{-}n}(32)$	1805	-128	$B_{no\text{-}n}(80)$	4256	720
			$B_{no\text{-}n}(40)$	2128	360

Table 14.7. Combinations of alternatives that compose strategies for scenario 4
(figures in brackets refer to units, no brackets means max. number of units)

Alternative	Costs short-term P red (1,000$/kg/y)	Shortterm P-red (kg/y)	Longterm P-red (kg/y)	Pathogens (% dairy farms)	Fixed costs (1,000$/y)	Variable costs (1,000$/y)
$C_{sur}+B_{no\text{-}n}$	-0.071	9024	163072	98%	3522	-4161
$C_{onf}+B_{no\text{-}n}$	-0.067	9024	163072	100%	2018	-2622
$C_{all}+B_{no\text{-}n}$	0.008	9024	163072	100%	4470	-4397
$B_{no\text{-}n}$	0.169	8512	0	90%	1440	0
B_{nutr}	0.220	6554	0	90%	1440	0
$N_{no\text{-}wm}$	0.221	2176	70080	0%	0	480
$T+B_{no\text{-}n}$	0.256	9024	163072	98%	1752	561
$D_{sur}+B_{no\text{-}n}$	0.312	9024	163072	98%	2195	619
$D_{all}+B_{no\text{-}n}$	0.328	9024	163072	100%	2273	685
W_D	0.679	1753	0	0%	1190	0
W_S	0.831	928	0	0%	771	0
W_W	0.895	1969	0	0%	1763	0
W_H	1.349	147	0	0%	198	0
S	1.633	1688	6500	0%	2755	0

Table 14.8. Values for individual alternatives, scenario 4 (ranked for costs)

Results for scenario 5, optimistic estimations for wastewater treatment

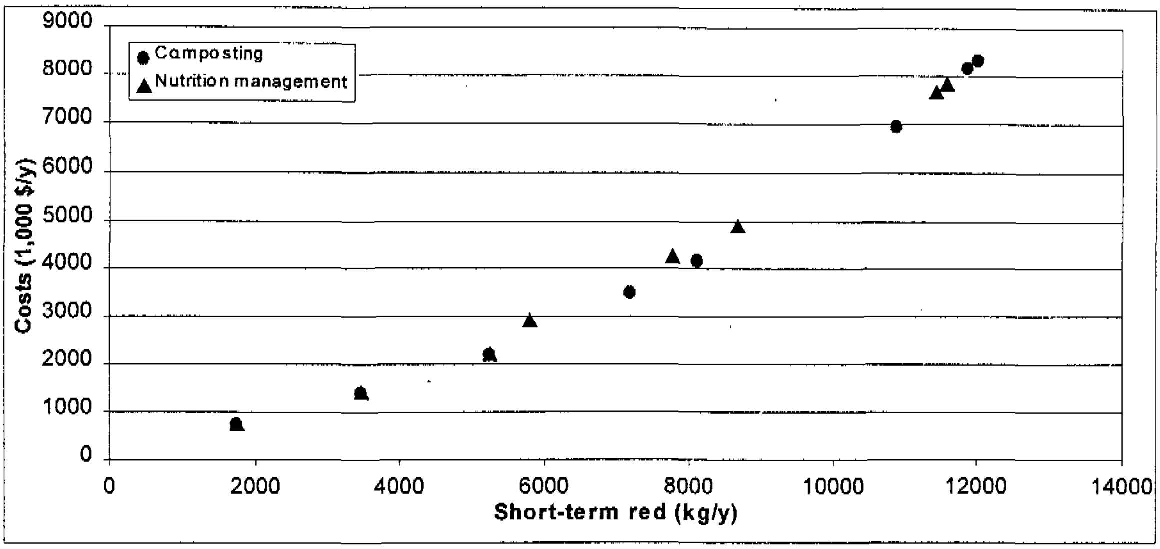

Figure 14.5. Cost-effectiveness of strategies for scenario 5

Strategies with waste management	**Short-term reduction (kg/y)**	**Costs (1,000 $/y)**	**Strategies without waste management**	**Short-term reduction (kg/y)**	**Costs (1,000 $/y)**
$C_{onf}+B_{no\text{-}n}+S+W_{W,D,S,H}$	12011	8321	$N_{no\text{-}wm}+B_{nutr}+S+W_{W,D,S,H}$	11582	7835
$C_{onf}+B_{no\text{-}n}+S+W_{W,D,S}$	11864	8155	$N_{no\text{-}wm}+B_{nutr}+S+W_{W,D,S}$	11435	7670
$B_{no\text{-}n}+S+W_{W,D,S}$	10872	6950	$N_{no\text{-}wm}+B_{nutr}+W_{W,D,S}$	8685	4915
$B_{no\text{-}n}+W_{W,D,S}$	8122	4195	$N_{no\text{-}wm}+B_{nutr}+W_{W,D}$	7757	4254
$B_{no\text{-}n}+W_{W,D}$	7194	3534	$N_{no\text{-}wm}+B_{nutr}+W_D$	5788	2931
$B_{no\text{-}n}+W_D$	5225	2211	$B_{nutr}+W_D$	5225	2211
$B_{no\text{-}n}$	3472	1440	$B_{no\text{-}n}$	3472	1440
$\boldsymbol{W_D}$	**1664**	**771**	$\boldsymbol{W_D}$	**1664**	**771**

Table 14.9. Combinations of alternatives that compose strategies for scenario 5
(strategies in ***bold*** *are sub-optimal, figures between brackets refer to units, no brackets means max. number of units)*

Alternative	**Costs short-term P red (1,000$/kg/y)**	**Shortterm P-red (kg/y)**	**Longterm P-red (kg/y)**	**Pathogens (% dairy farms)**	**Fixed costs (1,000$/y)**	**Variable costs (1,000$/y)**
$B_{no\text{-}n}$	0.415	3472	0	70%	1440	0
W_D	0.440	1753	0	0%	771	0
$N_{no\text{-}wm}$	0.511	1408	64320	0%	0	720
B_{nutr}	0.548	2627	0	70%	1440	0
$C_{onf}+B_{no\text{-}n}$	0.593	4464	112032	100%	1764	881
W_W	0.672	1969	0	0%	1322	0
$C_{sur}+B_{no\text{-}n}$	0.678	4464	112032	88%	2935	92
W_S	0.713	928	0	0%	661	0
$T+B_{no\text{-}n}$	0.799	4464	112032	88%	1876	1692
$D_{sur}+B_{no\text{-}n}$	0.884	4464	112032	88%	2163	1784
$C_{all}+B_{no\text{-}n}$	0.951	4464	112032	100%	3682	563
$D_{all}+B_{no\text{-}n}$	0.965	4464	112032	100%	2394	1915
S	1.002	2750	11000	0%	2755	0
W_H	1.124	147	0	0%	165	0

Table 14.10. Values for individual alternatives, scenario 5 (ranked for costs)

Alternatives' costs compared over different scenarios

Besides the scores of alternatives for each separate scenario, as shown above, it might also be interesting to compare the cost-effectiveness of alternatives between scenarios. The annual costs per kilogram of short-term phosphorus reduction of the alternatives are shown for the three different estimations (optimistic, pessimistic and most likely) in Figure 14.6. Again, agricultural waste management alternatives have been depicted in combination with BMPs, because of the model's structural goals. This figure shows that rehabilitation of septic systems (*S*) is often the least attractive alternative. Cost-effectiveness of the upgrading of WWTPs (W_W, W_D, W_S and W_H) does not differ very much among scenarios. Composting of manure is the only alternative for which net benefits might be generated in the most optimistic situation.

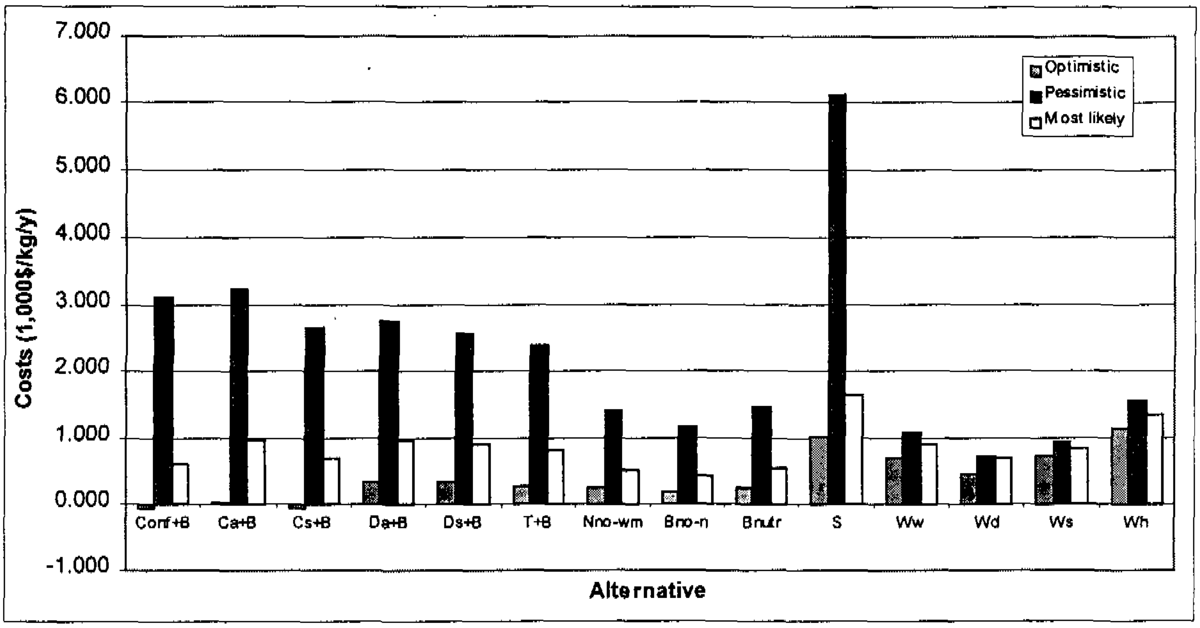

Figure 14.6. Costs of short-term P-reductions per alternative for different scenarios

Distribution of costs

Fixed and variable costs

The distribution of costs is an important aspect for the actual implementation of a strategy. An important indicator is the division between capital costs that are fixed and the operational costs that are variable. For fixed capital costs, funds might be available and no ongoing financial obligations are required. In the current situation there is some distrust between the local actors in Delaware and New York City. In this situation it is easier to reach an agreement on costs that have to be paid for once, than on costs that need to be covered continually. The division between fixed and variable costs for the five scenarios are shown next, in the Figures 14.7 to 14.11.

These figures show that the largest part of the costs is fixed. With a good market for compost, as in scenario 1 and 4, the variable costs are negative, i.e. they are in fact benefits. In this case farmers might actually benefit from implementing the phosphorus reduction measures because the variable benefits are larger than the fixed costs. For the non-agricultural measures the costs are only fixed. This is because these alternatives are improvements of existing systems/plants that already have to be operated and maintained. It is not expected that implementation of the alternatives will require extra operation and maintenance efforts. If this assumption proves to be wrong for the WWTPs, then New York City has agreed to pay for the additional operation and maintenance costs (Chapter 8).

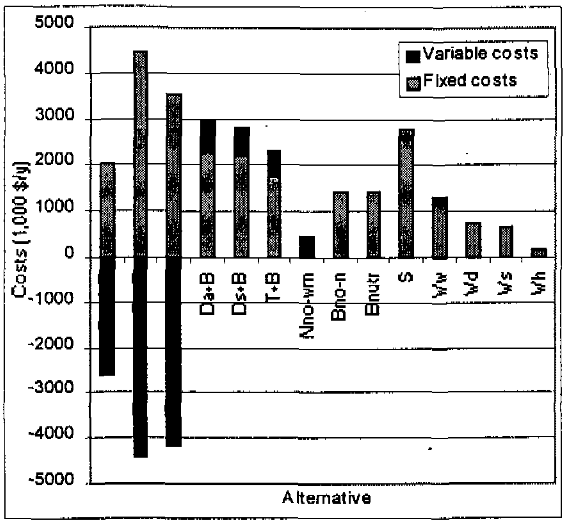

Figure 14.7. Fixed and variable costs, scen 1

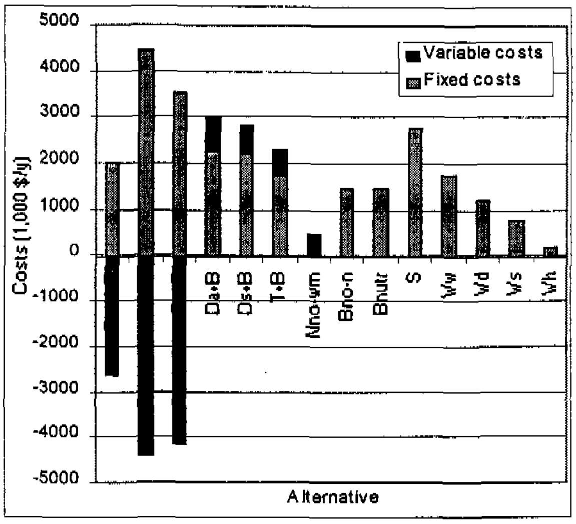

Figure 14.10. Fixed and variable costs, scen 4

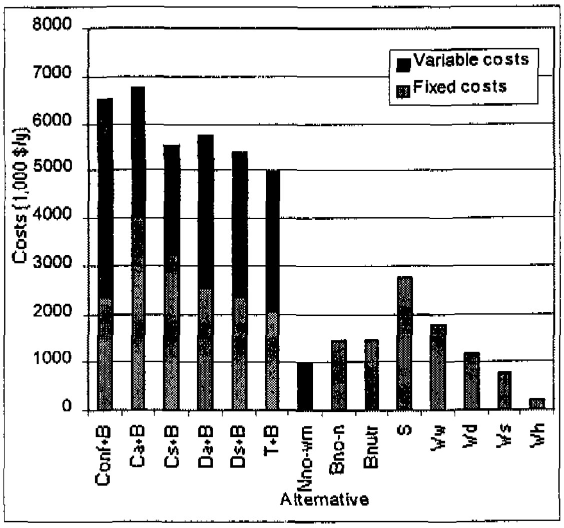

Figure 14.8. Fixed and variable costs, scen 2

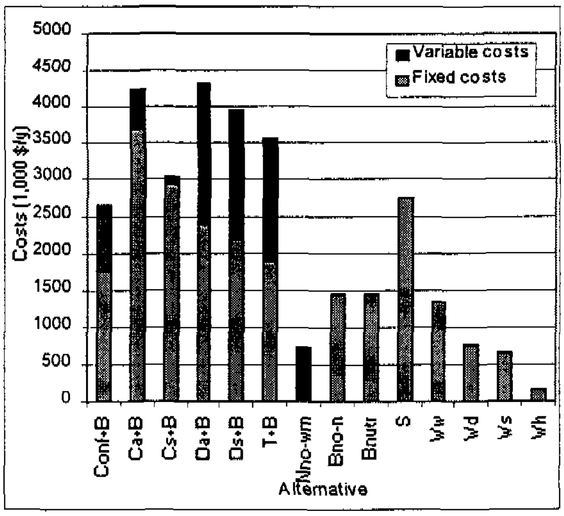

Figure 14.11. Fixed and variable costs, scen 5

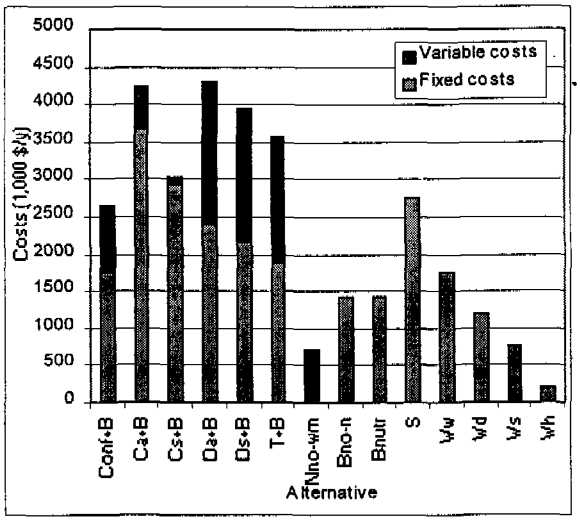

Figure 14.9. Fixed and variable costs, scen 3

Available funds and distribution of costs between different actors

Except for the division between fixed and variable costs, it is also useful to look at the funds that are available for the implementation of alternatives. A substantial part of the funds has been provided for the New York City watershed as a whole, to support the Watershed Agreement. Although the Cannonsville basin is the only phosphorus restricted basin, it does not have any precedence over the other basins regarding the distribution of these funds. Therefore the funds that are available for the Cannonsville basin have been estimated according to the surface area of the basin, relative to that of the other basins that are part of the Catskill and Delaware systems. For the agricultural funds, the area occupied by agriculture has been used. The specifics of the funds that are used in this section can be found in Appendix A.

The depicted figure shows the funds that have been made available by New York City, New York State and the U.S. federal government. Funds that have been earmarked for activities that are not of relevance to this study have been excluded, such as funds for the operation of the Catskill Watershed Corporation, funds for sand and salt storage, public education etc. A part of the funds that are shown has been earmarked for purposes that correspond with certain alternatives in this study. These funds have been subtracted from the costs for the implementation of these alternatives. What was left, is shown in the figure as costs for farmers and owners of septic systems. Regarding the costs for farmers, it is also important to note that in the agreement on the Watershed Agriculture Program, NYCDEP agreed to pay all of the farmers' costs to comply with the watershed requirements. It is not known if this agreement still holds after the MOA however.

There are also funds for the support of the Watershed Agreement in general, and at least a part of these funds could be used for agricultural measures and rehabilitation of septic systems. The second-last group of columns show the amount of these general funds that the Cannonsville basin could claim if distribution would be based on each basin's surface area. The last group of columns shows the net costs for the actors in the Cannonsville basin if the general funds would be used entirely for implementation of the strategies identified in this study. However this is not very likely to happen, because part of the general funds will probably be used for administrative and organizational purposes and for the implementation of measures that are not included in this study.

Based on Figure 14.12 it seems that the actors in Delaware County do not have to pay a very large amount of the costs for phosphorus reduction measures. New York City pays the largest part of the costs, together with the federal government. However there are two things that should be noted regarding these observations. The first is that the contribution of New York City includes all the costs for the upgrade of the WWTPs. The City agreed to pay these costs, but estimated them to be much lower than they now appear to be (Chapter 8). If under the current conditions New York City still agrees with paying all the costs remains to be seen. The second remark is that it has been assumed that the Cannonsville basin receives an amount of the available funds relative to its size. In reality the part of the funds that will be available for the Cannonsville basin depends on the efforts of the actors in the basin to acquire funds.

