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Cost-benefit analysis for flood risk management and water governance in the Netherlands:

An overview of one century

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Korte samenvatting

Nederland heeft wereldwijd een grote reputatie op het gebied van waterveiligheid. Al meer dan een eeuw worden grote Nederlandse investeringsprojecten op het gebied van waterveiligheid ondersteund door een economische analyse van de kosten en baten voor de Nederlandse samenleving. Dit rapport geeft voor het eerst een overzicht van deze Nederlandse traditie. Belangrijke voorbeelden hiervan zijn de kosten-batenanalyse in het wetsvoorstel uit 1901 voor afsluiting van de Zuiderzee, de beroemde formule van Van Dantzig over de optimale hoogte van een dijk en de kosten-batenanalyses in het kader van 'Ruimte voor de Rivier' en het 'Deltaprogramma'.

Dit rapport besteedt niet alleen uitgebreid aandacht aan de ontwikkeling van de methode van analyse, maar ook aan de relatie met de politieke besluitvorming. Berekeningen laten zien dat het gebruik van kosten-batenanalyse voor waterveiligheidsprojecten de Nederlandse samenleving veel geld heeft bespaard en de veiligheid en welvaart heeft verhoogd.

Abstract

The Netherlands is a global reference for flood risk management. This reputation is based on a mix of world-class civil engineering projects and innovative concepts of water governance. For more than a century, cost-benefit analysis has been an important tool for both flood risk management as well as water governance in the Netherlands. It has helped to select the most effective and efficient flood risk projects and to coordinate and reconcile the interests of various policy areas, levels of government and private stakeholders.

For the first time, an overview of this well-developed practice is provided in this report. This overview includes the cost-benefit analysis in the 1901 act for enclosure of the Zuiderzee, Van Dantzig's famous formula for the economically optimal strength of dikes and a whole set of cost-benefit analyses for 'More room for rivers and the 'Delta Program' for the next century. Dutch practice illustrates how cost-benefit analysis can support and improve flood risk management and water governance; other countries may learn from this. Calculations indicate that investing in cost-benefit analysis has been highly profitable for the Dutch society.

Key-words: History of cost-benefit analysis in the Netherlands, management of natural resources, optimal strength of dikes, value of statistical life, biodiversity, Lely, Tinbergen, Van Dantzig, Eijgenraam, Zuiderzee Works, Delta Works, More room for rivers, Delta Program.

JEL-codes: A10, B00, C44, D61, H54, Q50

Contents

Summary and conclusions

The battle of the Dutch against water is famous. Two Dutch flood protection works, the Zuiderzee Works and the Delta Works, are considered to be world wonders of civil engineering. These huge public investments affected many different private and public stakeholders, like local inhabitants, farmers, fishermen, transport companies, cities, provinces, water boards and various Dutch Ministries. They also required massive amounts of public funding, about 6 or 7% of Dutch annual GDP at that time, and were a challenge for political decision-making. For more than a century, economic analysis facilitated and improved public decision-making on flood protection and water governance by making an ex-ante overview of a project's costs and benefits to the Dutch society.

This paper provides for the first time an overview of the evolution of this practice from a one-off cost-benefit analysis (CBA) to a regular analysis for flood risk management and water governance. Attention is paid to two issues: firstly, the role of CBA in flood risk management and water governance and secondly, innovation in terms of CBA-methods.

Role of CBA in flood risk management and water governance

Water governance refers to the management of flood risk and water resources and their interaction with political decision-making and society. Over time, water governance in the Netherlands has been changed substantially, e.g. towards more integral and adaptive water management. According to the OECD (2014), Dutch water governance is very efficient and innovative. What has been the role of cost-benefit analysis in this development?

At the end of the 19th century, cost-benefit analysis was for the first time used in Dutch flood risk management and water governance. A lobby-group by citizens and local government wanted to engage the central government in organizing and financing closing off the Zuiderzee and reclaiming major pieces of land. After having successfully tackled the enormous technical challenges of this project, public debate started about the economic and budgetary consequences. For example, would the extra expenditure of about 6% of Dutch GDP not lead to bankruptcy of the central government and would public benefits indeed be substantially more than the costs? Should there be compensation for damage to national defense, local harbours and fishermen? These worries and questions were addressed by drawing up an overview of costs and benefits of the project and by providing additional economic analyses. In the end, this lobby was successful, as Dutch parliament agreed on construction of the Zuiderzee Works 1918 and its construction actually started in 1927. The role of the cost-benefit analysis was acknowledged by a cost-benefit table in the draft Act on the Zuiderzee Works of 1901 (Lely, 1901).

Table 0.1 Highlights of one century of CBA's for Dutch flood risk management: conclusions and applications

Year	Topic of CBA	Size of investment mln euro	% GDP	Conclusion or application
1901	Enclosure of the Zuiderzee and land reclamation	43	6.3	Enclosure of the Zuiderzee and land reclamation is a good investment for Dutch society and should include compensation for fishermen.
1954	Delta Works for flood risk protection of the south-western part of the Netherlands (Tinbergen)	890	7.4	The Delta Works are cheaper and safer than raising dikes. The price (net costs) of 0.5 bln euro for the Delta Works for increasing safety does not seem too high and is equal to the material damage during the 1953 floods.
1956	Optimal strength of dikes formula (Van Dantzig)			Water safety is for the first time formulated mathematically as an economic optimization problem. Dikes should be raised until the benefits of the flood risk reduction in terms of less material damage and loss of life and other *imponderabilia* is equal to the additional costs of raising dikes.
1960	Optimal strength of dikes formula applied (Van Dantzig and Kriens)	68	0.4	Formula Van Dantzig applied to dike ring Central Holland and further analysis of the Delta Works. This study played a major role in setting the new safety standards for dike rings.
2000	Room for water (Stolwijk and Verrips)	235	0.1	More water safety not only by technical solutions like dikes, sluices and storm surge barriers, but also spatial solutions, like temporary water basins and making the rivers less straight.
2005	More room for rivers: Optimal strength of dikes (Eijgenraam)	2,215	0.5	Formula Van Dantzig improved by making it more dynamic, i.e. take account of economic growth. This approach was applied to all dikes in the Dutch river regions.
2011	Delta Program for next century: Optimal safety norms for Dutch dikes	10,438	1.8	Improved formula of Van Dantzig applied to all major dike rings in the Netherlands. Extensive set of new estimates of failure rates, economic damage and costs of heightening dikes rings. Detailed modelling of dike rings into parts. Conclusion: in the most urbanized areas it is efficient to raise safety standards before 2050. However, the recommendation by the second Delta commission to raise all current safety standards by a factor 10 is not efficient.
2011	Delta Program for next century: Renovating the Zuiderzee enclosure dam	1,390	0.2	Installing major pumps at the Zuiderzee enclosure dam may result in major safety benefits. The safety of the Zuiderzee enclosure dam has a major impact on the safety of dikes around the former Zuiderzee. This interaction was overlooked in previous analyses on the safety of Dutch dike rings.
2012	Delta Program for next century: Safety and fresh water in the Zuiderzee-region	1,098	0.2	In order to meet rising sea water levels, installing major pumps at the Zuiderzee enclosure dam will save billions of euro's as dikes around the former Zuiderzee need not to be raised substantially any more. Limited investments suffice to triple the fresh water stock in the former Zuiderzee-region in about a decade.
2014	Delta Program for next century: Optimal safety norms for dikes in the Zuiderzee-region			Installing major pumps at the Zuiderzee enclosure dam will indeed result in major safety benefits. In order to take account of the interaction between safety of the Zuiderzee enclosure dam and dikes surrounding the former Zuiderzee, six new types of failure are defined. The study results in new economically optimal safety norms for two barrier dams ('Afsluitdijk' and 'Houtribdijk') and all dikes around the former Zuiderzee.

In the 1950s, following the massive flooding of the southwestern part of the Netherlands, cost-benefit analysis became a tool for the central government to justify and help design their massive new flood protection plans, i.e. the Delta Works and the official safety norms for the strength of dikes. In line with Tinbergen's cost-benefit analysis (Tinbergen, 1954), it was decided to drastically increase safety in the southwestern part of the Netherlands by constructing the Delta Works. In line with Van Dantzig's optimal dike height analysis (Dantzig, 1956), safety norms for dikes were developed. These norms were much stricter in the most populous and economically most valuable areas, because the benefits of flood protection are much higher in these areas.