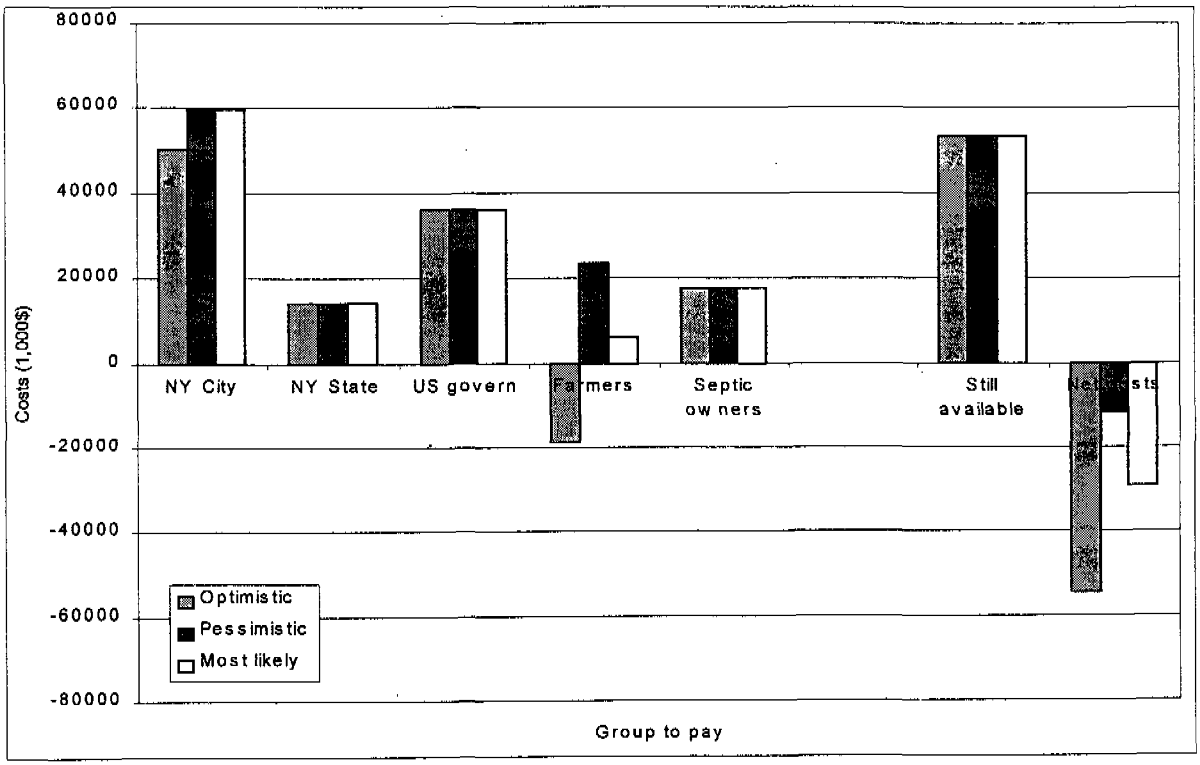

Figure 14.12. Distribution of the total costs among the different actors and available funds (total amounts for a 15-year period)

14.2 Analysis of the model results

General observations

The model results that are presented in the previous section have to be interpreted and analyzed. This will be done in this paragraph, based on certain observations that can be made:

- The target for short-term phosphorus reductions is not met by the alternatives included in the model;
- Agricultural waste management and nutrition management exclude each other;
- Implementing traditional agricultural BMPs seems to be the most promising individual alternative;
- Upgrading the Delhi, Stamford and Walton WWTPs produces reasonable and robust results;
- Upgrading the Hobart WWTP is not very cost-effective, but effects are 'certain';
- Rehabilitation of septic systems seems to be the least attractive alternative;
- Off-farm processing of all manure is inferior to the processing of only surplus manure;
- Composting is the dominant agricultural waste management alternative in all but one scenario;
- Preference for either nutrition management or composting differs per scenario;
- Implementation of a successful phosphorus reduction strategy brings along considerable savings for New York City;
- Implementation of the phosphorus reduction measures itself does not necessarily have negative economic impacts on Delaware County;
- Under the current circumstances economic growth remains impaired in the Cannonsville basin.

These observations are all made with regard to the model and they will now be discussed in some more detail. The results of a sensitivity analysis have been included in this section. A more detailed overview of the way in which this sensitivity analysis has been carried out can be found in Appendix F.

Target for short-term reductions is not met

The model results make clear that the targets for short-term phosphorus reductions are not met. The highest short-term reduction that can be reached is 16,571 kg/y under the most optimistic assumptions of scenario 1. This means that the target for short-term reductions of total phosphorus of 17,000 kg/y are not met by the alternatives included in this study.

Possibilities for additional reductions

The target might be reached when additional reductions are realized by alternatives that are not included in the current model. These are the alternatives that did not pass the first screening. They aim at a reduction of the loads from forests, urban runoff and non-dairy farms.

In the model estimates for agricultural alternatives, not all the farms, cattle and farmlands in the basin have been included. In the manure estimations for the model, only milk cows have been included because for this category accurate data were available. Including other cattle as well would lead to additional phosphorus load reductions. One very large dairy farm has also been excluded from the model because it is large enough to implement its own measures. Only dairy farms have been included, while most BMPs can also result in phosphorus reductions on other farms.

Potential additional reductions from agriculture are shown in the next table. Details on how these estimations have been made can be found in Appendix G.

	Optimistic scen.		**Pessimistic scen.**		**Most likely scen.**	
	Add.red.	**Max red ag**	**Add.red.**	**Max red ag**	**Add.red.**	**Max red ag**
Waste man. all cattle + BMPs on all farms	10022	19046	2148	4228	4794	9258
Only BMPs on all farms	9560	18072	1384	2616	3899	7371
Nutrit. man. on dairy farms + BMPs all farms	8765	17495	1333	3012	3706	7741
Unknown: nutrition man. non-dairy farms	?	?	?	?	?	?

Table 14.11. Additional short-term TP reductions in kg/y if alternatives for all agricultural sources are included in model.

Reductions from urban runoff will not exceed the annual load, which is estimated by GWLF-model calculations to be 1200 kg [NYCDEP, January 1998].

These possibilities for additional reductions combined with the strategies from the IP-model show that for the optimistic scenario and the agriculture scenario the value for short-term reduction targets can be met. In the most likely scenario and the wastewater treatment scenario, the maximum short-term reduction that can be realized is close to the target of 17,000 kg/y. These results and the possibility to meet targets for a critical concentration of 20 μg/l instead of 15 μg/l, make additional analysis an interesting option. Because this information only has been available after the proposed Phase II calculations were released in the spring of 1999, this additional analysis has not been executed as part of this project. Before the Phase II calculations were known, the reduction targets were estimated to be 25,000 to 35,000 kg/y (see Par. 6.2), which is difficult to realize, even with additional measures.

Evaluation of targets: impact on algae growth

Table 14.11 shows that even with the additional measures in agriculture, it will be difficult to meet the current targets. Perhaps it is necessary to reconsider the targets and the process by which they are developed. As described in Chapter 6, the annual load of total phosphorus is not the most accurate indicator for the algae growth in the reservoir. A factor that has a large impact on the algae growth is the dissolved part of the phosphorus, because this is more readily available for plant uptake than particulate phosphorus. Another important factor is the time of year in which the phosphorus reaches the reservoir: loads during the spring and summer have more impact on the algae problems than winter loads. Targets might be more accurate if these factors are incorporated in them.

The current distribution of phosphorus loads is shown in Figure 14.13. This figure can help to get an indication of the effects of the alternatives on loads of dissolved phosphorus.

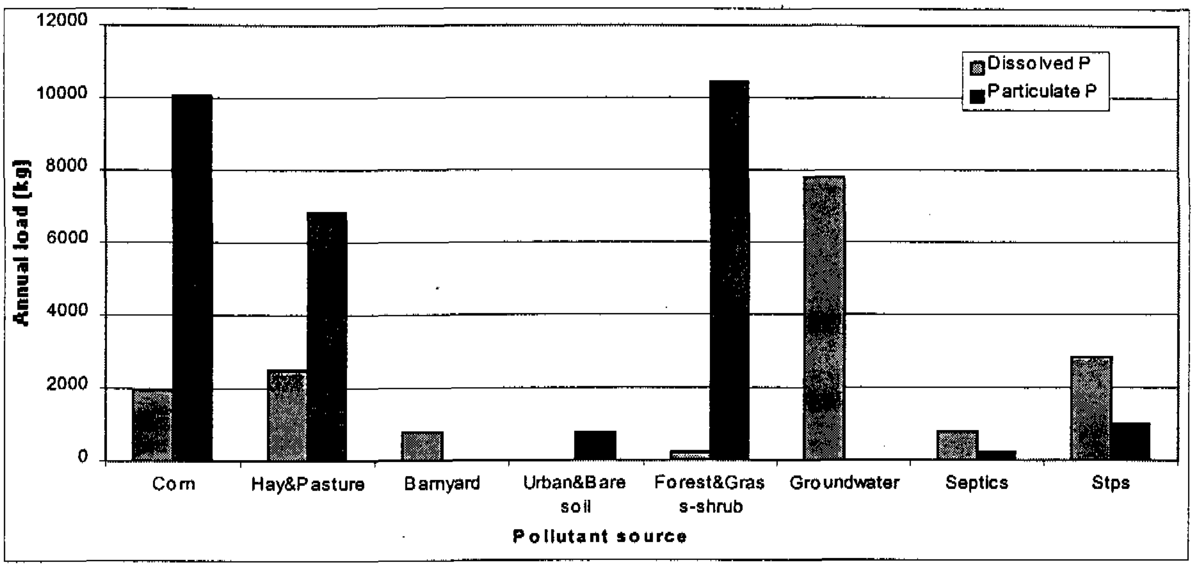

Figure 14.13. Loading profiles for dissolved and particulate phosphorus, according to the GWLF model
(source: NYCDEP 1998, figure 42)

Dissolved phosphorus is reduced by the agricultural waste and nutrition management alternatives and by upgrading of WWTPs and rehabilitation of septic systems. Groundwater loads are reduced by balancing the phosphorus loads on agricultural lands. For DP-reductions, implementing BMPs on non-dairy farms and alternatives for urban runoff are less promising because they reduce the loads during runoff events. This mainly affects the loads of particulate phosphorus during the wet winter period. It would be very interesting to see if the alternatives that are considered in this study would be sufficient if one looked mainly at seasonal dissolved phosphorus. Unfortunately there are currently not enough data to make estimations for this. But for future targets dissolved phosphorus and seasonal variability should play a more important role.

Evaluation of targets: reservoir-specific target concentrations
Except for the issue of annual total phosphorus versus dissolved and seasonal phosphorus, there is another issue that is of relevance for decisions about targets. Currently the guidance value for the critical phosphorus concentration is the same for all of the 19 reservoirs in the New York City Watershed. The proposed guidance value of 15 µg/l is based on the need for the frequency of algal blooms and dominance of blue-green algae to remain below 25% in the City's reservoirs [NYCDEP, March 1999b]. However the New York City Watershed covers a large area and there are considerable differences between the reservoirs. It might be appropriate to develop reservoir-specific guidance values which take into account the location and individual characteristics of a reservoir.

The New York City water supply system is managed as a whole and has a high degree of flexibility [NYCDEP, March 1999b]. It might be possible to develop 'flexible' targets that reservoir-specific, while still meeting the requirements of the system as a whole. The Cannonsville reservoir is currently the only reservoir in the Catskill/Delaware watershed with a eutrophic state [NYCDEP, March 1999b, Figure 1.2]. A higher guidance value for the phosphorus concentration in the Cannonsville reservoir might be compensated by lower guidance values in some of the other reservoirs in the Catskill/Delaware system. Such a practice seems to be in line with the current operation practice, since from 1987 to 1997 on average less than 40% of the water from the Cannonsville Reservoir was used for New York City's water supply, in contrast to the Pepacton and Neversink Reservoirs, where this percentage was almost 80% [NYCDEP, March 1999b].

Agricultural waste management and nutrition management exclude each other
When an agricultural waste management alternative is included in a strategy, nutrition management is always excluded. Nutrition management does not result in extra phosphorus reductions because waste management balances the phosphorus loads on farms. Once these phosphorus loads are balanced, they cannot be further reduced. Adding nutrition management would only result in extra costs and no extra phosphorus reduction.

The only situation in which a combination of both types of alternatives could be attractive, is when waste management is very expensive but has to be implemented because of the long-term phosphorus reductions or because of pathogen reductions. Combining waste management with nutrition management now would lead to less manure surplus to be treated and thus to lower costs. This combination is attractive if these cost savings are higher than the costs for nutrition management,. However this situation does not occur in the investigated scenarios and it is unlikely that it will occur in reality.

Because this observation was done early on in the analysis, the decision variables that represent a combination of waste and nutrition management are not included in any of the previous tables or figures.

Implementing traditional agricultural BMPs is the most promising individual alternative
Implementation of agricultural BMPs is the most cost-effective alternative aiming at agriculture for all of the scenarios. And if one wants to realize long-term reductions with waste management, BMPs are also needed (Chapter 11). Thus implementation of BMPs is advisable, either in combination with manure processing/transportation or individually. The costs for BMPs are mainly fixed and funds are available. Implementation has already been started on about a third of the farms in the watershed and produces good results.

Upgrading the Delhi, Stamford and Walton WWTPs produces reasonable and robust results
The scores for upgrading the municipal wastewater treatment plants at Delhi, Stamford and Walton (W_D, W_S, W_W) fluctuate a little among the different scenarios, but not too much and they are always reasonable. Because their effects are quite certain, it seems wise to implement these upgrades. Costs are mainly fixed, and New York City agreed to pay for them from the point where the plants meet the official State standards. A problem might be caused be the fact that the costs are more than twice as high as was expected at the time of the Watershed Agreement.

Upgrading the Hobart WWTP is not very cost-effective, but effects are 'certain'
The upgrade of the Hobart wastewater treatment plant is among the least cost-effective alternatives, but its effects are quite certain. Costs are fixed and New York City also agreed to pay for this upgrade. Because every effort has to be made to reach the target reductions, upgrading the Hobart plant seems necessary.

Rehabilitation of septic systems is the least attractive individual alternative
In four out of five scenarios, rehabilitation of septic systems is inferior to the other alternatives included in optimal strategies. This is because of the relatively high costs compared to the other alternatives. Only in scenario 5, where the conditions for septic systems are assumed to be more optimistic than those for agricultural practices, agricultural waste management is a little worse than rehabilitation of septic systems.

The rehabilitation of septic systems has more effect for systems from which a large part of the leaking phosphorus eventually reaches watercourses. In the model it has been assumed that 25% of the leaking phosphorus is reaching surface water. If this is raised to 50%, then the rehabilitation of septic systems is more cost effective for short-term reductions than some other alternatives. This is shown in Table 14.12.

	Cost short term P-red (1000$/kg/y)	With waste management			With nutrition		
		Original max (kg/y)	New max (kg/y)	Difference new-original	Original max (kg/y)	New max (kg/y)	Difference new-original
Scenario 1	0.501	16053	18803	17,1%	15759	18509	17,4%
Scenario 2	3.149	6809	7234	6,2%	6408	6833	6,6%
Scenario 3	0.848	10431	11993	15,0%	10002	11564	15,6%
Scenario 4	0.848	14991	16553	10,4%	14696	16259	10,6%
Scenario 5	0.501	11493	14243	23,9%	11064	13814	24,9%

Table 14.12. Short-term phosphorus reductions for strategies if 50% of leaking phosphorus from failing septic systems would reach surface water

On average the rehabilitation of septic systems does not seem to be very promising, but this is different for failing systems on hazardous locations (near streams, on steep, rocky hills etc.) where a large part of the phosphorus leakage is reaching the surface water. Because of the difference in cost-effectiveness per system, a selection of the failing systems before rehabilitation would ensure a more effective use of available funds.

Decentralized waste management for all manure less promising than for surplus only

The processing of all the manure in decentralized off-farm installations is in all of the scenarios less profitable than the processing of the surplus manure only. This is caused by the fact that the part of the processed manure that is returned to the farms is not paid for. If farmers would be willing to pay some price for this material, then this situation will change. The minimal prices for which processing all the manure is preferred are shown in the next table. With these minimal prices paid by farmers, there are still net costs for the production of compost for farms. These costs are offset by the benefits caused by the economies-of-scale for processing a larger amount of manure.

	Scenario 1 and 4	Scenario 2	Scenario 3 and 5
Minimal price compost for farms	$\$12.57\ \mathrm{m}^{-3}$	$\$10.77\ \mathrm{m}^{-3}$	$\$10.77\ \mathrm{m}^{-3}$
Net costs for compost on farms	$\$1.12\ \mathrm{m}^{-3}$	$\$1.42\ \mathrm{m}^{-3}$	$\$1.42\ \mathrm{m}^{-3}$
Minimal price digested liquid for farms	$\$1.98\ \mathrm{m}^{-3}$	$\$1.98\ \mathrm{m}^{-3}$	$\$0.78\ \mathrm{m}^{-3}$
Net costs for digested liquid on farms	$\$4.50\ \mathrm{m}^{-3}$	$\$4.50\ \mathrm{m}^{-3}$	$\$5.70\ \mathrm{m}^{-3}$

Table 14.13: Minimal prices to be paid by farmers for compost or digested manure for which processing all manure is preferred over processing only the surplus

Under the current assumptions where farmers do not pay for processed manure, processing all of the manure will only be preferred if pathogen reduction receives a very high priority.

Composting is the most promising waste management alternative

In the optimistic and most likely scenarios, composting dominates anaerobic digestion and transportation. This is probably caused by the fact that the market value of compost is much higher than that of raw or digested manure. Only when the market situation is bad, in the pessimistic scenario, transportation and anaerobic digestion are preferred over composting. This can be explained by the fact that investments in increasing the value of manure are not profitable because of the market situation. This means that alternatives with the least costs are preferred, even if they add little or no value to the raw manure. If the market situation is really this bad, then probably waste management is not a good option. If it still is necessary because of long-term phosphorus reductions, then transportation will be the best option. Anaerobic digestion is never preferred in any of the five scenarios.

The dominance of composting changes when the assumed market prices for compost or digested manure are different. Analysis has showed that the price of digested manure has to be raised by $8 to $23 per m^3, before anaerobic digestion is preferred. Such raises in prices are thought to be very unlikely. And even if they would occur, compost prices will probably be higher than assumed here as well.

On the other hand compost prices might be lower than assumed, while prices for digested manure stay the same. For the positive market situation assumed in scenarios 1 and 4, anaerobic digestion is preferred over composting if the prices for compost are below $9.70 m^{-3} (instead of $25 m^{-3}; price for digested manure stays at $4.00 m^{-3}). In scenario 2, anaerobic digestion is already preferred over composting, as explained above. In scenarios 3 and 5, anaerobic digestion is preferred over decentralized off-farm composting if compost prices are lower than $11.50 m^{-3} (instead of $17 m^{-3}; price for digested manure stays at $2.60 m^{-3}). But in this scenario, anaerobic digestion is never more profitable than on-farm composting, not even when the compost is given away for free.

The changes in market prices for compost are more likely to occur than the changes in prices for digested manure. But still it is not very likely that the price for compost is lower while the price for digested manure stays the same. Compost and digested manure are competing products. This means that for most markets, lower prices for the one product will also imply lower prices for the other.