Since the 1970s, cost-benefit analysis became a more regular but still quite incidental tool for assessing public investments in the Netherlands. CBA was not only applied to waterworks but also to some other public investments, like railroads and the national airport. In the 1990s, public decision-making about a freight railway track from Rotterdam harbor to Germany became a topic of a national debate fueled by an enormous pile of contradictory economic reports. In order to remedy the procedure and the poor analytical quality of some reports, in 2000 national guidelines on cost-benefit analysis for transport infrastructure (Eijgenraam et al., 2000) were introduced. Cost-benefit analysis became obligatory for all public investments in infrastructure with costs over 0.5 bln euro. Cost-benefit analyses are now publicly available and their quality and compliance with the guidelines are checked by an independent economic expert institute (CPB). This was all laid down in a rule book for investments in public infrastructure mainly financed by the central government.

Cost-benefit analysis was also important in the flood protection program 'Room for water' in 2000 (Stolwijk and Verrips, 2000) and 'More room for rivers' in 2005 (Ebregt et al., 2005 and Eijgenraam, 2005 en 2006). 'Room for water' and 'More room for rivers' meant a paradigmatic change in Dutch flood risk management: not higher dikes and land reclamation but giving land back to the water and making rivers curlier as a way of flood protection. Not only was CBA used for the major investment of the More room for rivers-project, but also to consider and compare hundreds of supplementary small-scale local projects. In this way, CBA's were used to coordinate investments by central government, local government and private parties. As a consequence, in 'Room for water' and 'More room for rivers', CBA served as a tool for integrated water resources management in a much more decentralised political environment.

The governance approach of 'Room for water' and 'More room for rivers' was extended in the Delta Program for the next century with an Adaptive Delta Management philosophy (Alphen, 2015). In the various stages of decision-making, CBA's were used to calculate the effectiveness, robustness and flexibility of various national and local adaptation strategies and to design water management plans. The two major policy decisions in the Delta Program for the next century, the new safety norms for dikes, and the huge pumps at the Zuiderzee Enclosure dam to avoid raising the water level in the Lake IJssel, have been based on CBA's (Kind, 2011 and Bos et al., 2012).

Rough calculations indicate that investing in CBA has been a highly profitable investment for Dutch society. For example, recent economic analysis shows that it is efficient to increase flood protection standards in only three critical regions. In 2014, these results were accepted as a basis for policy by the Dutch government. This led to investment cost savings of 7.8 billion euro while reducing expected material damage and human casualties by two-thirds

(Eijgenraam et al., 2014). Similarly, the decision to install huge pumps at the Enclosure dam is expected to result in a net saving of about 1 billion euro (Bos et al., 2012).

According to OECD (2011), water policy in many countries is ineffective due to fragmentation of tasks between different parts of government and lack of technical and scientific capacity. Dutch experience illustrates that cost-benefit analysis can be a great help to overcome these common water governance problems and improve public decision-making.

The role of cost-benefit analysis in Dutch political decision-making fits very well in modern theories about government and economic growth. It can be regarded as a way to overcome common pool problems[1] (e.g. Ostrom, 1990 and 2005), as a reflection of inclusive institutions[2] (Acemoglu and Robinson, 2012), as a way to limit the influence of lobby groups (e.g. Olson, 1971 and 1982), as a procedure for accountable government (Fukuyama, 2011, in particular part IV) and as a way to cooperate between government, business and research institutes (the concept of the Triple Helix, see Etzkowitz and Leydesdorff, 1995).

CBA in Dutch flood risk management and water governance is not a purely technical tool of economic analysis. It serves as a tool for joint fact finding and reaching consensus on the 'best' solution. A typical large flood risk project involves many different types of governments, e.g. different Ministries, provinces, municipalities and water boards. Furthermore, many different private stakeholders are involved, e.g. local citizens and business affected and national and local tax payers.

Compiling CBA in the Netherlands is therefore part of an interactive exercise with many public and private stakeholders and a multi-disciplinary set of experts. This fits well into the Dutch style of political decision-making with trust in independent experts and consultation of stakeholders inside and outside the government (Bos and Teulings, 2013a). Key feature of the Dutch approach is that cost-benefit analysis serves as one of the inputs for public decision-making. As a consequence, its results do not mechanically translate into approval or rejection of a public investment.

Innovation in CBA-methods

In the first Dutch CBAs for flood risk management, benefits from extra safety were only addressed indirectly as a breakeven analysis. The costs and benefits in monetary terms were calculated and this was compared with the non-monetary benefits from additional safety and

[1] These are problems in exploiting resources whose size or characteristics make it costly but not impossible to exclude potential beneficiaries from obtaining benefits from its use. Unlike pure public goods, common pool resources face problems of congestion or overuse, because their use is rivalrous. Common pool problems can not only be resolved by a purely private solution by assigning individual property rights or by a purely collective solution by the government taking over the management, but also by management as a group with joined responsibilities. Water and water management in the Netherlands may be considered as 'commons' in more than one way (see Toonen et al., 2006). Commons consists of natural (water, fisheries, and nature areas) or cultural and man-made resources (dykes, polders, irrigation systems). Specific institutional arrangements, like water boards or a Delta program for next century, are needed to guarantee the durability and sustainability of the use of these resources.

[2] Institutions can be inclusive or extractive. Inclusive economic institutions, like property rights, patents or water boards, create the incentives and opportunities necessary to harness the energy, creativity and entrepreneurship in society and this leads in the long run to economic growth and welfare. Extractive economic institutions, like repressive dictatorship, do not.

Table 0.2 Highlights of one century of CBA's for Dutch flood risk management: benefits and uncertainty estimations

Year	Topic of CBA	Benefits Safety	Biodiversity	Other benefits	Uncertainty estimations
1901	Enclosure of the Zuiderzee and land reclamation	Monetary benefits and costs	No	Value of land reclamation, saving in costs for drainage	No
1954	Delta Works (Tinbergen)	Monetary benefits and costs	No	Value of land reclamation, benefits for agriculture due to less salination and dehydration, time saved in transport, new opportunities for leisure activities	No
1956	Optimal strength of dikes (Van Dantzig)	Expected savings of the value of material damage and loss of lives (static method)	No	No	No
2000	Room for water, 6 projects	Reduction of high water level in m^2	Yes, extra landscape with high quality of biodiversity in hectares	Extra landscape with spatial beauty per kilometer along the river, extra landscape attractive for leisure activities per kilometer along the river	No
2005	More room for rivers: Optimal strength of dikes (Eijgenraam)	Expected saving in the value of material damage and loss of lives, damage increases due to economic growth	No	No	No
2011	Delta Program for next century: Optimal safety norms for Dutch dikes	Expected saving in the value of material damage and loss of lives (extension of Eijgenraam method)	Compensating costs	No	Yes, extended Monte-Carlo analysis showing the sensitivity of the results for different assumptions and scenarios
2011	Delta Program for next century: Renovating the Zuiderzee enclosure dam	All alternatives should meet the same safety standards. Only additional safety benefits are expressed in monetary terms	Yes, different measures including compensating costs, legal standards and biodiversity points	Qualitative discussion of impact on fresh water supply, monuments, mobility, recreation and quality of landscape	Yes, sensitivity analysis showing the extra costs in case of a much faster rise in the sea level
2012	Delta Program for next century: Safety and fresh water in the Zuiderzee-region	Expected saving in the value of material damage and loss of lives minus any extra costs to avoid damage due to raising the water level in the Zuiderzee	Yes, different measures: legal standards, biodiversity points, costs of avoiding or compensating environmental deterioration	Extra fresh water in euro/m^3	Yes, sensitivity analysis with different scenarios for economic, demographic and climatic change
2014	Delta Program for next century: Optimal safety norms for dikes in the Zuiderzee-region	Expected saving in the value of material damage and loss of lives (dependencies between dikes are taken into account)	No	No	Yes, sensitivity analysis with different scenarios for economic, demographic and climatic change

any other non-monetized benefits. Environmental effects were completely ignored: they were not even mentioned qualitatively.

Since that time, major advances have been made in the quality and scope of economic analysis. Van Dantzig's formula for economically optimal strength of dikes was a breakthrough in 1956 and implied the introduction of a probabilistic approach. To assess the optimal safety level, the extra costs of heightening dikes were compared with its extra safety benefits. The benefits of extra safety were estimated as the expected value of the reduction in material damage multiplied by a pragmatic factor 2. The latter was motivated as a rough minimum estimate of the value of the loss of life, the personal and societal costs of chaos and shock, and the value of cultural assets damaged or lost. Valuation of loss of life on the basis of expected lifetime income and the expenditure by government to avoid loss of life due to car accidents. However, both were rejected as being clearly too low.