Another situation in which anaerobic digestion of manure might be preferred over composting, is when the electricity benefits from the production of biogas are very high. In order for anaerobic digestion to compete with composting, electricity prices should be at least $0.20 per kWh (scenario 3 and 5) to $0.40 per kWh (scenario 1 and 4). For these electricity prices, anaerobic digestion of all manure is preferred over digestion of only surplus manure because of the high electricity benefits. In certain regions, commercial electricity prices are over $0.10 per kWh, but prices paid by utilities are often around $0.02 per kWh [Jewell et al., 1997]. Therefore it is not expected that electricity prices will result in a preference for anaerobic digestion under the current circumstances. This might changes in the future, when there is a demand or subsidy for energy from renewable sources such as biogas.

Finally it is assumed that dry bulk material for composting is available at no costs. If the price for bulk material is $3.50 per m^3 or higher, then anaerobic digestion is preferred over composting in scenarios 3 and 5. For the most optimistic estimations (scenarios 1 and 4), composting has net benefits as long as bulk prices stay below $7.00 per m^3.

No clear preference for nutrition management or composting

In the scenarios where the compost market is good or reasonable, the strategies that include composting are slightly better than the ones with nutrition management. However the differences are not very big. It seems that additional knowledge is necessary in order to be able to make a good choice between either nutrition management or composting. The two most important issues are the market situation for compost and the need to balance the phosphorus loads on agricultural lands. If the market for compost is good then composting seems better. If on the other hand the market is bad and if the soil-saturation does not make strict balancing necessary, then nutrition management would be preferred.

The market situation for composting is good if the production costs of compost are offset by the benefits from marketing the compost. This depends on the distance to the markets. In general a market situation is good if compost can be sold at $0.15 (for distant markets; around 200 miles) to $0.40 (for close markets; around 40 miles) per m^3 and per mile to be traveled to the market. Prices per mile are higher for close markets, where the influence of production costs is still high. In general, market prices must cover the production costs, which are between $8.00 and $9.50 per m^3 for off-farm composting, and the transportation costs, which range from $0.14 to $0.18 per m^3 per mile. The distance to the market has shown to be a sensitive variable in the model: if market distances change, also the costs/benefits change considerably (see Appendix F).

If there is no existing market for compost that is promising, then it might be an option to create a new market inside the basin. This could be done by shifting or expanding the agricultural activities to other fields such as for example ornamental horticulture. Such activities would use the compost efficiently and the product could be exported to buyers outside the basin. It is not known if such a new market could indeed be created inside the basin, but it would be in line with the diversification of agriculture, which has been identified as one of the potential areas for economic growth in the basin (Chapter 4).

A practical issue regarding the choice between nutrition management and composting is the preference of the farmers. Composting requires more efforts from the farmers, especially in case of on-farm composting. On-farm composting might cause problems for the smaller farms that can not afford to hire extra personnel. On the other hand composting has lower variable costs than nutrition management and might even be profitable. Decentralized off-farm composting stimulates the economic activity in Delaware County and increases the employment.

Implementation of a successful phosphorus reduction strategy brings along considerable savings for New York City

If a successful phosphorus reduction strategy is implemented in its watershed, then New York City does not have to build a filtration plant for its drinking water supply. The annual costs for the strategies identified in this study are between $5 million and $12 million for the Cannonsville reservoir, which is the biggest and most 'problematic' of the six reservoirs in the Catskill and Delaware system. It should be noted however that more costs than this $5 to $12 million will have to be made for the Cannonsville basin, because the targets are not met by the modeled strategies and because also other issues besides phosphorus are of importance for filtration avoidance (such as pathogens and turbidity).

The capital costs for building a filtration plant are estimated to be $4 to $6 billion, with operation and maintenance costs of approximately $300 million a year [Pfeffer 1998, Okun 1992]. This results in annual costs of $762 to $905 million, based on a 50 years depreciation period and a 10% interest rate. This is much higher than the annual $5 to $12 million for the Cannonsville basin. Even if a higher amount has to be spent on additional activities and on activities in the other five basins, the annual benefits for New York City are expected to be substantial.

Implementation of the phosphorus reduction measures itself does not necessarily have negative economic impacts on Delaware County

It seems that the available funds for phosphorus reduction measures are sufficient to cover a substantial part of the implementation costs. Some general funds should be used to supplement the specific funds for rehabilitation of septic systems and agricultural improvements. It is also important that New York City maintains its agreement to pay the costs for the upgrade of the WWTPs and that Delaware County does indeed acquire the part of the funding that it would be entitled to based on its size.

Under the current circumstances economic growth remains impaired

The phosphorus reductions efforts agreed upon in the Watershed Agreement seem to exclude possibilities for economic growth in Delaware County. To solve this problem, a phosphorus offset pilot program has been initiated. This is meant to facilitate economic growth under strict conditions. One of these conditions is that every extra kilogram of P-load from point sources such as WWTPs, must be offset by a reduction of three kilograms of P from nonpoint sources. This possibility of increasing phosphorus loads in the basin, even if they are offset by reductions elsewhere, seems to be incompatible with the aim of phosphorus reduction. All possible reductions will probably have to be realized to meet the current loading target. This does not leave any room for 'extra' reductions to offset increased phosphorus loads due to economic growth.

So if Delaware County wants to meet the reduction target, there seems to be no room for economic growth that results in increased phosphorus loads. If Delaware County on the other hand chooses to use the offset pilot program to expand the economic activities, then the target will most probably not be met. In this latter case the Cannonsville basin will remain phosphorus restricted and the pressure from New York City and environmental pressure groups will increase. This will impair economic growth as well, because of the stringent rules and regulations that this will bring along.

This means that with the current reduction targets, the economic growth in the Cannonsville basin will probably remain severely restricted. With a target concentration between 15 and 20 µg/l, target loads might be met, which would lift the phosphorus impediments for economic growth. Thus the economic situation seems to form another incentive to seriously consider an evaluation of the current targets as described in Paragraph 14.1.

14.3 Evaluation of the use of the IP-model

The choice for an integer programming modeling approach has been made based on the structural and formal models that have been constructed to describe the phosphorus management problems. The construction of the IP-model has consumed a considerable amount of time and efforts, but these efforts have been useful for the generation and analysis of strategies.

The IP-model makes it possible to analyze trade-offs between certain content goals and to investigate what the effects of certain target values are on the composition of strategies. Unfortunately this feature of the model has not been used extensively, because it appeared that the target value for short-term phosphorus reduction could not be met by the modeled alternatives. Because this short-term reduction is considered to be the most important content goal, it would not be reasonable to investigate trade-offs between even more failure to meet the short-term reduction target and other criteria.

The discovery that the target for short-term reductions is very hard to meet was not expected in advance, although it was known that a lot of reduction efforts would be required. Before the Phase II TMDL calculations were released, the targets where estimated to be even higher (see Par. 6.2). For these estimations there was a considerable chance that the targets would not be met even if all possible efforts were made. The proposed Phase II TMDLs leave some more room to realize the short-term reduction target, but this will still remain a very difficult process.

Although not all the features of the IP-model have been used optimally in this study, the model can be of use for future policy analysis. The way in which the model has been constructed makes it relatively easy to make changes in the model or to expand it with more alternatives or content goals. It can be of use in situations where it is possible to meet short-term reduction targets, for example because the division between dissolved and particulate phosphorus has been incorporated in targets, because the critical phosphorus concentration has been heightened or because new alternatives are identified. The short-term reduction targets can be used as a model constraint while the other target values can be used as constraints that are varied. This variation of the other content goals should be based on existing needs or preferences. This variation could show what the effects of certain preferences are on the composition of strategies. It will help to identify conflicts and trade-offs between preferences and to see what preferences are compatible.

For a better estimation of some values of model parameters, the GWLF-model might be useful. This simulation model can generate the necessary data on the physical consequences of modeled alternatives or it can support the identification of additional alternatives. The GWLF-model has already proven to be a useful instrument to evaluate some of the physical impacts of reservoir operation strategies [Owens et al. 1998]. Combining the GWLF-model with the IP-model to integrate the physical impacts with the other aspects that are considered to be relevant by the decision makers might provide a useful instrument for policy analysis.

15. Conclusions and recommendations

For both Delaware County and New York City, a lot is at stake in achieving a reduction of phosphorus loads to the Cannonsville basin. To aid Delaware County in prioritizing its reduction efforts and in securing its potential for future economic growth, a quantitative analysis of the current situation in the Cannonsville basin has been executed. Based on this analysis, certain conclusions can be drawn and some recommendations can be made to Delaware County.

15.1 Conclusions

If the current efforts to reduce the phosphorus loads in the Cannonsville basin are successful, this may prove to be very beneficial to all actors involved, especially those in New York City and Delaware County. Successful phosphorus management takes away the need to build a filtration plant, it enhances the quality of the environment and it creates room for economic growth in Delaware County. If, on the other hand the phosphorus management efforts fail to realize the necessary reductions, both New York City and Delaware County will face severe negative impacts. New York City and Delaware County are mutually dependent in this case and can only succeed in solving their phosphorus management problems through cooperation with each other.

The current targets for short-term phosphorus reductions are very difficult to realize. Current targets are expressed as annual total phosphorus (TP) loading, but it might be necessary to incorporate the differences between dissolved and particulate phosphorus and the effects of seasonal loading in the loading targets, as well as the differences between the reservoirs in the New York City Watershed. The currently proposed targets for total phosphorus for the Cannonsville basin bring along considerable risks for both New York City and Delaware County. The efforts to realize those targets require that economic development in the County is impaired. But even then it is still possible that the targets for total phosphorus will not be achieved. This will have a negative influence on the EPA determination on filtration avoidance, which will pose New York City for serious problems. Both Delaware County and New York City benefit from targets that are both feasible and scientifically sound.

To reduce agricultural phosphorus loads, the implementation of traditional best management practices (BMPs) on farms is the most cost-effective alternative regarding short-term phosphorus reductions. BMPs are also necessary if waste management is implemented on farms. The choice between composting or nutrition management for dairy farms depends on the urgency of the need to balance the phosphorus loads to the agricultural lands and on the market situation for compost. Based on analysis of the model results, anaerobic digestion of manure is never preferred as an agricultural waste management alternative.

Upgrading the wastewater treatment plants (WWTPs) seems to be promising. The effects of the upgrades are quite certain and positive, also because mainly dissolved phosphorus loading is reduced, the whole year round. Upgrading the municipal plants at Delhi, Stamford and Walton is reasonably cost-effective, upgrading the plant at Hobart is more costly. The capital costs for the upgrades are much higher than was estimated before, which might put pressure on the arrangements for the funding.

The effects of a rehabilitation of failing septic systems differ greatly per system. On average, it is the least promising alternative. Making a selection of the failing systems that will be rehabilitated can increase the cost-effectiveness. The failing systems that are not selected may be rehabilitated in a later stage or may be considered to have too little impact on surface water quality. A good selection of the failing systems is difficult at this moment because of the existing legal regulations. Owners are reluctant to report failures of their septic systems. If their systems are officially known to be failing, they are obliged to fix them, also if costs are not refunded by the Catskill Watershed Corporation. Most of the failures seem to be caused by inappropriate design and installation practices. Design and installation of septic systems is overseen by New York City inspectors, but until recently standards that were not entirely appropriate have been used. Thus it does not seem fair to put the responsibility for the failure solely by the owners of the systems.

It seems that in general enough funds are available for the implementation of phosphorus management measures. Some funds that have not yet been earmarked for specific purposes should be used to supplement the specific funds for rehabilitation of septic systems and agricultural improvements. It is also important that New York City maintains its promise to pay the costs for the upgrade of the WWTPs and that Delaware County does indeed acquire the part of the funding that it would be entitled to based on its size.

15.2 Recommendations

Based on the previous conclusions and on the insights gained during the project execution, certain recommendations can be made. These recommendations are made to Delaware County and the County Phosphorus Study Committee.

1. Evaluate current target values
It seems very useful to evaluate the current targets for short-term phosphorus reductions and for the critical phosphorus concentration in the Cannonsville reservoir. Delaware County should do this in collaboration with the other members of the County Phosphorus Study Committee, especially NYCDEP, NYSDEC and independent scientists. In this regard the following activities are recommended:

1. Discuss the possibilities to raise the guidance value for the critical phosphorus concentration in the Cannonsville reservoir. This should be part of an effort to develop reservoir-specific guidance values for the whole New York City water supply system. A critical phosphorus concentration in between 15 and 20 μg/l would probably be feasible for the Cannonsville reservoir. Such a higher concentration for the Cannonsville reservoir could be accompanied by measures related to the operation of the reservoir system. The Cannonsville reservoir could be shut off during certain periods (as is done already sometimes), it could be flushed more often or the reservoir's water could be mixed with water from other sources. It should be investigated if such options are feasible and what the impacts are on the use of the other reservoirs in the Catskill/Delaware system, on the hydroelectric power plants and on the lower Delaware River. This should be done primarily by NYCDEP, but Delaware County could urge DEP to indeed undertake these activities.
2. Reconsider the targets and investigate the consequences of shifting the accent in targets from total to dissolved phosphorus and from annual to seasonal loading. This is advised because it seems that the current legal procedures for target development do not comply with the physical system.
3. Currently experts develop the phosphorus guidance values from a water quality perspective, but the feasibility of these target values is not considered. For health reasons, it is a good thing that targets are only based on scientific water quality considerations. But if targets for a designated water use are set for a certain water body, they should be accompanied by a plan on how to realize them. This should ensure feasible targets and realistic expectations by the actors.

2. Upgrade wastewater treatment plants
The municipal wastewater treatment plants of Delhi, Stamford, Walton and Hobart should be upgraded as planned. However the costs are much higher than was foreseen, so the arrangement with New York City should be reassured to prevent future discussions about the funding.

3. Continue the implementation of traditional agricultural best management practices
The implementation of best management practices (BMPs) is advisable, either in combination with manure processing/transportation or individually. Implementation has already been started in the Watershed Agricultural Program. Already about a third of the farms in the watershed joins this program and this produces good results.

4. Implement either composting or nutrition management on farms

Composting might a good alternative for phosphorus reductions on farms if the market situation for compost is promising. If this is not the case, nutrition management might be a better alternative. Transportation of compost is only preferred if current soil conditions urgently require balancing of phosphorus loads. The following sequence of activities is recommended:

1. Explore the following conditions related to composting:
    - Availability and price of dry bulk material. Prices for bulk should be under $3.50, unless market conditions are very favorable;
    - Market situation: the location, the demand and the price. The demand should be high enough to sell the compost produced in the Cannonsville basin: at least 464 m^3/day. The prices should cover the production and transportation costs: approximately $9.00 per m^3 plus $0.16 per m^3 and per mile to be traveled. Also the possibilities of creating a compost market by starting for example ornamental horticulture inside the basin should be investigated. This might provide opportunities for economic development through a diversification of agricultural activities as well as for phosphorus reductions.

If the market situation appears to be promising, a choice could be made for either on- or off-farm composting. This choice should be made in consultation with the farmers.

2. If the market situation for compost is bad, then it is best to start with the implementation of nutrition management on the dairy farms. This then has the lowest costs and almost no capital equipment is needed.
3. When nutrition management is implemented, research is necessary to determine the need for balancing the phosphorus loads to the agricultural soils. If this need appears to be high, then nutrition management should be expanded with or replaced by transportation of surplus manure. This again has to be decided in consultation with the farmers and will probably have considerable costs.

These activities could be executed or coordination by the Manure Infrastructure Committee or they might be incorporated in the Watershed Agricultural Program.

5. Review the execution of the rehabilitation program for septic systems

The prioritizing procedure for septic systems rehabilitation should be reviewed. The current procedure is first come, first served, which results in a very inefficient use of funds. The use of more specific selection procedures is recommended. This may make it necessary to loosen the regulations for septic failures because else people will hesitate to report failures. To ensure cost-effectiveness, the failing systems on 'safe' locations do not have to be rehabilitated right away, while failing systems on sensitive locations do. The possibilities for a different prioritization procedure should be discussed with the Catskill Watershed Corporation, which administers the septic program funds.

6. Study further possibilities for phosphorus reductions

The alternatives that are included in this study are not sufficient to realize the necessary short-term phosphorus reductions. Therefore it is necessary to identify additional possibilities to reduce phosphorus loads. It is expected that the following alternatives are promising ways to realize additional reductions:

- Implementation of BMPs on all farms in the basin (instead of only on dairy farms);
- Include other cattle in waste or nutrition management measures (instead of only milk cows).

In addition, there are also other ways to further reduce phosphorus loads. Possible alternatives in the following directions need to be studied before they can be selected:

- Possibilities to reduce loads from urban areas and from storm water runoff;
- Possible phosphorus reductions from forests.

7. Prepare economic development plans

Economic development is impaired by the current phosphorus management problems. It is not likely that these phosphorus problems are solved on the short-run, so economic development will remain impaired in the immediate future. Because of the problems in meeting the current phosphorus reduction target, the current pilot phosphorus offset program is not very likely to be successful. To ensure at least some room for economic development, plans on the desired economic development and its implications for phosphorus loading could play a useful role. Currently the existing problems for businesses are addressed by the development of a 'one-stop-center' [BRE, 1998]. This center could also be used to assist expanding and new businesses based on a planning for economic growth in the County. The formulation of plans for economic development might perhaps limit the areas in which the economy can grow, but if there are no plans, growth will probably be limited altogether. Plans for economic development should be prepared by the Delaware County Department of Planning and Economic Development or by Delaware's County Office for Business Retention and Extension. The plans should be discussed with the partners in the Phosphorus Study Committee.

8. Analyze policy options from physical, economic and social perspectives

The phosphorus management problems are mainly caused by physical phenomena, but they also affect economic and social issues. Therefore decisions regarding the phosphorus management problems should also be analyzed from social and economic perspectives. These aspects might be incorporated in the decision analysis by using the integer programming model that has been developed for this study. This model can be used to identify trade-offs between different interests (either in the social, the economical or the physical system or in between these systems). It can be expanded or altered to fit future situations without much difficulty. It could be advantageous to combine this IP-model with the simulation models developed by NYCDEP so that physical and other aspects are better integrated in the decision making process.

16. Evaluation: the possible contribution of policy analysis to phosphorus management

In this last chapter the possible contribution of policy analysis to the decision making on phosphorus management issues will be evaluated. This will be done based on general theory about decision making and policy analysis, combined with experiences gained during this project on phosphorus management in the Cannonsville basin.

16.1 Conceptual models of decision making

General model types to describe the decision making process

In the political sciences, there are numerous theories and models that describe the process of decision making. A general distinction that can be found in these theories, is the distinction between the theories that emphasize the rational elements in decision making and the theories that emphasize the political elements that cause a lack of structure and irregularities.

The decision making about the water supply of New York City fits the political models better than the more rational ones. For this chapter, one model has been selected to provide a framework for the analysis of decision making processes. However, there are numerous other models and theories that could probably function just as well as a guide for this analysis. The model selected here is the interaction model, as discussed by In 't Veld and Teisman [In 't Veld and Teisman, 1996].

The interaction model

In the process of decision making, different actors are involved. In the interaction model, the interaction between these different actors plays a central role. Each actor has its own interests, its own perception of the situation, its own strategy and its own network of relations with other actors. The interaction between the actors determines the outcome of the decision making process. Through interaction, the actors can learn about each other's perceptions. This allows them to determine if there is a mutual interest and if so, how they can serve it. In this way, interaction functions to tune perceptions and activities and to deal with dissimilarities in the strategies of different actors.