The approach to assess the economical optimal strength of dikes and flood protection has been extended and improved over the years, e.g. by making it dynamic (optimal safety levels are not fixed but should get tighter over time in line with economic growth), by incorporating interactions between the safety of different dikes and by making separate estimates of the value of loss of lives and casualties in case of flooding. The value of statistical life for flooding in the Netherlands is estimated to be 7 mln euro: twice the value of statistical life for Dutch road casualties (SWOV, 2014).

Starting from CBA Room for rivers in 2000, environmental effects were addressed in non-monetary terms by cost-effectiveness analyses and by developing a method for quantifying biodiversity. Later, also monetary estimates were added by estimating the costs required to prevent or compensate environmental damage. Willingness-to-pay or willingness-to-accept measures for biodiversity have not been used due to inherent uncertainty of these approaches. Uncertainty was captured by making sensitivity analyses on the basis of different long term scenarios for economic, demographic and climatic changes.

For a good assessment of costs and benefits of flood risk projects, a lot of non-economic knowledge is essential, e.g. about hydrology, the engineering of water constructions and the consequences for ecology. Over the years, major advances have been made in these areas and this knowledge and experience became a Dutch export product applied in Deltas all over the world.

Lessons for other countries

Other countries may learn in various ways from the Dutch history to use CBA for flood risk management and water governance. This can be summarized in five major lessons:

1. Cost-benefit analysis can improve flood risk management and water governance by helping to select the most effective and efficient flood risk projects and to coordinate and reconcile the interests of various policy areas, levels of government and private stakeholders.

2. CBA in flood risk management and water governance is not a purely technical tool of economic analysis. In the Netherlands, CBA serves as a tool for joint fact finding and reaching consensus on the ‘best’ solution.
3. Many different types of CBA’s make sense. They can range from simple quick-scans and back-of-the envelope-calculations to detailed and very sophisticated analyses. Simple quick-scans can be useful at an early strategic stage of a large project, but could also serve to select the best investment proposals out of a large number of small and local projects.
4. For calculating optimal water safety norms, various methods can be used which are all based upon the seminal formula of Van Dantzig.
5. Environmental effects should be assessed. Multiple approaches exist: by cost-effectiveness analysis, by quantifying the change in biodiversity and by monetary estimates.

1 Introduction[3]

"Thinking of Holland
I see broad rivers,
Slow and never ending,
Flowing through the lowlands,
...
And in all corners of the land,
Is apparent the voice of water,
With a constant loom of disaster,
Feared and heard by all."[4]

Two-thirds of the Netherlands is vulnerable to flooding. For centuries, major investments in water construction works, like dikes, dams, floodgates, canals and pumping stations, have been crucial to ensure safety, to reclaim land, to drain land, to reduce transport costs and to provide fresh water. All these investments allowed the Netherlands to become a rich and densely populated country.

Figure 1.1 Major parts of the Netherlands are vulnerable to flooding.

[3] An earlier draft of this paper was presented at the 5th Annual Conference of the Society for Benefit-Cost Analysis, Washington, February 21-22 2013. The authors would like to thank Carel Eijgenraam, Free Huizinga, Carl Koopmans, Ekko van Ierland, Thomas van der Pol, Jarl Kind, Koos Poot, Robert Slomp, André Wooning and Auke van der Woud for comments.

[4] H. Marsman's poem Herinnering aan Holland, translation by Max Birkin.

Thousand years ago, these investments in waterworks were mostly private and local initiatives, e.g. dikes by farmers and small water boards. Over time, the investments became more public, regional and national. Since the end of the nineteenth century, Dutch flood risk management has been supported by an economic analysis of costs and benefits to Dutch society. This paper discusses this Dutch cost-benefit practice and its importance for flood risk management and water governance in the Netherlands.

What is cost-benefit analysis of an investment project?

Public and private investments will always be based on an assessment of their expected costs and benefits. For private investments, only private costs and benefits and private discount rates are relevant. For public investments, all cost and benefits to society are relevant and a social discount rate should be used to obtain net present values. Strictly speaking, an informal overview of arguments pro and con of a public investment could already be regarded as a cost-benefit analysis[5]. However, in this paper an analysis is only regarded as cost-benefit analysis if it meets the following three requirements:

- The costs of investment and maintenance are assessed in monetary terms.
- Major other public costs and benefits are identified and described.
- Some major public benefits are also assessed in monetary terms.

Major early investment in Dutch water works without cost-benefit analysis

Several major investments in Dutch water works before the end of the nineteenth century meet some but not all of the requirements in this definition. Examples are:

- Investments in dikes by local water boards.
- Major public-private land reclamation projects like the Beemster and the Haarlemmermeer.
- Canals built by the autocratic King Willem I.
- Railway tracks and the channels for the harbours of Rotterdam and Amsterdam.

We will briefly discuss these investments in order to understand why cost-benefit analysis was not used for these investments but was only introduced much later.

For more than thousand years, local water boards have played a major role in constructing and maintaining dikes and reclaiming land in the Netherlands. Local water boards often started as a private cooperation by local farmers and other property owners threatened by flooding. They agreed that the benefits of constructing such dikes clearly surpassed its costs and made calculations of the costs in kind (number of hours work to be provided by the participants) and in cash. But they did not make any explicit calculations of the size of the benefits due to the reduction of flooding. Over time the private water boards developed into

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[5] A famous case in point is the bookkeeping approach to public decision-making by Benjamin Franklin, founding father of the USA (see Franklin, 1772). He advocates a pragmatic four step approach for public decision-making on any issue:

- make a balance sheet with one column of arguments pro and one column of arguments contra.
- attach weights to the various arguments;
- strike out where arguments on both sides cancel out;
- make a decision.

a separate type of Dutch local government with their own elections and taxes as a cost-sharing arrangement. They continued to construct and maintain dikes, made detailed calculations of their costs, but did not make any explicit calculations of the public benefits.

Major early land reclamation projects, like the Beemster (1607-1612) and the Haarlemmermeer (1849-1852; now the location of national airport Schiphol), did not only serve private interest but also public interest. The principal investors were a group of rich merchants. In order to convince the province of Holland they stressed several public benefits, like extra land for agriculture for the rapidly rising population, extra employment and extra safety for Amsterdam against flooding. The province of Holland agreed with their assessment of public benefits. It did not only give permission for these projects, but also supported them by giving subsidies. The province required the construction of alternative water discharge canals and bridges over these canals (see Ham, 2009, p. 28-29). However, despite the explicit discussion of public costs and benefits, no cost-benefit analysis meeting our four requirements could be traced.

Cost-benefit analysis was also absent during the reign of 'canal king' Willem I (1815-1848). He was an autocratic and unselfish ruler with hardly any countervailing power from the Parliament. He ordered the construction of roads and canals and granted cheap loans to industries like iron manufacturing, textiles and mining. However, his decision-making on roads and canals was ad hoc, intuitive and without any systematic analysis of short comings of the current infrastructure and without any solid financial analysis of costs and expected benefits (see Filarski, 1995). According to Van der Woud (1992), his purpose was not to serve the public interest by reducing transport cost for Dutch society, but to create a personal source of income by combining the new roads and channels with many new tollhouses.

In 1848, the King abdicated and the constitution was changed, which resulted in much more power and information for Parliament. The budget became annual, complete, much more detailed and much better audited (see Bos, 2008). This arrival of democracy in mid-nineteenth century implied that cost-benefit analyses could in principle be used for public debate and decision-making. However, major investments in railway tracks (first railway act of 1859) and channels connecting the harbours of Rotterdam and Amsterdam with the Northsea (Nieuwe Waterweg en Noordzeekanaal, act of 1863) were not supported by such analysis[6]. These investments were considered to be risky, but also urgently needed to catch up with the harbours of Antwerp and Hamburg and to cope with major new developments, like steamships[7].