An important feature in decision making as described by the interaction model, is the mutual dependency between the different actors. To describe the mutual dependency over time, the concept of decision rounds is introduced. A decision round is defined as the period between two crucial decision moments. These crucial moments are the moments when decisions are made that have an important influence on the behavior of actors in later periods. Decision rounds enable the analysis of how certain decisions are strengthened or weakened during later stages of the decision making process.

Except for decision rounds, also policy arenas are used to describe mutual dependencies. Policy arenas consist of the different actors that are involved in a certain aspect of the decision making process and the relations they maintain. The actors that are part of an arena might change. Certain actors may leave the arena or new actors may enter the arena. Also the actors in an arena may change their behavior and strategy. These dynamics of actors and their relations can be analyzed with the concept of policy arenas.

Based on the insights of the interaction model, decision making processes should be designed in a way that allows for the actors to learn from each other. This should lead to a product of the interactive decision making process that is more valuable than the product with which the process was started. This will be easier to achieve if actors are aware of the mutual dependencies and if they are willing to learn about the perceptions and ideas of the others.

16.2 Policy analysis and decision making

This paragraph will describe the role that policy analysis has played in the decision making process and how this role has developed in recent years. Most of the information in this paragraph has been derived from a publication by Van der Heijden and Thissen [Van der Heijden and Thissen, 1996].

Traditionally the role of policy analysis fitted the rational decision making processes better than the political ones that are described by the interaction model. Policy analysis used knowledge about the relations between problems, alternatives and goals to execute a scientific analysis. This scientific analysis should support the decision makers in their political process of negotiating and choosing. At the same time it should also be separated from this process to maintain the perceived objective and scientific character.

This traditional approach of policy analysis has difficulties in dealing with decision making processes that have only a limited rationality and that proceed more in line with the interaction model described above. For these situations, the traditional approach has certain limitations. These limitations are caused by some of the following characteristics of the decision making process: there are multiple actors involved; perceptions of problems, alternatives and priorities change; decision making is not always a sequential process; objective knowledge is not available; the results of scientific analyses incorporate a large margin of uncertainty; it is often more important to gain support for a certain point of view than actually being 'right'.

To overcome these limitations of policy analysis, the process-related aspects have received more attention in recent years. This has led to a form of policy analysis that still remains neutral towards the involved actors, but that focuses on producing information that is of relevance to all actors involved and on an effective progress of the decision making process. Policy analysis now concerns with the question how it can support interactive decision making in terms of process-efficiency, process-quality and quality of the contents.

16.3 Filtration avoidance for New York City's drinking water supply

The project described in this report uses a formal method for policy analysis to support the decision makers involved in Delaware County's phosphorus management issues. The need for a phosphorus management strategy for the Cannonsville basin is part of the bigger issue of filtration avoidance for the drinking water supply of New York City. This case will be used here to illustrate the theoretical concepts discussed above.

Short description of the decision making process related to filtration avoidance

The decision-process on filtration avoidance started with the amendments to the federal Safe Drinking Water Act in 1987. This led to the formulation of Surface Water Treatment Rules by the EPA in 1989. Because of these new rules, New York City had to comply with several conditions in order to be able to continue operating its water supply system without a filtration treatment step. In addition, New York City needed and official determination by EPA to be granted filtration avoidance. In 1992 New York City issued an official request for filtration avoidance to EPA. In order to be able to make a proper decision, EPA formed an expert panel to advise it in this matter. After a study of the New York City water supply situation, the expert panel recommended EPA not to grant New York City filtration avoidance. This was mainly based on the panel's opinion that the waterborne pathogen Cryptosporidium posed important health risks, which could only be controlled by filtration combined with watershed protection [Okun et al. 1997]. EPA did not follow these recommendations, but granted New York City conditional filtration avoidance in January 1993.

In the mean time, New York City had started cooperative efforts to protect its watershed together with the local governments and farmers. In 1992 the Watershed Agricultural Program started as a cooperative program between NYCDEP and farmers in the watershed. Also in 1992, Whole

Community Planning was started as a platform for negotiations between New York City and the communities on maintenance of water quality standards.

However, by the end of 1993 the cooperation between New York City and the watershed communities ended abruptly when New York City presented its plans for meeting the filtration avoidance requirements. New watershed rules and regulations and the large-scale purchase of lands were considered unacceptable by the watershed communities. In December 1993 the Coalition of Watershed Towns filed a lawsuit against New York City to prevent it from executing its plans.

The conflict between New York City and the watershed towns lasted for over a year, until the Governor of New York State intervened in April 1995. The negotiations that started in 1995 resulted in an agreement in principle later that year. In January 1997 the final Memorandum of Agreement was signed and formally executed.

Development of limits for phosphorus loads

A parallel track of events is the development of phosphorus limits for the New York City watersheds. In 1996 the Phase I TMDLs (Total Maximum Daily Loads) for phosphorus were calculated, based on the Reckhow land-use model. This model used land-use based coefficients and land-use data from 1993 to estimate the phosphorus loading to the reservoirs. The TMDLs that resulted from this model, were based on a guidance value for the critical phosphorus concentration in the reservoirs of 20 μg/l. This guidance value was based on the State value for recreational water uses and required further investigation.

It was agreed that the Phase II TMDLs should be based on more detailed models, and for this purpose the GWLF-model was developed. Recently, by the end of March 1999, the results of the application of this model have been published as the proposed Phase II TMDLs [NYCDEP, March 1999a]. Further research after the critical phosphorus concentration in reservoirs lead to a lowering of the critical concentration to 15 μg/l. Combined with data collected by event-based sampling of watershed surface waters, the GWLF-model calculations led to new loading targets for the Cannonsville watershed. These targets seem to be a little more feasible than the ones based on previous figures.

Cooperation for watershed protection in Delaware County

In Delaware County, the local government agencies are now cooperating with NYCDEP and with State agencies. But the County government does have difficulties in convincing the local people and businesses that cooperation is the best way to deal with the current problems. Most people are still very suspicious towards New York City because of past experiences. NYCDEP on the other hand has difficulties with criticism from parties who favor filtration and from environmental parties that were involved in the negotiations for the Watershed Agreement. The environmentalists criticize NYCDEP because they feel that it does not control the local actors, but instead 'cultivated cozy relationships with upstate developers and local and state officials who favored (economic) growth' [Kennedy, 1998].

Application of the interaction model to the case

Based on this very short description of the case of filtration avoidance for New York City's water supply, certain elements from the interaction model can be recognized. For example critical decisions that mark different decision rounds can be recognized. Examples of such decisions are the decision by New York City to request permission for filtration avoidance from EPA and the decision by EPA to grant New York City (conditional) filtration avoidance. Some of the critical decisions by the watershed towns are the decision to start cooperation with New York City at first, followed later on by the decision to file suit against New York City and finally the decision to support the Watershed Agreement. All of these decisions are based, at least partly, on information that has come up during the decision making process and that has been obtained through interaction between actors. The decision of EPA to ignore the advice of its expert panel on the filtration determination shows that actors choose their own way to deal with the information that is presented to them.

An important decision round is started by the intervention by the State Governor of New York to end the impasse in the conflict between New York City and the watershed towns. Apparently the process needed a new actor in the arena to enable the start of a new round and the negotiation of new steps.

Because of uncertainties and insufficient scientific knowledge, the development of targets for phosphorus is evolving over time. Also priorities differ over time and for different areas. At first pathogens were identified by the EPA panel as the most serious threat to filtration avoidance. Later on the priorities for the Cannonsville basin shifted to phosphorus.

The interaction between parties involved in Delaware County is hampered by the differences between the actors. Not only by the differences in interests, but also by different perceptions and frames of reference. The people from NYCDEP have a scientific and/or engineering background and they rely on scientific models and methods. Most of the people in Delaware County have little understanding for and faith in such scientific models. What counts for the people in Delaware is not so much the faith in the scientific methods, but rather the faith in the people who develop, apply and present them.

16.4 Policy analysis for phosphorus management in the Cannonsville basin

The phosphorus management problems in the Cannonsville basin seem complex enough to allow for a useful contribution from policy analysis. A policy analysis study for the Cannonsville basin will have the most impact when all the decision makers trust its results. To gain this trust, the analysis must have a sound scientific basis, although this alone will not be sufficient. Probably equally important is the presentation of the results and the support of dominant actors for the analysis. Also the personal trust in the analyst can play an important role. However, regardless of the trust in the results, a good policy analysis study should contribute to the quality and progress of discussions and its results should be of relevance to all the decision makers involved.

Results of the presented analysis
The study presented in this report has used a formal quantitative approach and an optimization model to analyze the phosphorus management issues. The main results of this analysis are conclusions and recommendations that focus on the alternatives for phosphorus reductions and their cost-effectiveness. It is concluded that it will be very difficult to realize the existing target reductions and that these targets might need to be reconsidered. Furthermore it is concluded that some of the investigated alternatives seem to be more cost-effective and that for some alternatives additional research will be useful. Also some recommendations regarding the improvement of current practices have been made, such as the allocation procedure for septic system rehabilitation funds and the need for planning of economic development.

These recommendations have been based on a scientific analysis and it has been tried to indicate any uncertainties underlying them. The results of the study are related to three levels of discussion. First there is the discussion about the target reductions. This discussion is within an arena where both County, City and State actors are involved. Second there is a discussion about the cost-effectiveness of alternatives for reductions within the Cannonsville basin. This discussion is mainly one that has to be held in Delaware County, although NYCDEP will be involved partially. Thirdly, the recommendations regarding current practices are of relevance to actors involved in those practices such as Delaware County and watershed organizations and towns. On all three levels of discussion, also other actors concerned with New York City's watershed are at least partially involved, because they all have an interest in pollution control and watershed protection.

The use of the analysis to support decision making on phosphorus reductions
It is believed, based on the formal analysis, that all of the recommendations would lead to improvements in the process towards phosphorus reduction. The contribution of the analysis is the presentation of information concerning possible improvements, based on a scientific foundation. In this way, the study has introduced new information in the decision arena, or at least new information to certain actors. This new information can trigger new discussions or it can steer existing discussions in a certain direction. This will be necessary to agree on a way of dealing with issues that have not received too much attention in the past, but that appear to be of relevance to phosphorus management. It is up to the decision makers to actually use this information and to discuss a proper approach of dealing with it.

The decision makers' response to the study's findings will be influenced by the extent to which the results fit in with their existing perceptions and strategies. For example, the conclusion on target reductions will be more readily accepted by the environmental pressure groups that are sceptical about the use of the filtration avoidance efforts than by officials of New York City and Delaware County. But even for the latter actors, this is in fact useful information. It makes them aware of some of the risks of the process they are taking part in. This awareness could enable them to agree on a way to deal with these risks, for example by discussing possible ways to reformulate the targets or to mitigate the consequences of a failure to meet the targets.

The use of a formal approach to execute the analysis
The study has used formal and mathematical instruments to execute the analysis. The use of such formal methods is probably not the only way to reach the presented findings. The formal methods provided a framework for a structured and integral analysis and in this regard they played a useful role. The formal methods with the focus on quantitative data made it possible to investigate uncertainties and their range and also their relevance to several policy options. This could help to define future discussions and to raise the awareness about the risks involved in different policy options.

Looking back, it seems that perhaps a part of the results and conclusions could also be reached by a common-sense reasoning. The use of formal methods merely brought these 'common-sense' conclusions to the surface, where before they were floating around in sometimes untransparent information streams.

The formal approach in this study lead to the formulation of a mathematical model, a tool that might still be of use later on in the decision making process. This tool could be used to analyze trade-offs between different interests and various possible alternatives. Again, if this model will indeed be used for this purpose in the future is mainly up to the decision makers.

Generally it seems that the extent to which this study will contribute to the decision making process for the Cannonsville basin depends on the extent to which the decision makers are willing to use its results. But regardless of their willingness, it is hoped that this study has made at least some of them aware of certain issues that deserve discussion and of the possibilities that quantitative policy analysis offers to produce insights that are useful to support decision making.

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Appendices

Appendix A: Selection of available funds

	Funding source	**Administrating agency**		**Eligible activities**			**Resources** (million $)
	NY State						
1	Clean Water State Revolving Fund	EFC	DEC	NPS projects			321.4
2	Drinking Water State Revolving Fund	EFC	DOH	water system projects	land purchase	source water protection	90
3	Clean Water/Clean Air Bond Act	Various state agencies		NPS projects [*1]			1750
4	EPF - Non-Ag	DEC		NPS assessment	NPS planning	NPS abatement	2
5	EPF - Ag Projects	DAM		NPS agricultural initiatives	NPS assessment	BMPs	2
6	EPF - Solid Waste (Title 3)	DEC		closure of waste landfills			NA
7	EPF - Solid Waste (Title 5)	DEC		closure of waste landfills	leachate measures	landfill reclamation	10
8	EPF- Open Space	DEC		watershed protection	various other		30
9	EPF- Ag Open Space	DAM		implementation of local ag protection plans			4
10	EPF - Local Waterfront Revitalization	DOS		waterfront revitalization	water quality improvement		5.75
11	Envnm. Quality Incentives Program	USDA-NRCS		conservation practices	manure management		200
12	Conservation Reserve Program	USDA-FSA		protection of erodible and environmentally sensitive lands			15
13	County WQCC grants	DEC	State SWCC	water quality strategy	strategy implementation		0.001
	NYC Watershed besides MOA						
14	NYC Watershed Agricultural Program	WAC		implementation of WAP			35.2
	MOA funds for WOH communities						
15	CWC operating funds	CWC		operating of CWC			3.5
16	SPDES Upgrade Funds	DEP	EFC [*2]	upgrade of existing WWTPs to meet conditions for SPDES permits			5
17	New Infrastructure Funds	DEP&EFC	CWC [*3]	on-site WWTS upgrades	creation of WWTPs with only subsurface discharge		75
18	Sewer Extension Funds	DEP		extensions to sewer colleting systems serving NYC owned WWTPs			10
19	Septic Program Funds	CWC		rehabilitate septic systems	upgrade subsurface sewage treatment systems		13.6
20	Stormwater Retrofit Funds	CWC		stormwater BMPs			7.625
21	Sand and Salt Funds	CWC		improve storage of sand, salt and other road de-icing materials			10.25
22	Stream Corridor Funds	DEP	CWC [*4]	stream corridor protection projects [*5]			3

23	New Stormwater Funds	CWC		new stormwater measures [*6]		31.7
24	Alternate Septic Funds	CWC	DEP	design, constr. and install. of alternate design septic systems [*7]		3
25	Forestry Funds	WAC		promote forestry practices [*8]		0.5
26	Education Funds	CWC		public education [*9]		2
27	Economic Development Study	CWC		study econ., social and environmental goals consistent with NYC's water quality objectives		0.5
28	Catskill Fund for the Future	CWC	EFC	responsible, environmentally sensitive economic development projects [*10]		59.7
29	WPPC operating funds			operating of WPPC		1.5
30	Land Aqcuisition Program Funds	NYC?		purchase of lands	purchase of ag easements (up to $10 million)	250

Table A.1. Selection of funding sources

Notes:

1 Of these funds, $87 million is earmarked for water quality improvements, and an additional $87 million will be available in SFY 98-99

2 DEP is responsible for fund allocation, EFC for administration and disburse

3 EFC administers the funds that DEP allocated for new WWTPs or community septcis. CWC controls funds for the creation of septic districts

4 DEP selects, designs and allocates primary funds. CWC administers and disburses funds transferred from some other Programs

5 projects such as stream stabilization and fish habitat improvements

6 only measures that are pursuant to Watershed Regulations, and are not otherwise required by state or federal laws

7 alternate systems are systems which, because of site conditions, require importation and deposit of fill material and/or pumping to an adsorption field

8 practices that protect NYC's water supply against runoff and other pollution

9 education on the nature and importance of the NY City's water supply system, and the critical role of Watershed residents as stewards of water quality

10 Qualified Economic Development Projects (QEDP) are projects which encourage environmentally sound development and which encourage the goals of Watershed protection and job growth.

Funds used to analyze the distribution of costs between different actors in Chapter 13.

Funds	Service area	Total fund (1,000$)	Est. amount C-basin (1,000$)
Agriculture			
WAP-Implement. BMPs	Catskill&Delaware watersheds	19700	9616
WAP-Whole Farm Plans	Catskill&Delaware watersheds	8900	4344
EPF-Ag Projects	NY State	2000	20
EPF-Ag Open Space	NY State	4000	41
Env.Quality Incentives Progr	US, annual fund	*200000*	41
Conservation Reserve Progr	US, annual fund	*15000*	3
Total agriculture		*249600*	*14065*
Septic system rehabilitation			
Septic Program Funds	Catskill&Delaware watersheds	13600	3310
New Infrastructure Funds	Catskill&Delaware watersheds	5000	1100
Alternate Septic Funds	Catskill&Delaware watersheds	3000	660
Sewer Extensions	Catskill&Delaware watersheds	10000	2200
Total septic systems		*31600*	*7270*
WWTPs upgrade			
WWTP upgrades	Catskill&Delaware watersheds	undetermined	undetermined
General			
Good Neighbour Payments	Catskill&Delaware watersheds	9765	2729
SDWA support Watershed Agreement	Catskill&Delaware watersheds	105000	29349
Water Resources Development Act	Catskill&Delaware watersheds	25000	6988
NYS support for W Agreement	Catskill&Delaware watersheds	51000	14255
Total general funding		*190765*	*53322*
Total funding for Cannonsville basin (excl. WWTP funds)			**74657**

Table A.2. Funds used to determine the distribution of costs among various actors
(Sources: WAC, 1997; DEC Oct.1997; Catskill Center for Gons&Devel 1997; MOA, 1997)

Appendix B: Animal Nutrition

This appendix contains some general information in animal nutrition to provide a background to paragraph 7.3 of the report. The issues that will receive attention are:
- Nutrients: categories and functions;
- Digestive system of dairy cows;
- Phosphorus as a nutrient;
- Feeding and nutrition of dairy cattle.

Most of the information is coming from the book "Applied Animal Nutrition" by Peter R. Cheeke. Some additional figures have been found in papers that were written by P.E. Cerosaletti et al. and L.E. Chase for the Cornell Nutrition Conference of October 1998. Only where other sources have been used references have been added.

B.1 Nutrients: categories and functions

A nutrient is a dietary that is essential for one or more species of animals. They can be ordered according to the following categories: protein, carbohydrates, lipids, minerals, vitamins and water. Nutrients are necessary for the animal body structure (muscle and connective tissues and bones) and for the energy needed by animals (expressed as calories). This energy is obtained by a cellular process of metabolism, which is basically the reverse of photosynthesis.

Nutrients with important structural roles are protein, calcium, phosphorus and, to a lesser extent, lipids and carbohydrates. Carbohydrates and lipids are the main sources of energy. Protein can be metabolized, but this is generally undesirable because it is a more expensive source of energy. Vitamins and most minerals function as cofactors or activators of enzymes.

A typical diet for livestock will contain 10 to 20 percent protein, 80 to 90 percent of energy yielding nutrients (carbohydrates and lipids), 3 to 4 percent of minerals and a trace of vitamins.

B.2 Digestive system of dairy cows

Livestock can be classified in three groups according to their digestive tract: simple nonruminants (humans, poultry, swine), ruminants (cattle, sheep, goats) and nonruminant herbivores (horses, rabbits, guinea pig). This digestive system determines a great part of the animal's the nutritional requirements and the ability to utilize feedstuffs.

Cows are ruminants. They have a large, compartmentalized stomach and much of the work of digestion is accomplished by microbes that inhabit the stomach. The largest segment of the ruminant stomach is the rumen, which functions as a fermentation vat. It contains an immense microbial population of bacteria, protozoa, fungi and yeasts that ferment the ingested feed. The major source of absorbed energy in ruminants are fermentation end products, volatile fatty acids (VFA). The fermentation produces large quantities of gases that are removed by belching. The breakdown of feeds into smaller particles to facilitate fermentation is accomplished by the process of rumination (or "chewing the cud").

The ruminant stomach has profound implications in nutrition and feeding. The fermentation allows the utilization of fibrous feeds. No mammal produces cellulase, the enzyme that degrades cellulose. Cellulose is a major constituent of plant fiber is considered to be the most abundant organic compound on earth. Rumen microbes secrete cellulase and this enables cows to utilize fibrous feeds, in contrast to simple nonruminants, which cannot.

Another advantage conferred by rumen fermentation is the ability of rumen microbes to synthesize amino acids and proteins from ammonia. Ruminants can be fed poor quality proteins and even just sources of nitrogen; these are upgraded by rumen fermentation to microbial protein. In addition to providing the cow with a major portion of its energy and protein needs, it is also important in

providing vitamins. Cows have a dietary requirement only for vitamins A, D and E. In fact, for cows that graze green forage and that are exposed to the sunlight, there is no need for vitamin supplementation at all.
Thus the dietary needs of ruminants can be satisfied with a much simpler diet than is the case with monogastrics.

Disadvantages associated with rumen fermentation are an energy loss during fermentation. Methane production results in a loss of carbon, which otherwise could have been oxidized in the cow's own metabolic processes. Ammonia produced in rumen digestion of protein may be excreted in the urine, representing a loss of dietary protein.

B.3 Phosphorus as a nutrient

As an animal nutrient, phosphorus is closely related to calcium. Bone mineral consists mainly of tricalcium phosphate and other salts of these two minerals. Approximately 99% of the calcium and 80% of the phosphorus in the animal body occur in the bones and teeth.

Nonskeletal phosphorus is involved in almost all, if not all, metabolic reactions. It is involved in almost every aspect of feed metabolism and utilization of fat, carbohydrate, protein and other nutrients in the body. High energy phosphate bonds, such as in ATP (adenosine triphosphate), provide energy ot drive most metabolic reactions. Phospholipid formation allows fatty acids to be transported throughout the body. Phosphorus also functions in protein metabolism in nucleoproteins and phosphoproteins. Because P is a component of nucleic acids (RNA and DNA), it is necessary for genetic transmission. [McDowell, 1992].

Vitamin D functions in phosphorus absorption and bone mineralization. The utilization of phosphorus is further influenced by the ratio of phosphorus-to-calcium, the quantity of phosphorus consumed, feed source, age of the cow and levels of other minerals such as calcium, magnesium and potassium.

In most feeds, organic phytate phosphorus may account for 50-70% of the total P. Monogastrics have a limited ability to utilize phosphorus in the phytate form because of low intestinal phytase levels. However the cow's rumen microorganisms have the ability to hydrolyze phytate phosphorus. Results of past studies show that it is not necessary to make adjustments for phytate P levels in feeds when regulating formulations for ruminants. [Chase, 1998].

The primary route of phosphorus excretion is fecal. In a study mentioned by Chase, 68.6% of the total P excreted was in the feces compared with 1% in the urine and 30.3% in milk.

B.4 Feeding and nutrition of dairy cattle

The nutrition of high-producing dairy cows is probably more complex than that of any other livestock. Besides the need to consider nutrient requirements to support a very high level of production, there are complications in meeting these needs through a combination of concentrate and forage. These include maintaining a very high feed intake, maintaining an optimal ratio of VFA in fermentation end products, providing an optimal nitrogen-to-bypass protein ratio, and avoiding metabolic diseases such as milk fever, ketosis, displaced abomasum (the abomasum is a part of the ruminant stomach), downer cow syndrom, milk-fat depression etc.

Calcium is particularly important in dairy nutrition because of the high calcium content of milk and its relationship to milk fever, a major metabolic disease in dairy cattle.

Lactating cows, calves, heifers and dry cows each have different nutrient needs and are therefore fed separate diets on most farms. The energy requirements of lactating cows are related to the milk production, which will increase during the first few weeks of lactating.

Among the most used ingredients in the dairy industry include grains, alfalfa hay, and corn silage. These feedstuffs may be complemented by feed additives. The composition of some selected feed ingredients are showed in Table C.1. The table is on a dry matter basis (except for dry matter percentage) and is extracted from the Feed Industry Red Book, 1996 edition.

Feedstuff	**DM %**	**CP %**	**CF %**	**ADF %**	**NDF %**	**Ca %**	**P %**	**K %**	**TDN %**	**NE$_m$ Mcal/lb.**	**NE$_g$ Mcal/lb.**	**NE$_l$ Mcal/lb.**
Alfalfa hay, mature	88	13	38	45	59	1.18	0.19	1.5	50	0.50	0.12	0.49
Alfalfa silage	30	17	28	37	50	1.40	0.29	2.6	55	0.55	0.21	0.55
Corn silage, mature	34	8	23	27	47	0.25	0.22	1.1	70	0.73	0.44	0.71
Corn grain, whole	88	9	3	3	10	0.02	0.30	0.4	87	0.96	0.64	0.90
Grass hay	91	12	33	40	62	0.70	0.25	2.0	58	0.58	0.26	0.58
Grass silage	30	12	32	39	60	0.80	0.25	2.1	61	0.62	0.31	0.61
Oat hay	90	10	30	39	63	0.38	0.28	1.8	0.59	0.28	0.59	
Oat silage	35	12	30	39	61	0.53	0.31	2.8	60	0.60	0.30	0.60

Table B.1. Composition of some selected feeds

Abbreviations used in table: DM: dry matter content; CP: crude protein; CF: crude fiber; ADF: acid detergent fiber (related to digestibility); NDF: neutral detergent fiber (related to voluntary intake and availability of net energy); Ca: calcium; P: phosphorus; K: potassium; TDN: total digestible nutrients; NE$_m$: Net energy for maintenance; NE$_g$: Net energy for gain; NE$_l$: Net energy for lactation.
(source: Feed Industry Red Book, 1996)

Requirements for dairy cattle vary. Phosphorus requirements are stated in the regular text in Chapter 7. Other requirements can be found in the book by Cheeke.

Appendix C: Costs of waste and nutrition management

This appendix contains some print-outs of Excel sheets used to estimate the costs for various agricultural alternatives. References in this appendix are usually either to the On-Farm Composting Handbook by Rynk et al., 1992 (references as p.23 etc.) or to the Anaerobic Digestion Study by Jewell et al. 1997. (references as p.2-14 etc.)

C.1 Costs of composting

Assumptions done for on-farm composting:

	Rynk	Jewell	Mean	
Manure per cow (gal/d)	13.9	20.1	17.0	
Manure per cow (l/d)	52.6	76.1	64.4	
Used estimate (m3/d)	0.0644			minus 1 farm with appr. 750 cows
	Farm	**County**	**basin**	**total included**
# Dairy farms		336	161	160
Number of dairy cows	50	17500	8750	8000
Average manure/farm (m3/d)	3.2			
Mixing ratio (manure:bulk)	1 to 2			
Total raw material (m3/d)	9.7			1546
Time needed (days)	**composting**	**curing**	**storage**	
windrow infrequent	180	45	90	p.11
windrow frequent	60	45		p.11
passively aerated	70	45		p.11
Turning frequency	**#/day**	**#/cycle**		
infrequent	0.017	3	p.91	
frequent	0.143	weekly	p.28	
passively aerated	0			
Windrow measures	**height**	**width**	**cross-section**	
infrequent	2.5	4.5	7.5	p.70
frequent (drum-type 510, p.119)	1.3	3.0	2.6	p.119
passively aerated	1.2	3.0	2.5	p.29
Curing pile measures	**av. height**	**width**	**cross-section**	
Curing pile measures	1.2	5.5	6.7	p.75
Storage area	2.4	extended piles		p.75
Volume reduction				
Total	0.50			
For windrow design	0.75			
Market value land ($/acre)	1373	(Ag census 1992)		
Market value land ($/ha)	3392			
Tractor operating cost ($/hr)	34	p.93		
Turning capacity	**m3/hr**	**yd3/hr**		
tractor (1yd3 bucket loader)	50	70		p.91
rotated drum (model 510)	900	1200		p.119/118

Piling capacity	**m3/hr**			
tractor (1yd3 bucket loader)	50		p.91	
	28 days	**135 days**	(4.5 months)	
Manure storage ($)	3540	17066		
Labour costs ($/hr)	10	BR&E		
Diversion costs ($/m)	0.62	BMPs		
Compost selling price ($/m3)	15	6.5	65 p.3	
Assumed lifespan of system (yr)	15			
CRF, 10y, 10% interest	0.1628		CPI 1992	87.4
CRF, 15y, 10% interest	0.1315		CPI 1997	100.0
CRF, 20y, 10% interest	0.1175			

Costs for on-farm composting

The three options considered are: windrow composting using the available farm-equipment (infrequent turning), windrow composting using special windrow-turning equipment (frequent turning) and passively aerated windrow composting.

	Infrequent turning:		Frequent turning:		Passive aeration:	
Composting:						
Total compost material (m3)	1304.1		434.7		507.2	
Windrow length (m)	173.9		167.1		204.7	
Composting area:						
windrow width (m)	4.5		3.0		3.0	
spacing per windrow (m)	6.1		3.0		6.1	
Total width (m)	10.6		6.1		9.1	
Area needed (m2)	1842.4		1018.7		1862.0	
Curing:						
Total curing material (m3)	217.35		217.4		217.35	
Pile length (m)	32.5		32.5		32.5	
Curing area:						
pile width (m)	5.4864		5.5		5.5	
spacing per windrow (m)	0		0		0	
Total width (m)	5.4864		5.5		5.5	
Area needed (m2)	178.3		178.3		178.7	
Storage area:						
Total storage material (m3)	434.7		434.7		434.7	
Area needed (m2)	178.3		178.3		178.3	
Total area needed (m2):	**2199**		**1375**		**2219**	
Operation time (hrs)	**per cycle**	**per day**	**per cycle**	**per day**	**per cycle**	**per day**
Windrow piling (hrs)	34.8	0.19	11.6	0.06	13.5	0.08
Windrow turning (hrs)	78.2	0.43	4.1	0.0	0	0
Curing piling (hrs)	4.3	0.10	4.3	0.10	4.3	0.10
Storage piling (hrs)	8.7	0.10	8.7	0.10	8.7	0.10
Total (hrs)	126.1	0.82	28.8	0.28	26.6	0.27
Compost production (m3/day)	4.83		4.83		4.83	
Tractor operating cost ($/m3)	5.83		1.99		1.91	
Rotated drum op costs ($/m3)	0.00		0.05		0.00	
Labour costs	1.70		0.58		0.56	
Total operational costs ($/m3)	7.53		2.63		2.46	
Capital costs:						
Land value	745.9		466.5		752.7	
Diversions	121.9		99.8		112.2	
Manure storage	3539.7		3539.7		3539.7	
Other site preparation	150.0		150.0		150.0	
Rotated drum	0.0		1750.3		0.0	
Aeration pipes	0.0		0.0		175.0	
Total capital costs	4557.5		6006.3		4729.7	
Annualized capital costs	599		790		622	
Compost op cost p year (m3)	1763		1763		1763	
Capital costs ($/m3)	**0.34**		**0.45**		**0.35**	
Total prod costs ($/m3)	**7.87**		**3.08**		**2.81**	

Assumptions done for (de)central composting:
(Only new assumptions are stated here)

Time needed (days)	**composting**	**curing**	**storage**	
agitated bed	14	45	90	p.38
transportable containers				p.39

Agitated bed properties	**low**	**high**	**mean**	
Handling capacity (m3/d)	15.3	30.6	22.9	p.38
Capital costs ($)	114398	200196	157297	p.38
Av. cost in $ per m3/d	7481	6546	6857	

# farms with >500 cows	1		
estimated # of cows	750		
Farms with < 500 cows	160	(WRI: 161 dairy farms)	
average # of cows	50	50	
Number of shared composters	5	1	
Farms per composter	32	160	
Cows per composter	1600	8000	
	1997	**1992**	
Front loader cap costs ($)	148717	130000	p.93
Front loader op costs ($/hr)	25	22	p.93
Front loader capacity (m3/hr)	172		p.93
Compost selling price ($/m3)	15	p.3	
Life time of capital equipment (yrs)	15		
CRF, 15 yrs, 10% interest	0.1315		

Estimated costs for (de)centralized composting:

	Decentralized installation			One central installation		
	60%	80%	All	60%	80%	All
Composting:						
Manure (m3/d)	62	82	103	309	412	515
Bulk material (m3/d)	124	165	206	618	824	1030
Total raw material (m3/d)	**185**	**247**	**309**	**927**	**1236**	**1546**
Compost production (m3/d)	**93**	**124**	**155**	**464**	**618**	**773**
Compost capacity (m3)	1947	2597	3246	9737	12983	16229
Curing capacity (m3)	4173	5564	6955	20866	27821	34776
Storage capacity (m3)	8346	11128	13910	41731	55642	69552
Total capacity (m3)	**14467**	**19289**	**24111**	**72334**	**96445**	**120557**
Average bed-depth (m)	3	3	3	3	3	3
Average bed-width (m)	6	6	6	6	6	6
Area of agitated bed (m2)	**639**	**852**	**1065**	**3195**	**4260**	**5324**
Average curing&storage-depth (m)	3.0	3.0	3.0	3.0	3.0	3.0
Curing+storage area (m2)	**4173**	**5564**	**6955**	**20866**	**27821**	**34776**
Total area needed (m2)	**4812**	**6416**	**8020**	**24060**	**32080**	**40100**
Operation time (excl. transport)	Day	Day	Per day	Day	Day	Per day
Curing pile formation (hrs)	0.5	0.7	0.9	2.7	3.6	4.5
Storage pile formation (hrs)	0.5	0.7	0.9	2.7	3.6	4.5
Total (hrs)	**1.1**	**1.4**	**1.8**	**5.4**	**7.2**	**9.0**
Operation cost (excl. transport)	Day	Day	Per day	Day	Day	Per day
Front loader cost ($)	27	36	45	136	181	226
Agitated bed op ($)	79	79	79	393	393	393
Labor costs ($)	11	14	18	54	72	90
Total op cost ($)	**117**	**129**	**142**	**583**	**646**	**709**
Front loader costs ($/m3)	0.29	0.29	0.29	0.29	0.29	0.29
Agitated bed op ($/m3)	0.85	0.64	0.51	0.85	0.64	0.51
Labor costs ($/m3)	0.12	0.12	0.12	0.12	0.12	0.12
Variable prod costs ($/m3)	**1.26**	**1.04**	**0.92**	**1.26**	**1.04**	**0.92**
Capital costs						
Land value	1632	2176	2720	8161	10882	13602
Agitated bed system	1271870	1695827	2119784	6359352	8479136	10598920
Front loader	148717	148717	148717	297434	297434.1	297434.1
Total annualized capital costs	**187022**	**242844**	**298666**	**876441**	**1155550**	**1434659**
Production in year	33849	45132	56414	169243	225658	282072
Cap prod costs ($/m3)	**5.53**	**5.38**	**5.29**	**5.18**	**5.12**	**5.09**
Total prod costs ($/m3)	**6.78**	**6.43**	**6.21**	**6.44**	**6.17**	**6.00**

C.2 Costs for Anaerobic Digestion

Assumptions done for anaerobic digestion:

(Only assumptions that have not been stated in previous sections of this appendix are shown)

Capital costs	**1320**	**$/cow**	**1600**	**6125**	**$/cow**	**8000**	**#cows**
Digester ($)	221887	168.10	268954	825041	134.70	1077605	p.6-2
Mix tank ($)	24404	18.49	29581	42250	6.90	55184	p.6-2
Generator ($)	241537	182.98	292772	929725	151.79	1214335	p.6-2
O&M costs							
Digester ($ per year)	25155	19.06	30491	103024	16.82	134562	p.6-2
Electricity per cow (kW)	0.14	p.6-4					
Generator on-line time (%)	0.99	p.6-4					
Daily energy per cow day (kWh)	3.33						
Electricity price ($/kWh)	0.025	0.09	p.5-14				
Electricity benefits per cow ($/day)	0.083						
Number of shared digesters	5		1				
Farms per digester	32		160				

Costs of anaerobic digestion:

	All		**80%**		**60%**	
	Decentral	**Central**	**Decentral**	**Central**	**Decentral**	**Central**
Operational costs						
Digester($/year)	30491	134562	24393	107650	18295	80737
Digester op costs ($/m3)	0.81	0.72	0.81	0.72	0.81	0.72
Capital costs						
Digester ($)	268954	1077605	215163	862084	161372	646563
Mix tank ($)	29581	55184	23664	44147	17748	33110
Generator ($)	292772	1214335	234218	971468	175663	728601
Total capital investments ($)	591307	2347123	473045	1877698	354784	1408274
Annualized capital costs ($/yr)	77757	308647	62205	246917	46654	185188
Capital costs ($/m3)	2.07	1.64	2.07	1.64	2.07	1.64
Transp costs to&from farms ($/m3)	3.61	7.16	3.95	7.27	3.86	7.58
Prod costs for farms ($/m3)	**6.49**	**9.52**	**6.83**	**9.62**	**6.74**	**9.93**
Sales transp costs ($/m3)						
Near-scenario (40 miles)	7.59	7.59	7.59	7.59	7.59	7.59
Med-scenario (120 miles)	19.39	19.39	19.41	19.41	19.37	19.37
Far scenario (200 miles)	31.14	31.14	31.12	31.12	31.15	31.15
Total prod costs for sales ($/m3)						
Near-scenario (40 miles)	14.08	17.11	14.43	17.22	14.33	17.53
Med-scenario (120 miles)	25.88	28.91	26.24	29.03	26.11	29.31
Far scenario (200 miles)	37.62	40.65	37.95	40.74	37.89	41.09
Potential electricity benefits, low price						
Electricity per day (kWh)	5322	26611	4258	21289	3193	15967
Electricity benefits ($/m3)	1.29	1.29	1.29	1.29	1.29	1.29
Potential electricity benefits, high price						
Electricity benefits ($/m3)	4.65	4.65	4.65	4.65	4.65	4.65

C.3 Costs for manure transportation

Assumptions done for manure transportation:

(Only assumptions that have not been stated in previous sections of this appendix are shown)