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[6] Since the end of the nineteenth century, investments by the city of Rotterdam in extending its harbour often raised public debate. In 1907, the city council asked a commission to conduct a cost-benefit analysis taking into account all benefits for the city of Rotterdam and its citizens, like more traffic by ship, more employment, more profit and extra taxes and harbour fees. This excludes toll fees because these were forbidden by European agreements since 1831 on free transport over European rivers, like the Rhine. After three years the commission provided a report containing only an overview over the period 1906-1908 of public investments in the harbour and a rough guess of its consequences for capital consumption, interest payments and some harbour fees. The commission stressed the limitations of its analysis and the impossibility to properly estimate all indirect costs and benefits. After substantial and long debates, the city council decided to keep the report confidential (see Laar, 1999).
[7] See Ven (2008).

All these examples refer to major public investments. In most cases there was also public debate about the need and financing of the investment. Furthermore, financial literacy and analytical skills in the Netherlands were well developed, in particular since the seventeenth century. But these requirements did not suffice to support public decision-making with a cost-benefit analysis.

Outline of the paper

In the Netherlands, the introduction of cost-benefit analysis is closely linked to four huge and innovative investments in water construction:

- Closing off the Zuiderzee with an enclosure dam to protect Amsterdam and the northern part of the Netherlands and to reclaim land for agriculture.
- The Delta Works to protect the south-western part of the Netherlands.
- The investment plans to ensure safety along the Dutch rivers.
- The new 'Delta Program' to ensure safety and fresh water supply for next decades and next century.

The linkage between these investments and the birth of cost-benefit analysis in the Netherlands is not surprising. This reflects that cost-benefit analysis is in particular suited for helping political decision-making on large scale and risky investments with a substantial claim on public resources and many stakeholders. The first two investments even cost about 5% GDP. In such circumstances, it is wise to make more sophisticated, detailed, time-consuming and expensive cost-benefit analyses and to recruit the best experts on the various topics.

The first instance of cost-benefit analysis in the Netherlands was the cost-benefit table in the draft law of 1901 proposing to close off the Zuiderzee. This is discussed in section 2.

Following the disastrous flooding of the south-western part of the Netherlands in 1953, Tinbergen and Van Dantzig made analyses how to increase safety. On behalf of the first Delta commission, Tinbergen, director of CPB Netherlands Bureau for Economic Policy Analysis, made a cost-benefit analysis of the Delta Works, i.e. a series of construction works to protect south-western Netherlands from flooding (Tinbergen, 1954). Van Dantzig, a professor in mathematics, developed a formula for economically optimal failure rates for dikes and levees (Van Dantzig, 1956). Their analyses are the topic of section 3.

National guidelines on cost-benefit analysis of major public investments in infrastructure were introduced in 2000 (Eijgenraam et al., 2000). Following a near flooding situation and a large scale evacuation in the Dutch river-regions in 1995, an extensive set of policy measures to increase safety was proposed and evaluated by cost-benefit analysis in 2000 and 2005. To this end, Van Dantzig's formula was extended by Eijgenraam to consider also the optimal timing of investments (Eijgenraam, 2005 and 2006). These national guidelines, the extended formula and the cost-benefit analyses of the many specific proposals for improving safety along the river are discussed in section 4.

Following a report by the Second Delta Commission in 2008 (Deltacommissie, 2008), a new 'Delta Program' was initiated to investigate the best strategies to ensure safety and fresh water supply for next decades and next century. As part of this program, several CBA's were conducted and this has led to new water safety standards. These CBA's for the 'Delta Program' are discussed in section 5.

Added value of this paper

This paper contributes in various ways to the existing literature on cost-benefit analysis, flood risk-management and water governance:

- It provides, for the first time, an overview of the well-developed practice of cost-benefit analysis for flood risk management and water governance in the Netherlands;
- It discusses the role of cost-benefit analysis and the Zuiderzee Works; this cost-benefit analysis of more than a century old was thus far not known, not even to experts in Dutch water governance[8] and economic history[9].
- It provides, for the first time, an overview of the evolution of cost-benefit analysis in the Netherlands, not only for flood risk investment but also for other public investment (see annex 1).
- It stresses the important role CBA could play in water governance. This importance is often overlooked in discussions and overviews on water governance, like those of the OECD (see OECD, 2011 and 2014).