Truck characteristics		
Capacity (gal)	**6000**	**4000**
Capital costs ($/yr)	158000	132000
Cap Costs (Jewell) 0.62 ratio	100323	80258
Lifespan (yrs)	15	15
Fuel consumption (analogue liquid)	8	7

Truck operation	**6000**	
Driver costs ($/hr)	20	p.4-2
Driver hours (hrs/day)	8	p.4-2
Effective driving (of DH))	0.9	p.4-2
Operational labor (relation to driver hrs)	1.2	p.4-3
Fuel price ($/gal)	1.35	p.4-4
Fuel consumption (mpg)	5	p.C-3
Maintenance ($/mile)	0.43	
Average travel speed (mph)	35	p.4-6
Truck loading time	0.60	p.4-5
Unloading time at plant	0.45	p.C-2
Working schedule (8 hrs/d)	8	
Days per year manure is hauled	260	
Working days per week	5	

Manure transp volume	**60%**	**80%**
Daily prod at farm (gal)	507	676
Daily prod at farm (m3)	1.9	2.6
# farms in basin	160	160
Total manure surplus (gal/d)	81154	108205
Total surplus p truckday (gal)	113615	151487

Loading area costs	p.4-4, per yd3	WRI, per farm,	Annual costs
Storage facilities ($)	1	17066	2244
Access roads		5400	710
Storage facility (28 days)	108	3540	
Annual storage costs ($/yr)		465	

	Size (ft)	**total cost ($)**	
Basic machine storage	54 x 75	30300	p.4-5
Length in m	23		
Width in m	16		
Cover area (m2)	376		
Cost per m2 covered ($/m2)	80.53		
Area per truck (m2)	169	13610	
Outside parking area ($/truck)	1311		p.4-5

Costs for manure transportation:

	Near-scenario (40 miles)		**Med-scenario (120 miles)**		**Far scenario (200 miles)**	
	60%	**80%**	**60%**	**80%**	**60%**	**80%**
Truck capacity (gal):	**6000**	**6000**	**6000**	**6000**	**6000**	**6000**
Days to fill truck at farm	11.8	8.9	11.8	8.9	11.8	8.9
Full trucks per farm per week	0.6	0.8	0.6	0.8	0.6	0.8
Total trips from all farms per week	95	126	95	126	95	126
Total trips per day in basin	19	25	19	25	19	25
Time per trip (hr)	3.34	3.34	7.91	7.91	12.48	12.48
Time per day (hr)	63.2	84.2	149.7	199.6	236.3	315.1
Trucks needed	**8**	**11**	**19**	**25**	**30**	**40**
Total (basin, incl.reserve trucks)	**9**	**12**	**20**	**26**	**31**	**41**
Operational costs						
Driver hours per day	70.2	93.6	166.4	221.8	262.5	350.1
Driver costs per day ($/d)	1404	1872	3327	4436	5251	7001
Operator costs	281	374	665	887	1050	1400
Travel distance (mpd)	1515	2020	4545	6059	7574	10099
Fuel consumption (gpd)	303	404	909	1212	1515	2020
Fuel costs ($/d)	409	545	1227	1636	2045	2727
Maintenance costs ($/d)	651	869	1954	2606	3257	4343
Total op costs ($/d)	2745	3660	7174	9565	11603	15471
Compost transp (gal/d)	113615	151487	113615	151487	113615	151487
Variable transp costs ($/gal)	0.02416	0.02416	0.06314	0.06314	0.10213	0.10213
Variable transp costs ($/m3)	**6.38**	**6.38**	**16.68**	**16.68**	**26.98**	**26.98**
Capital costs						
Truck costs ($)	902907	1203876	2006460	2608398	3110013	4113243
Annual truck costs ($/yr)	118732	158310	263849	343004	408967	540891
Parking area ($)	11799	15732	26220	34086	40641	53751
Annual parking costs ($/yr)	1552	2069	3448	4482	5344	7068
Roofed truck storage ($)	122486	163315	272191	353849	421897	557992
Annual truck storage costs ($/yr)	16107	21476	35793	46531	55479	73376
Annual farm manure storage costs ($/y)	74476	74476	74476	74476	74476	74476
Annual costs farm-roads (50% farms)	56808	56808	56808	56808	56808	56808
Total annual capital costs	267674	313138	434374	525301	601074	752619
Cap transp costs ($/gal)	0.00906	0.00795	0.01470	0.01334	0.02035	0.01911
Cap transp costs ($/m3)	**2.39**	**2.10**	**3.88**	**3.52**	**5.38**	**5.05**
Total transp costs ($/m3)	**8.78**	**8.48**	**20.57**	**20.20**	**32.35**	**32.03**
Costs per cow per year ($)	**123.00**	**158.52**	**288.24**	**377.57**	**453.48**	**598.52**
Costs per cow in Jewell et al ("short" distance)	**highest:**	**157.79**	**lowest:**	**82.69**		

C.4 Costs for nutrition management

Samples/analyses*	**Frequency*** (1 per # days)	**Time** (hr)	**Costs per sample** low ($)	high ($)	**Monthly costs** high ($)	low ($)	average ($)
Dry matter intake	30						
Body condition	30						
Barn temp	1						
Forage analysis	60	NA	15	35	7.5	17.5	12.5
Concentrate analysis	90	NA	15	35	5	11.7	8.3
Milk sold	30?	NA	15	35	15	35	25
Total sample collection		*2*	*20*	*40*	*20*	*40*	*30*
Other activities*							
Ration evaluation and reformulation	30	8	200	400	200	400	300
Total			**265**	**545**	**247.5**	**504.2**	**375.8**

Soil, manure and crop samples not included: will be done regularly for existing nutrient management activities

Costs for sample analysis based on costs for manure analysis as stated in Ag BMP list

Costs for ration formulation by consultant, based on own estimates: rate used is $25 to $50 per hour

*Source: Barry et al. 1996

Appendix D: Agricultural Best Management Practices

D.1 List of agricultural BMPs

This section contains several tables with information on some agricultural best management practices (BMPs). This information has been derived from a literature review from the following sources: NYS Nonpoint Source Management Practices Task Force, May 1996; US EPA, January 1993; and NYCDEP, March 1995.

Name	Definition	Type*
Barnyard runoff management	System for controlling the amount and quality of runoff water from concentrated livestock areas	All
Livestock/Pasture management	Control of livestock movement and density on pastureland (fencing, stream crossing, congregation areas)	Op
Manure storage/Timing of application	Collection and storage of animal waste until conditions are suitable for land application	Op
Rate & method of manure application	Application of manure in a way that maximizes nutrient utilization by plants & improves soil tilth	Op
Manure nutrient analysis	Laboratory analysis of livestock manure to determine nutrient content	Op
Soil testing	Chemical analysis to estimate the ability of soil to supply plant nutrients to crops	Op
Filter strips	Strip of vegetation established adjacent to areas of high pollutant delivery potential	Veg
Stripcropping	Growing crops in a systematic arrangement of strips or bands	Veg
Access Road Improvement	Structural and vegetative improvements to farm roadways	V&S
Pathogen management	Improvements to youngstock raising and manure handling facilities	All
Fertilizer management	Managing the rate, timing and placement of fertilizer to encourage maximum nutrient recycling	Op
Streambank protection	Use of vegetation, structures, biotech or management to stabilize and protect streambanks	All
Cover and green manure crop	Close growing crops for temporary, seasonal soil protection and improvement	O&V
Crop rotation	A planned sequence of annual and/or perennial crops grown on the same field	O&V
Terraces	Earth embankment, channel, or a combination ridge & channel constructed across the slope	Struc
Grassed waterway	A channel that is below groundlevel for the stable conveyance of runoff	V&S
Riparian forest buffer	An area of trees, shrubs and grasses located adjacent to and upgradient from water bodies	Veg
Conservation tillage	Tillage and planting system that leaves at least 30% of soil surface covered with plant residue	O&V
Milking center wastewater management		

Table D.1. Description of some agricultural BMPs

*Type: Op: Operational; Veg: Vegetative; Struc: Structural

Name	Reduction of P-Loads (%) Lowest	Highest	Reduction of N-Loads (%) Lowest	Highest	Reduction of pathogens (%) Lowest	Highest
Barnyard runoff management	23	70	+			90
Livestock/Pasture management		60	+		+	
Manure storage/Timing of application	50	85	+	86	0	
Rate & method of manure application	15	50	17	83	0	
Manure nutrient analysis	+		+		+	
Soil testing	+		0			
Filter strips	50	85		83	+	
Stripcropping	52	99				
Access Road Improvement	+		+		+	
Pathogen management	+		+		+	
Fertilizer management	35	91	+		0	
Streambank protection	+		+	90	0	
Cover and green manure crop	13	75	9	50	0	
Crop rotation	+		50	80	0	
Terraces	55	90	30	90	0	
Grassed waterway		52		29		
Riparian forest buffer		50				
Conservation tillage		45	+		0	

Table D.2. Literature values for possible pollution reduction through BMPs

"+" means that no value has been specified, only a reducing effect on the concerned pollutant

D.2 Effectiveness of BMPs

How much of TP and TN that is put as manure on the lands is lost in runoff?

Base loading from agricultural lands can be estimated from successional forests:
SRP is 0.143 kg ha^{-1} yr^{-1}, net SRP is 0.123 kg ha^{-1} yr^{-1} [Scott et al. 1998].

Relation SRP to TP loads:

Parameter	Loading Rate Farm (kg/ha/yr)	Loading Rate Control Site (kg/ha/yr)
TP	1.037	0.126
TSP	0.465	0.049
SRP	0.321	0.009
NO3	3.770	0.760
NH3	1.040	0.040
TN (Kjeldahl)	2.720	0.770
TOC	29.100	14.800
TSS	217.000	44.900

Table D.3. Loading from one monitored farm for one year (1993/94)
Source: WAC, 1997

Combined with loading measurement data from Longabucco and Rafferty, the ratio between SRP/TP is estimated to be 0.3 for nonpoint sources. This estimation of some kind of linear relationship in combination with data on successional forests gives a base load of TP from farmland of 0.410 kg ha^{-1} yr^{-1}.

Current TP loading from the one monitored farm is 1.037 kg ha^{-1} yr^{-1}, so maximum possible reduction through BMPs is estimated to be 0.627 kg ha^{-1} yr^{-1}. This successional forest base load was measured 40-50 years after agricultural practices ended, so it can well serve as a minimum to cover the <20 years studyperiod. The loading rate estimated for farm lands from the GWLF model is 0.680 kg ha^{-1}

yr^{-1}. This is based on 31902 ha of land that accounted for 21700 kg/yr of TP loading. Based on this information, the maximum possible reduction is 0.270 kg ha^{-1} yr^{-1}.

So maximum possible reductions from BMPs range between 0.270 and 0.627 kg ha^{-1} yr^{-1}. Minimum reduction of BMP that is still effective is assumed to be 50% of maximum. Thus there is a possible range for reductions from 0.135 to 0.627 kg ha^{-1} yr^{-1}.

Reductions of TN from effective BMPs have been reported to be approximately half of the reductions of TP. USEPA reported reductions ranging from 22.8 to 84.2 lbs./acre for TP and 11.5 to 47.5 lbs./acre for TN loads to surface water (which is much higher than the possible reduction here assumed; 100 times higher than the total loading from agriculture) [USEPA, 1993]. So it will be assumed that possible reductions in TN from effective agricultural BMPs are about half of the possible TP-reductions. So the range for TN-reductions from BMPs is assumed to be 0.068 to 0.314 kg ha^{-1} yr^{-1}.

Another possible way to calculate reductions from BMPs is based on literature data that report reductions in percentages. These can be linked to the loading found in the GWLF Model and the monitoring data from the WAP. This gives the following reductions:

Reductions	TP-low	TP-high	TN-low	TN-high
Percentage	35%	90%	15%	80%
GWLF (kg/ha/yr)	0.238	0.612		
WAP (kg/ha/yr)	0.363	0.933	0.480	2.176

Table D.4. Reductions based on literature percentages

Summarizing the above, two different estimations can be made for possible reductions from BMPs. They are stated in the table below:

Method	TP-low	TP-high	TN-low	TN-high
Successive forests	0.135	0.627	0.068	0.314
Percentages	0.238	0.933	0.480	2.176

Table D.5. Possible reduction from agricultural BMPs in kg ha^{-1} yr^{-1}, as estimated by two different methods.

The question remains which of these estimations will be the better ones. The estimation for TP reduction are comparable, but for TN the difference is greater. For now, the boundary values of the two methods combined will be used. They have been marked in the above table.

Total cropland was 39126 ha (65298 acres) in Delaware in 1992 [USDA, AgCensus, 1992]. Acres for Cannonsville will be estimated to be half of this: 19563 ha (48340 acres). This will be used in the models as maximum acreage where reductions can be reached. Forest land on farms is thus excluded. Average size per farm is based on AgCensus 1992 data for Delaware: 57 ha (141 acres) of cropland per farm (686 farms in Delaware: 343 in Cannonsville basin).

Short-term reductions due to nutrition management

The same data as above will be used to estimate short-term reductions from reduced phosphorus in the applied manure due to balanced diets:
For TP, a maximum reduction of 0.680 kg ha^{-1} yr^{-1} can be reached through traditional BMPs. This point will be reached if none of the phosphorus applied to the lands is prematurely lost in runoff, but if it can all settle in and be bound by the soil/used by plants. If one applies less phosphorus to the lands, than this reduction can be regarded as being bound by the soil for short-term purposes. How much of the phosphorus not bound by the soil will be actually contributing to the loading to the reservoir?

To answer this question, the phosphorus balances for 15 WAP farms will be used [NYSWRI, December 1998]. They show a surplus of 18 lbs./acre/year; 20 kg ha^{-1} yr^{-1}. It further is assumed that there is some sort of linear relationship between this surplus and the surplus loading (that is, the difference between actual loading and base loading). This will not be correct, but hopefully it will be close enough. This ratio between surplus and actual loading can then be used to estimate the decrease in loading due a reduction in phosphorus applied to the lands.

Based on the data from the GWLF Model the ratio is 0.013 and based on WAC measurements the ratio is 0.031. This ratio will differ for different areas and for different times (wet periods), but still it is generally applied here to obtain some rough estimations.

The nutritional efforts lead to a reduction of TP applied to the lands of some 5.76 to 7.68 kg ha^{-1} yr^{-1} (based on 57 ha cropland per farm). This will reduce the loading with 0.077 to 0.179 kg ha^{-1} yr^{-1}. This results in total reductions of 4.3 to 13.6 kg/y per farm.

Appendix E: Calculation of model parameters

Five different scenarios have been formulated for which the values of some of the input variables are different. These variable and their values have been summarized in the two tables in Chapter 13, which are also shown below for reasons of convenience.

Input Variable	Optimistic	Pessimistic	Most likely
Manure Surplus	80%	60%	60%
Price on-farm compost	\$20 m^{-3}	\$10 m^{-3}	\$15 m^{-3}
Price central compost	\$25 m^{-3}	\$12 m^{-3}	\$17 m^{-3}
Price digested manure (derived from Jewell, 3-10)	\$4.00 m^{-3}	\$1.60 m^{-3}	\$2.60 m^{-3}
Price raw manure (Jewell, p.3-10)	\$2.60 m^{-3} (\$0.01 gal^{-1})	\$0.70 m^{-3} (\$0.003 gal^{-1})	\$1.60 m^{-3} (\$0.006 gal^{-1})
Distance to markets	64 km (40 miles)	322 km (200 miles)	193 km (120 miles)
On-farm composting method	frequent turning	infrequent turning	frequent turning
P-content manure	1.1 g/kg	0.9 g/kg	1.0 g/kg
Short term effects BMPs	53.2 kg/farm/y (or 90% reduction)	7.7 kg/farm/y (or 35% reduction)	21.7 kg/farm/y (avg. Successive forests method; or 60% reduction)
P-reductions in manure from nutrition man.	24 g/cow/day (438 kg/farm/y) – 29,3%	18 g/cow/day (329 kg/farm/y) – 18,4%	22 g/cow/day (402 kg/farm/y) – 23,9%
Pathogens reduction BMPs	90%	50%	70%
Manure surplus when nutrition is combined with waste man.	less: 72%	less: 51% (less P in excretion)	less: 47%
BMPs with balancing (short term)	higher (10% ratio)	higher (65% of surplus/loads ratio)	higher (40% ratio)
Costs nutrition management	\$3,000 per year	\$6,100 per year	\$4,500 per year
Short term effects nutrition	13.6 kg/farm/y	4.3 kg/farm/y	8.8 kg/farm/y

Table E.1. Effectiveness and efficiency of agricultural alternatives

Input variable	Optimistic	Pessimistic	Most likely
Cost WWTP Upgrades			
Walton	\$12 million (Dec98)	\$16 million (March99)	\$16 million
Delhi	\$7 million (Dec98)	\$10.8 million(March99)	\$10.8 million
Stamford	\$6 million (Dec98)	\$7 million (March99)	\$7 million
Hobart	\$1.5 million (15%)	\$1.8 million (March99)	\$1.8 million
TP conc. after upgrade			
Walton	0.05 mg/l	0.2 mg/l	0.05 mg/l
Delhi	0.05 mg/l	0.2 mg/l	0.05 mg/l
Stamford	0.02 mg/l	0.2 mg/l	0.02 mg/l
Hobart	0.05 mg/l	0.5 mg/l	0.05 mg/l
Effect septic systems	4.4 kg/system/y	0.7 kg/system/y	2.6 kg/system/y

Table E.2. Effectiveness and efficiency of non-agricultural alternatives:

These changing variables are used together with the other variables to calculate the scenario-specific parameters for the IP-model. For the most important parameters, the calculation steps and any appearing assumptions are shortly explained per scenario.

E.1. Parameter values for scenario 1: optimistic estimations

Short-term phosphorus reductions

Short-term reductions due to waste management

When waste management is implemented, a certain amount of phosphorus is transported to locations outside the watershed. This means that this phosphorus is not even reaching the lands in the watershed, let alone the surface water. The short-term reductions that are the result of this are calculated in the same way as those for nutrition management, described in Appendix D.2. For these calculations the ratio between surplus phosphorus applied to the lands and the non-base phosphorus load from those lands is used. Here the ratio is 0.031 and the TP reduction on farms is 1274 kg/farm/year. This results in a short-term reduction of 31.6 kg/farm/year.

However, waste management activities must always be combined with agricultural BMPs (see the structural model). In this scenario the BMPs prevent 90% of the phosphorus to runoff from the lands. Only for the last 10% that does run off when BMPs are implemented, the short-term effects of waste management are of relevance. Short-term effects thus are 10% of 31.6: TP reduction of 3.2 kg/farm/year.

Short-term reductions due to nutrition management

The short-term reductions due to nutrition management are calculated as described in Appendix D.2. For these calculations the ratio between surplus phosphorus applied to the lands and the non-base phosphorus load from those lands is used. Here the ratio is 0.031 and the TP reduction in manure is 24 g/cow/day. This results in a short-term reduction of 13.6 kg of TP per year.

When nutrition management is combined with waste management, the short-term reduction due to nutrition management is zero. This is because both alternatives aim at reducing the phosphorus that is applied to the lands, but waste management is more drastic.

Short-term reductions due to agricultural BMPs

Short-term reductions due to agricultural BMPs are calculated as described in Appendix D.2. For the most optimistic estimations this results in a reduction of 53.2 kg/farm/year. This is higher than 100% of the runoff due to surplus manure (approx. 31.6 kg/farm/y), because BMPs also address fertilizers and other (smaller) phosphorus sources.

Short-term reductions due to agricultural BMPs combined with nutrition management

When nutrition management is combined with BMPs, then the short-term effects can not just be added. The short-term effects of the combination will be less than this sum, just as is the case when BMPs are combined with waste management. Combined, the reduction will be the reduction due to BMPs plus 10% of the reduction due to nutrition management (because the other 90% would already be prevented from running off by the BMPs). The parameter for the BMPs on farms that also engage in nutrition management now is 53.2 – 0.9*13.6 = 41.0 kg/y.

Short-term reductions due to rehabilitation of septic systems

For septic systems it has been assumed that the possible short-term reduction is 25% of the phosphorus that is released from failing systems. But if this is indeed a realistic assumption is not clear at this point.

Short-term reductions due to upgrade of WWTPs

The phosphorus reductions due to the upgrade of the four municipal waste water treatment plants have been calculated based on the current average flows, current phosphorus concentration in the effluent and the expected phosphorus concentrations in the effluent after upgrades. Values used for the average concentration of phosphorus in the effluent of WWTPs after the upgrade, have been estimated as the target values that the contractors plan to achieve through upgrading.

This results in the following table:

	Delhi	**Hobart**	**Stamford**	**Walton**
avg flow (m3/d)	1628	114	1514	5678
TP effluent (mg/l)	3	3,6	1,7	1
TP after upgrade	0.05	0.05	0.02	0.05
TP red (kg/y)	**1753**	**147**	**928**	**1969**

Table E.3. Reductions from upgrading WWTPs
(source: Delaware Eng and LVDV Eng, March 1999)

Long-term phosphorus reductions

Long-term reductions due to waste management

For waste management activities, the long-term reduction in phosphorus loads is equal to the amount of phosphorus that is contained in the surplus manure (which is brought to locations outside the watershed). For the optimistic scenario, the surplus is assumed to be 80%, the P-content of manure 1.1 g/kg. Together with the other relevant assumptions (see Appendix B), the phosphorus in surplus manure is 1019 kg/y per farm. Units for these activities are either 5 or 32 farms.

Long-term reductions due to nutrition management

For nutrition management, the long-term reductions are based on a reduction of TP in manure of 24 g/cow/day. This leads to a reduction of 438 kg/farm/y, based on an average of 50 cows per farm.

As for the long term P reductions for nutrition management combined with waste management, these will remain the same as for the waste management alternatives without nutrition management. Waste management aims at balancing the P loads on farms. Once these P loads are balanced, they cannot be further reduced.

Long-term reductions due to the rehabilitation of septic systems

Assumptions made here at that the system does not remove any phosphorus anymore, that on average 5 g of TP per capita is excreted, that 3 people are connected to a septic system and that a well functioning system would remove 80% of the phosphorus. This leads to a long-term reduction of 4.4 kg/system/year. (assumptions from Chapter 9)

Long-term reductions due to the upgrading of WWTPs

For WWTPs, long-term reductions are not specified. Long-term reductions are included in the model because the soil may get saturated with phosphorus in the future. The WWTPs effluent does not flow through the soil, but flows directly into the surface water, so it is not of relevance for the model's long-term reductions.

Reduction of pathogens from farms

Pathogens are killed in the composting or digestion process due to high temperatures. So if all manure is processed, all the pathogens are killed (reduction of 100%) and otherwise the pathogens in the surplus manure are killed (80% reduction). Again, waste management is combined with BMPs, so also the pathogen reductions must be tuned. The highest literature value found for BMPs is 90%, this is the value that is used in this optimistc scenario. So for the 100% reducing activities, the parameter value is 0.1 per farm (as it is 0.9 for BMPs). For the other activities, 80% of the pathogens is taken off the farms, and of the remaining 20%, again 90% is 'removed'. This results in a total reduction of 80 + 18 = 98%. Parameter value here is 0.08 (per farm). Units consist of 5 or 32 farms.

Apart from waste management and agricultural BMPs, no other alternatives lead to a reduction in pathogens from farms.

Costs for goal function and distribution of costs

Costs for composting, anaerobic digestion and transportation

Costs for these alternatives are calculated as shown in Appendix C. It is assumed that the compost from the decentral installations is of better quality than the compost that is produced on the farms. Compost prices are assumed to be \$20 m^{-3} for on-farm compost and \$25 m^{-3} for compost from a decentral facility (serving 32 farms). It is assumed that digested manure can be sold for \$4 m^{-3}, raw manure for \$2.60 m^{-3}. The distance to markets for these products is assumed to be 64 km (40 miles). This is indeed a very optimistic estimation, since this is just outside the watershed.

The distribution of the costs has been calculated based on variable and fixed costs. This distribution is calculated as the percentage of the total costs per m^3 that is variable and the percentage that is fixed (these add up to 100%). The benefits from sales and electricity generation have been treated as negative variable costs (since negative costs are benefits). These percentages have simply been multiplied with the total costs shown in the goal function.

Costs for nutrition management

The costs for nutrition management are also calculated in Appendix C. For this scenario, they are assumed to be \$3,000 per farm per year. When nutrition management is applied on a farm, there will be less phosphorus in the manure. This leads to a lower manure surplus, which means that less manure has to be taken off the farms. This results in a change in the costs for the waste management alternatives. So for the combinations of nutrition and waste management activities, the new costs for waste management activities have to be calculated.

The new percentage of manure that is needed on the farm is calculated as:

$$20\% * (100/(100-29.3\%) = 27\%$$

(20% is the original percentage used on farms, 29.3% represents the reduction of P in manure due to nutrition management)

The surplus percentage is 100% minus the percentage needed on farms: 100-28 = 72%. The changes in costs for the waste management activities must be included in the parameter values for nutrition management combined with waste management. For each waste management alternative, the difference between the costs is divided by the number of farms included in a unit (either 5 or 32). This is done because the unit for nutrition management consists of just one farm. The resulting amount is either substracted or added to the base costs for nutrition management. It is subtracted when the new costs are lower, and added when they are higher.

The distribution in fixed and variable costs of the extra costs or of the cost savings due to a combination of nutrition and waste management has been done using the same percentages as for waste management.

Costs for agricultural BMPs

The costs for the agricultural BMPs have been calculated based on the cost estimates from the Watershed Agricultural Program (see Chapter 7). These BMPs are mostly structural practices so the costs have been annualized using a 15 year lifespan and 10% interest rate. This resulted in costs of \$9,000 per farm per year.

Costs for rehabilitation of septic systems

These costs are estimated to be \$10,000 per system. This is based on information provided by the CWC (see Chapter 9). The rehabilitation costs are annualized using a 25 years lifetime (NYS BMPs) and a 10% interest rate. The corresponding cost recovery factor is 0.1102.

Costs for upgrading of WWTPs
The estimations for the costs for upgrades of WWTPs are based on information from the contracting firms who are implementing the upgrades. The optimistic (lower bound) costs are the estimations that were made in December 1998. The upper bound costs are the adjusted estimations as of March 1999. It is assumed that those recent estimations are the most accurate ones (the 'most likely'). The costs are annualized based on a 25 years lifetime and a 10% interest rate.

E.2. Parameter values for scenario 2: pessimistic estimations

Short-term phosphorus reductions

Short-term reductions due to waste management
See scenario 1. Changes: ratio between surplus phosphorus applied to the lands and the non-base phosphorus load from those lands is 0.013 and the TP reduction on farms is 1050 kg/farm/year. This results in a short-term reduction of 8.2 kg/farm/year. Combined with BMPs (35% reduction) the short-term effects are 65% of 8.2 = 5.3 kg/farm/year.

Short-term reductions due to nutrition management
See scenario 1. Ratio used is 0.013 and the phosphorus reduction in manure is 18 g/cow/day. This results in a short-term reduction of 4.3 kg of TP per year.

Short-term reductions due to agricultural BMPs
Short-term reductions due to agricultural BMPs are calculated as described in Appendix D.2. For the most pessimistic estimations this results in a reduction of 7.7 kg/farm/year.

Short-term reductions due to agricultural BMPs combined with nutrition management
See scenario 1. Here the parameter for the BMPs on farms that also engage in nutrition management is: 7.7 – 0.35*4.3 = 6.2 kg/y.

Short-term reductions due to rehabilitation of septic systems
See scenario 1.

Short-term reductions due to upgrade of WWTPs
See scenario 1. Values used for the average concentration of phosphorus in the effluent of WWTPs after the upgrade, have been estimated as the concentrations that are required under the MOA.

	Delhi	**Hobart**	**Stamford**	**Walton**
avg flow (m3/d)	1628	114	1514	5678
TP effluent (mg/l)	3	3,6	1,7	1
TP after upgrade	0,2	0,5	0,2	0,2
TP red (kg/y)	**1664**	**128**	**829**	**1658**

Table E.4. Reductions from upgrading WWTPs for scenario 2
(source: Delaware Eng and LVDV Eng, March 1999)

Long-term phosphorus reductions

Long-term reductions due to waste management
Same as scenario 1, but now the surplus is assumed to be 60%, the P-content of manure 0.9 g/kg. The phosphorus in surplus manure now is 630 kg/yr per farm.

Long-term reductions due to nutrition management
For nutrition management, the long-term reductions are based on a reduction of TP in manure of 18 g/cow/day. This leads to a reduction of 329 kg/farm/yr.

Long-term reductions due to the rehabilitation of septic systems
Assumptions made here at that the system does not remove any phosphorus anymore, that on average 3 g of TP per capita is excreted, that 2 people are connected to a septic system and that a well functioning system would remove 30% of the phosphorus. This leads to a long-term reduction of 0.7 kg/system/year. (assumptions from Chapter 9)

Long-term reductions due to the upgrading of WWTPs
See scenario 1.

Reduction of pathogens from farms
See scenario 1. 60% surplus. lowest value found for BMPs is 50%. So for the 100% reducing activities, the parameter value is 0.5 per farm (as it is 0.5 for BMPs). For the other activities, 60% of the pathogens is taken off the farms, and of the remaining 40%, again 50% is 'removed'. This results in a total reduction of 60 + 20 = 80%. Parameter value here is 0.3 (per farm). Units consist of 5 or 32 farms.

Costs for goal function and distribution of costs
Costs for composting, anaerobic digestion and transportation
See scenario 1. Compost prices are assumed to be \$10 m^{-3} for on-farm compost and \$12 m^{-3} for compost from a decentral facility. It is assumed that digested manure can be sold for \$1.60 m^{-3}, raw manure for \$0.70 m^{-3}. The distance to markets for these products is assumed to be 322 km (200 miles).

Costs for nutrition management
See scenario 1. Costs of nutrition management are \$6,100 per farm per year. For the combinations of nutrition and waste management activities, the new costs for waste management activities have to be calculated.

The new percentage of manure that is needed on the farm is calculated as:

$$40\%*(100/(100-18.4\%) = 49\%$$

(40% is the original percentage used on farms, 18.4% represents the reduction of P in manure due to nutrition management)
The surplus percentage is 100% minus the percentage needed on farms: 100-49 = 51%.

Costs for agricultural BMPs
Same as for scenario 1.

Costs for rehabilitation of septic systems
Same as for scenario 1.

Costs for upgrading of WWTPs
See scenario 1. Pessimistic estimations of these costs are the estimations made in March 1999 by the contractors who are supposed to implement the upgrades. Again these costs are annualized based on a 25 years lifetime and a 10% interest rate.

E.3. Parameter values for scenario 3: most likely estimations

Short-term phosphorus reductions
Short-term reductions due to waste management
See scenario 1. Changes: ratio is 0.022 and the phosphorus reduction on farms is 1167 kg/farm/year. This results in a short-term reduction of 15.4 kg/farm/year. Combined with BMPs (60% reduction) the short-term effects are 40% of 15.4 = 6.2 kg/farm/year.

Short-term reductions due to nutrition management
See scenario 1. Ratio used is 0.022 and the phosphorus reduction in manure is 22 g/cow/day. This results in a short-term reduction of 8.8 kg of TP per year.

Short-term reductions due to agricultural BMPs
Short-term reductions due to agricultural BMPs are calculated as described in Appendix D.2. For the most likely estimations this results in a reduction of 21.7 kg/farm/year (average values of the 'successuve forest method' are used, as described in D.2).

Short-term reductions due to agricultural BMPs combined with nutrition management
See scenario 1. Here the parameter for the BMPs on farms that also engage in nutrition management is: 21.7 – 0.60*8.8 = 16.4 kg/y.

Short-term reductions due to rehabilitation of septic systems
See scenario 1.

Short-term reductions due to upgrade of WWTPs
See scenario 1.

Long-term phosphorus reductions
Long-term reductions due to waste management
Same as scenario 1, but now the surplus is assumed to be 60%, the P-content of manure 1.0 g/kg. The phosphorus in surplus manure now is 700 kg/yr per farm.

Long-term reductions due to nutrition management
For nutrition management, the long-term reductions are based on a reduction of TP in manure of 22 g/cow/day. This leads to a reduction of 402 kg/farm/yr.

Long-term reductions due to the rehabilitation of septic systems
The most likely long-term reductions are considered to be the average of the reductions based on optimistic and pessimistic estimations, as calculated for scenario 1 and 2.

Long-term reductions due to the upgrading of WWTPs
See scenario 1.

Reduction of pathogens from farms
See scenario 1. 60% surplus. average value for BMPs is 70%. So for the 100% reducing activities, the parameter value is 0.3 per farm (as it is 0.7 for BMPs). For the other activities, 60% of the pathogens is taken off the farms, and of the remaining 40%, again 70% is 'removed'. This results in a total reduction of 60 + 28 = 88%. Parameter value here is 0.18 (per farm). Units consist of 5 or 32 farms.

Costs for goal function and distribution of costs
Costs for composting, anaerobic digestion and transportation
See scenario 1. Compost prices are assumed to be \$15 m^{-3} for on-farm compost and \$17 m^{-3} for compost from a decentral facility. It is assumed that digested manure can be sold for \$2.60 m^{-3}, raw manure for \$1.60 m^{-3}. The distance to markets for these products is assumed to be 193 km (120 miles).

Costs for nutrition management
See scenario 1. Costs of nutrition management are \$4,500 per farm per year. For the combinations of nutrition and waste management activities, the new costs for waste management activities have to be calculated.

The new percentage of manure that is needed on the farm is calculated as:

40%(100/(100-23.9%) = 53%*

(40% is the original percentage used on farms, 23.9% represents the reduction of P in manure due to nutrition management)
The surplus percentage is 100% minus the percentage needed on farms: 100-53 = 47%.

Costs for agricultural BMPs
Same as for scenario 1.

Costs for rehabilitation of septic systems
Same as for scenario 1.

Costs for upgrading of WWTPs
Same as for scenario 2.

E.4. Parameter values for scenarios 4 and 5

Parameter values for these two scenarios are derived by combining the scenarios 1 and 3. Scenario 4 uses the values of scenario 1 for the activities related to agriculture and the values of scenario 3 for the other activities. Scenario 5 uses the scenarios in exactly the opposite way.

Appendix F: Sensitivity analysis

To quantify the effects of the considered alternatives, a lot of variables have been used. The value for all these variables is not always known with certainty. If values are uncertain, it is necessary to investigate what the impact of a change in this value will be on the model results.

F.1. Inventory of input variables

In the list below, all of the used input variables are stated. Of these variables, an estimation has been made of the precision of the used value and of the sensitivity of model results regarding the variables value. If for example the capital costs for trucks only constitute a small part of the total capital costs for composting, it is assumed that the model is not very sensitive towards this variable as far as composting is concerned. For each variable also the category it affects is stated: it affects the model results for either the costs or the effectiveness or for both. The last column contains an assessment of the possibilities for decision makers in Delaware County to change the values of the variables in a positive direction (manageability).

Input variable	**Lower value**	**Upper value**	**Most likely value**	**Precision**	**Sensitivity**	**Costs / effect. / both**	**Manageable (yes/no)**
Manure per cow (gal/d)	*13.9*	*20.1*	17.0	+	+	B	N
Milk cows in County			17500	++	+	B	Y
Milk cows in basin			8750	+	+	B	Y
Dairy farms in basin			161	++	+	B	Y
Milk cows included			8000	+	+	B	Y
Dairy farms included			160	+	+	B	Y
Compost ratio manure:dry bulk			1 to 2	+	-	C	N
Infrequent turning, composting time (days)			180	+	-	C	Y
Frequent turning, composting time			60	+	-	C	Y
Passively aerated, composting time			70	+	-	C	N
Curing time compost			45	+	-	C	N
Storage time compost			90	+	-	C	Y
Turning frequency infreq. turning			3 times per cycle	+	-	C	Y
Turning frequency freq. turning			weekly	+	-	C	Y
Windrow measures infrequent turning			2.5x4.5x7.5	+	-	C	NA
Windrow measures frequent turning			1.3x3.0x2.6	+	-	C	NA
Windrow measures pass.aerated			1.2x3.0x2.5	+	-	C	NA
Curing pile measures			1.2x5.5x6.7	+	-	C	NA
Height storage area			2.4	+	-	C	NA
Volume reduction composting			50%	+	+	C	N
Market value land ($/acre)			1200	+	-	C	N
Market value land (1997$/ha)			3392	+	-	C	N
Tractor operating cost (1997$/hr)			34	+	+	C	N
Turning capacity tractor (m3/hr)			50	+	+	C	Y
Turning capacity rotated drum (m3/hr)			900	+	-	C	Y
Piling capacity tractor (m3/hr)			50	+	+	C	Y
Cost manure storage 135 days ($)			17066	+	+/-	C	N
Labour costs ($/hr)			10	+	+	C	N
Diversion costs ($/m)			0.61	+	-	C	N
Compost sales price ($/m3)	10	20	15	+	+	C	N?
CRF, 15y, 10% interest			0.1315	++	+	C	N
Use of CPI 1992			87.4	+	-	C	N
CPI 1993			90.0	++	-	C	N
CPI 1994			92.3	++	-	C	N
CPI 1995			95.0	++	-	C	N

Input variable	Lower value	Upper value	Most likely value	Precision	Sensitivity	Costs / effect. / both	Manageable (yes/no)
CPI 1996			97.8	++	-	C	N
CPI 1997			100.0	++	-	C	N
CPI 1998			101.6	++	-	C	N
Average bed-depth (m)			3	+	-	C	N
Average bed-width (m)			6	+	-	C	N
Average curing&storage-depth (m)			3.0	+	-	C	N
agitated bed composting time (days)			14	+	+	C	Y
agitated bed curing time (days)			45	+	-	C	Y
Storage time compost			90	+	-	C	Y
Handling capacity ag.bed (m3/d)	15.3	30.6	22.9	+	+	C	Y
Capital costs ag.bed ($)	114398	200196	157297	+	+	C	N
O&M cost ag.bed ($/cow.yr)	16.82	19.06	17.94	+	+	C	N
Front loader cap costs (1997$)			148717	+	+/-	C	N
Front loader op costs (97$/hr)			25	+	+/-	C	N
Front loader capacity (m3/hr)			172	+	+/-	C	Y
Life time of capital equipment (yrs)			15	+	+/-	C	Y
Manure density (kg/m3)			993	+	+	B	N
Capital costs digester 8000 cows($)			1077605	+	+	C	N
Capital costs digester 1600 cows($)			268954	+	+	C	N
Capital costs mix tank 8000 cows($)			55184	+	-	C	N
Capital costs mix tank 1600 cows($)			29581	+	-	C	N
Capital costs generator 8000 cows($)			1214335	+	+	C	N
Capital costs generator 1600 cows($)			292772	+	+	C	N
O&M costs digester 8000 cows($/yr)			134562	+	+/-	C	N
O&M costs digester 1600 cows ($/yr)			30491	+	+/-	C	N
Expected lifespan digester, mixer, generator (yrs)			15	+	+	C	Y
Electricity per cow (kW)			0.14	+	+	C	N
Generator on-line time (%)			*0.99*	+	-	C	N
Daily energy per cow day (kWh)			3.33	+	-	C	N
Electricity price ($/kWh)	0.025	0.09		+	+	C	N
Electricity benefits per cow ($/day)			0.083	+	+	C	N
Market price digested manure	1.6	4	2.600	+	+	C	N?
Market price raw manure	0.7	2.6	1.600	-	+	C	N?
Distance to markets (mile)	40	200	120	-	+	C	?
RTDT (hrs)	2.3	11.4	6.9	-	+	C	N
Truck capacity liquids (gal)			6000	++	+	C	Y
Capital costs ($/yr)			100323	+	+	C	N
Lifespan truck (yrs)			15	+	+	C	Y
Driver costs ($/hr)			20	+	+	C	N
Driver hours (hrs/day)			8	+	-	C	Y
Effective driving (of DH))			0.9	+	+	C	Y/N
Operational labor (relation to driver hrs)			1.2	+	+	C	Y/N
Fuel price ($/gal)			1.35	+	-	C	N
Fuel consumption (mpg)			5	+	-	C	N
Maintenance ($/mile)			0.43	+	+/-	C	Y/N
Average travel speed (mph)			35	+	+	C	N
Truck loading time			0.60	+/-	-	C	Y/N
Unloading time at plant			0.45	+/-	-	C	Y/N
Working schedule (8 hrs/d)			8	+	-	C	Y
Days per year manure is hauled (355)			260	+	-	C	Y
Trucking days per week			5	+	-	C	Y
Storage facilities ($)			2244	-	-	C	Y
Access roads (50% of farms)			710	-	-	C	Y

Input variable	Lower value	Upper value	Most likely value	Precision	Sensitivity	Costs / effect. / both	Manageable (yes/no)
Annual storage costs ($/yr)			465	-	-	C	Y
Basic machine storage size (ft)			54x75	+	-	C	N
Basic machine storage cost ($)			30300	+	-	C	N
Cover area (m2)			376	+	-	C	N
Area per truck (m2)			169	+	-	C	N
Lifespan storage etc.(yrs)			15	+	-	C	Y
Outside parking area ($/truck)			1311	+	-	C	N
Maintenance reserve truck			1 per 10	-	+/-	C	Y/N
Average RTD farm-plant (straight km)			8.6	+	+	C	Y/N
Ratio road/straight			2	+	+	C	N
Costs access roads (50% of farms; $/y)			710	-	-	C	N
Truck capacity compost (gal)			7272	++	+	C	Y
Capital costs trucks (1997$)			104717	+	+	C	N
Lifespan truck (yrs)			15	+	+	C	Y
Fuel consumption (mpg)			5	+	-	C	N
Nutrition management							
Forage analysis	15	35	25	+	-	C	Y/N
Concentrate analysis	15	35	25	+	-	C	Y/N
Milk sold	15	35	25	+	-	C	Y/N
Costs sample collection	20	40	30	-	-	C	N
Ration evaluation and reformulation	200	400	300	-	+	C	Y/N
TP red man (g/cow/d)	18	24	22	+	+	E	Y/N
TN red man (g/cow/d)	34	44	39	+	+	E	Y/N
Septic systems							
# systems Delaware Co.			10820	+	+	B	N
P-inflow (g/cap/d)	3	5		+	+	E	N
P-reduction (%)	30	95	80	+	+	E	Y
#People per system	2	4	3	-	+	B	N
Manure characteristics							
TP (g/kg)	0.9	1.1	1	+	+	E	Y
TN (g/kg)	4.5	5.6	5.1	+	+	E	Y
Density (kg/m3)			993	+	+	B	N
Prod.per cow (m3/y)			23.5	+	+	B	N
WWTPs	(Delhi)	(Stamford)					
avg flow (m3/d)	1590	1552		-	+	E	N
TP effluent (mg/l)	13	2		-	+	E	Y
TP after upgrade	0.2	0.2		++	+	E	Y/N
TP red (kg/y)	7428	1020		-	+	E	Y/N
Cap. costs Delhi (1,000$)	3500	7000	7000	+	+	C	Y/N
Cap. costs Hobart (1,000$)	750	1500	1500	-	+	C	Y/N
Cap. costs Stamford (1,000$)	3000	6000	6000	+	+	C	Y/N
Cap. costs Walton (1,000$)	6000	12000	12000	+	+	C	Y/N
#Farms (County)			686	+	+	B	Y
Total cropland Delaware (ha)			39126	+	+	B	Y
Capital costs BMPs ($)			68897	+	+	C	Y/N
Cap. costs septics ($)			10000	++	+	C	N

Explanation of the entries

Entries for precision:

++: very unlikely that actual figure is not contained in the considered range

+: actual figure probably contained in the considered range

-: actual figure could be outside the considered range

Entries for sensitivity:
+: change in value could have a big impact on final solutions
+/-: change in value could have some impact, but probably not too much
-: change in value will probably have little impact on final solutions

F.2. Model sensitivity for selected input variables

Some of the input variables in the above table have a minus assigned to them for precision and a plus for sensitivity. This means that these variables might have a different value than has been used for teh model calculations, and that this difference might affect the results of those calculations signifcantly. For these variables, model calculations have been repeated for different values. The results are shown in this section.

For each investigated variable, the new values for per unit costs are given if the variable affected the costs. If the variable affected the effectiveness, the new reductions and per unit costs have been shown. The new values sometimes resulted in differences for the costs or effectiveness of the optimal strategies. These differences have been calculated as percentages of the original strategy's values. If this difference is higher than 10%, the model is considered to be sensitive to that input variable. For these 'sensitive' variables, the results of the sensitivity analysis have been incorporated in Chapter 14.

Sensitive variables are shown in the gray areas

Agricultural waste management

Maintenance reserve truck
Used: +1 Now: +1 per 10 trucks

	Conf	Call	Csur	Dall	Dsur	T	New max costs	Difference	Changed preference
Scenario 1	-63.87	-273.3	-415.7	303.44	274.84	27.287	same	######	no
Scenario 2	159.68	1070.3	826.95	871.33	798.94	112.02	11703	0.4%	no
Scenario 3	38.149	563.91	320.51	576.86	504.47	66.981	9339	0.2%	no
Scenario 4	-63.87	-273.3	-415.7	303.44	274.84	27.287	same	######	no
Scenario 5	38.149	563.91	320.51	576.86	504.47	66.981	8336	0.2%	no

Price bulk material composting
Used: free Now: $2 per m3

	Conf	Call	Csur	Dall	Dsur	T	New max costs	Difference	Changed preference
Scenario 1	-40.27	-122.3	-294.9	303.44	274.84	27.287	5641	12.0%	no
Scenario 2	181.8	1211.9	908.1	862.2	789.8	110.6	same	######	no
Scenario 3	61.3	711.9	408.1	573.8	501.4	66.5	10079	8.1%	Cof<S<Wh
Scenario 4	-40.27	-122.3	-294.9	303.44	274.84	27.287	6644	10.0%	no
Scenario 5	61.3	711.9	408.1	573.8	501.4	66.5	9076	9.1%	Cof<Wh<S

Price bulk material composting
Used: free Now: $1.50 per m3

	Conf	Call	Csur	Dall	Dsur	T	New max costs	Difference	Changed preference
Scenario 1	-46.17	-160	-325.1	303.44	274.84	27.287	5490	9.0%	no
Scenario 2	175.9	1174.1	885.4	862.2	789.8	110.6	same	######	no
Scenario 3	55.4	674.1	385.4	573.8	501.4	66.5	9890	6.1%	Cof<S<Wh
Scenario 4	-46.17	-160	-325.1	303.44	274.84	27.287	6493	7.5%	no
Scenario 5	55.4	674.1	385.4	573.8	501.4	66.5	8887	6.8%	Cof<Wh<S

Distance to markets over roads
Used: 40-120-200 Now: x 1.5

	Conf	Call	Csur	Dall	Dsur	T	New max costs	Difference	Changed preference
Scenario 1	-46.31	-161	-303.3	393.06	364.47	41.216	5599	11.2%	no

Scenario 2	223.03	1475.8	1232.4	1195.3	1122.9	162.35	13313	14.2%	S>T
Scenario 3	76.493	565.91	809.31	772.43	700.04	97.37	10566	13.3%	Wh>S>Cof
Scenario 4	-46.31	-161	-303.3	393.06	364.47	41.276	6601	9.3%	no
Scenario 5	76.493	565.91	809.31	772.43	700.04	97.37	9563	14.9%	no

Lifespan of trucks

Used: 15y Now: 10 yrs

	Conf	Call	Csur	Dall	Dsur	T	New max costs	Difference	Changed preference
Scenario 1	-62.1	-250.9	-400.5	317.88	289.29	28.464	5113	1.5%	no
Scenario 2	162.3	1098.2	847.37	888.58	813.05	113.63	11754	0.8%	no
Scenario 3	40.447	589.64	338.85	593.28	517.75	68.468	9412	0.9%	no
Scenario 4	-62.1	-250.9	-400.5	317.88	289.29	28.464	6116	1.3%	no
Scenario 5	40.447	589.64	338.85	593.28	517.75	68.468	8410	1.1%	no

Costs access roads 'Change for Conf if sensitive parameter

Used: 50% of farms Now: 100% of farms

	Conf	Call	Csur	Dall	Dsur	T	New max costs	Difference	Changed preference
Scenario 1	**-63.87**	-261.6	-404.2	314.84	286.25	29.067	5094.5	1.1%	Cof>Cs>Ca
Scenario 2	**158.19**	1072.5	828.76	873.61	801.22	112.37	11714	0.5%	no
Scenario 3	**37.671**	**572.56**	**328.79**	**585.22**	**512.83**	**68.287**	same	**######**	**no**
Scenario 4	**-63.87**	-261.6	-404.2	314.84	286.25	29.067	6096.9	0.9%	Cof>Cs>Ca
Scenario 5	**37.671**	**572.56**	**328.79**	**585.22**	**512.83**	**68.287**	same	**######**	**no**

Costs access roads 'Change for Conf if sensitive parameter

Used: 50% of farms Now: 0% of farms

	Conf	Call	Csur	Dall	Dsur	T	New max costs	Difference	Changed preference
Scenario 1	**-63.87**	-284.7	-427.2	292.03	263.44	25.507	4980	-1.1%	no
Scenario 2	**158.19**	1049.5	805.87	850.81	778.42	108.81	11600	-0.5%	no
Scenario 3	**37.671**	**549.52**	**305.9**	**562.42**	**490.02**	**64.726**	same	**######**	**no**
Scenario 4	**-63.87**	-284.7	-427.2	292.03	263.44	25.507	6074	0.6%	no
Scenario 5	**37.671**	**549.52**	**305.9**	**562.42**	**490.02**	**64.726**	same	**######**	**no**

Most likely manure surplus

Used: 60% Now: 65% (scenario 3&5)

Scenario 3	Conf	Call	Csur	Dall	Dsur	T	New max costs	Difference	Changed preference
Unit costs	35.848	590.31	238.15	606.38	541.13	71.864	9265	-0.6%	no
Short P red.	33.5	214.4	214.4	214.4	214.4	33.5	10511	0.8%	
Long P red.	3793	24274	24274	24274	24274	3793	127876	7.9%	
Scenario 5	Conf	Call	Csurplus	Dall	Dsurplus	T			
Unit costs	35.848	590.31	238.15	606.38	541.13	71.864	8263	-0.7%	no
Short P red.	33.5	214.4	214.4	214.4	214.4	33.5	11573	0.7%	
Long P red.	3793	24274	24274	24274	24274	3793	132376	7.6%	

Septic systems

Short term P red septic systems´ rehabilitation

Used 25% of system leakage Now: 50% of system P leakage

	With waste management					With nutrition			
	Short P red per system	Or. max short P red (kg/y)	New max short P red (kg/y)	Difference	New preference	Or. max short P red (kg/y)	New max short P red (kg/y)	Difference	New preference
Scen 1	2.20	16053	18803	17.1%	S>Ww,s	15759	18509	17.4%	S>Ww,s
Scen 2	0.35	6809	7234	6.2%	S>T	6408	6833	6.6%	no
Scen 3	1.30	10431	11993	15.0%	S>Ww,s,h>Cof	10002	11564	15.6%	S>Ww,s,h
Scen 4	1.30	14991	16553	10.4%	S>Ww,s,h	14696	16259	10.6%	S>Ww,s,h
Scen 5	2.20	11493	14243	23.9%	S>Ww,s	11064	13814	24.9%	S>N>Ww,s

Short term P red septic systems´ rehabilitation

Used 25% of system leakage Now: 10% of system P leakage

	With waste management					With nutrition			
	Short P red per system	Or. max short P red (kg/y)	New max short P red (kg/y)	Difference	New preference	Or. max short P red (kg/y)	New max short P red (kg/y)	Difference	New preference
Scen 1	0.44	16053	14403	-10.3%	Wh>S	15759	14109	-10.5%	Wh>S
Scen 2	0.07	6809	6534	-4.0%	no	6408	6133	-4.3%	no
Scen 3	0.26	10431	9393	-9.9%	no	10002	8964	-10.4%	no
Scen 4	0.26	14991	13953	-6.9%	no	14696	13659	-7.1%	no
Scen 5	0.44	11493	9843	-14.4%	Cof>Wh>S	11064	9414	-14.9%	Wh>S

Appendix G: Additional reductions from agriculture

In the model estimates for agricultural alternatives, not all the farms, cattle and farmlands in the basin have been included. In the manure estimations for the model, only milk cows have been included because for this category accurate data were available. Including other cattle as well would lead to additional phosphorus load reductions. One very large dairy farm has been excluded from the model because it is large enough to implement its own measures. Only dairy farms have been included, while most BMPs can also result in phosphorus reductions on other farms. Including all agricultural sources in the model would lead to additional reductions. These additional reductions from agriculture are quantified in this appendix.

Only milk cows included

For manure estimations, only milk cows in basin are included, based on BRE 98 (17500 in Delaware Co.) Ag.Census 1992: 20706. Not included are beef cows, heifers and heifer calves, steers, bulls and steer&bull calves. Assumed that half of the cattle in Delaware is located in Cannonsville basin.

Cattle category	Number in Delaware
Beef cows	1865
Milk cows	20706
Heifer and heifer calves	14697
Steers, bulls, steer&bull calves	2020
Cattle and calves total	39288

Table G.1. Cattle inventory Delaware County, 1992
(source: Ag Census, 1992)

If the ratio between milk cows and the other cattle still is the same, then currently the toal cattle in Delaware is 33205, of which 15179 should be included in the Cannonsville basin study. Waste management is always combined with traditional BMPs and therefore the effect that is attributed to waste management is limited (Appendix E)

Including also the other cattle in the waste management activities gives a potential extra short-term phosphorus reduction as shown in the next table:

	Optimistic scenario		Pessimistic scenario		Most likely scenario	
	Addit. red	Total WM+BMP	Addit. red	Total WM+BMP	Addit. red	Total WM+BMP
100%	459	9483	761	2841	890	5354
90%	414	9438	685	2765	801	5265
75%	345	9369	571	2651	668	5132
50%	230	9254	381	2461	445	4909

Table G.2. Additional short term reductions waste management and BMPs if other cattle is included, assuming other cattle produces a certain percentage of the P as part of the manure of milk cows production.

Only area of dairy farms included

Area included in agricultural alternatives (BMPs) is 57 ha per farm: 9126 ha. The total area of agricultural lands is assumed to be half that of Delaware County, so can be estimated to 19563 ha in the basin. This land is not used for dairy farming, but probably it can also be used for implementation of BMPs, perhaps a little less efficient than for dairy lands. This would lead to a potential short-term phosphorus reduction of:

	Optimistic scenario		**Pessimistic scenario**		**Most likely scenario**	
	Current (dairy only)	**Extra non-dairy farms**	**Current (dairy only)**	**Extra non-dairy farms**	**Current (dairy only)**	**Extra non-dairy farms**
100%	8512	9736	1232	1409	3472	3971
90%	8512	8762	1232	1268	3472	3574
75%	8512	7302	1232	1057	3472	2978
50%	8512	4868	1232	705	3472	1986

Table G.3. Additional reductions if also non-dairy farms are included in estimations for BMPs on farms without nutrition management

One large dairy farm excluded

One of the larger dairy farms in the basin is excluded from the model. This is assumed to be a farm with 750 milk cows, so fifteen times as big as the average farms assumed in the model. Including this farm would result in additional short-term reductions as shown in the table:

	Optimistic scenario		**Pessimistic scenario**		**Most likely scenario**	
	Average red per farm	**Red. on largest farm**	**Average red per farm**	**Red. on largest farm**	**Average red per farm**	**Red. on largest farm**
B_{no-n}	53,2	798	7,7	115,5	21,7	325,5
B_{nutr}	41	615	6,2	93	16,4	246
$WM+B_{no-n}$	56,4	846	13	195	27,9	418,5
N_{no-wm}	0,2	3	4,3	64,5	8,8	132

Table G.4. Additional short-term TP reductions in kg/y if largest dairy farm is included in model.

Total possible additional P-reduction for agriculture

Combining the previous possibilities for additional reductions, results in the following additional reductions for the agricultural alternatives:

	Optimistic scen.		**Pessimistic scen.**		**Most likely scen.**	
	Add.red.	**Max red ag**	**Add.red.**	**Max red ag**	**Add.red.**	**Max red ag**
Waste man. all cattle + BMPs on all farms	10022	19046	2148	4228	4794	9258
Only BMPs on all farms	9560	*18072*	*1384*	*2616*	*3899*	*7371*
Nutrit. man. on dairy farms + BMPs all farms	8765	17495	1333	3012	3706	7741
Unknown: nutrition man. non-dairy farms	?	?	?	?	?	?

Table G.5. Additional short-term TP reductions in kg/y if all agricultural sources are included in model.

These additional reductions would mean that that target reductions could be met, but only in the most optimistic scenario for agriculture. For the other scenarios, a maximal reduction of the loads from farms together with the investigated non-agricultural alternatives, is not sufficient to meet the targets.