[8] For example, the report by the Second Delta commission (2008) states that "Lely only looked at the direct financial costs and benefits and was therefore not aware that the benefits of Zuiderzee enclosure dam would surpass the direct costs" (textbox, p. 80, based on Thijsse, 1972 and Geest et al., 2008). Also: "Critics of cost-benefit analysis stress the importance of vision instead of economic bookkeeping. They argue that major political decisions should not only be based on an overview of costs and benefits in monetary terms. Major investment projects like the Zuiderzee enclosure dam … would have never been made when a cost-benefit analysis would have been decisive" (p. 74, translated). The overview of cost-benefit analysis and flood control in the Netherlands by Brouwer and Kind (2005) starts with the analysis by Tinbergen of the Delta Works and do not mention the work by Van Dantzig and the analysis in the 1901 act for enclosure of the Zuiderzee.

[9] For example, this role was entirely absent in specialized Dutch water works histories, like Ven (2004) and Ham (2007 and 2009), and in the major historic overviews of Dutch economic and spatial development (e.g. Zanden and Riel,2000 and Woud, 1987; history professor Van der Woud confirmed by email that he did not know that such a cost-benefit analysis existed).

2 CBA for closing off the Zuiderzee (1901)[10]

The Zuiderzee (Southern Sea) was a lake transformed in a sea by a series of heavy storms in the thirteenth century. The Saint-Lucia flooding of 1287 completed this transformation: giant pieces of land were swallowed by the sea, dozens of villages were completely destroyed, 50 thousand people were killed and the region Friesland was split into two parts separated by the Zuiderzee. Since that time, small floodings became a regular phenomenon and now and then major floodings occurred, causing many victims and huge damage to the economy and houses.

Figure 2.1 Zuiderzee enclosure dam: Due to the 33 km long enclosure dam (Afsluitdijk) the former Zuiderzee was transformed into a lake (IJsselmeer and Markermeer); in addition, major parts of land were reclaimed from the sea. The reclaimed land became a new province and its capital became Lelystad, an entirely new city named after Lely, the engineer and Minister responsible for the Zuiderzee Works.

First plans to increase safety by closing off the Zuiderzee were made in the seventeenth century. Hendric Stevin proposed to close off the Zuiderzee by connecting the Frisian islands with dams and sluices and to improve shipping by connecting Amsterdam with a channel to the North Sea. However, at that time, technical skills were not at all sufficient for such a challenging project.

[10] Major references for this section are: Ven (2004), Ham (2007), Ham (2009) and Lely (1901).

In mid-nineteenth century, after some successful major land reclaiming projects, technical skills had been drastically improved. For example, the introduction of steam pumping made it possible to increase pumping capacity drastically and to pump also in the absence of wind. As a consequence, new designs for closing off the Zuiderzee, generally combined with proposals for reclaiming land, became common.

In the absence of any initiative by the Dutch central government, a society for studying and promoting closing off the Zuiderzee ('de Zuiderzeevereniging') was founded in 1886. For the technical expertise, the young engineer Lely was recruited. In five years, he succeeded to make a sound plan for closing off the Zuiderzee and reclaim land for making four new polders. This plan Lely of 1891 was based on systematically considering the various options for closing off the Zuiderzee, a limited set of data and a lot of new research on many topics, e.g. the depth and hydrodynamics in the Zuiderzee, the quality of the soil and the saltiness of the seawater. Also, an overview of costs and benefits was provided and several negative consequences of the project were explicitly discussed, e.g. for fishermen.

In comparison to major previous projects in the Netherlands, the Zuiderzee project was of an entirely different magnitude and complexity. This is illustrated by looking only at the size of land reclamation. The reclamation of land in de Beemster in 1612 was about 7 thousand ha and that of the Haarlemmermeer in 1852 18 thousand ha, while in the first proposals by Lely 232 thousand ha were to be reclaimed, i.e. more than ten times as much as any project of land reclamation before (Ham, 2009).

Lely's plan was well received. The basic idea was accepted by the central government and a Royal Commission was installed for critical examination. It only proposed some marginal changes. This was not very surprising, as Lely served as chairman of the Royal Commission and had become minister of Waterways, Trade and Commerce. Nevertheless, nothing was decided, as the central government was divided about the net benefits of this huge investment and the cabinet fell shortly after.

After a period of seven years, Lely returned as minister and immediately put his proposal in a draft law. In order to limit the financial risks for the central government, the size of land reclamation was drastically reduced. This draft law contains an elaborate motivation, including a discussion of costs and benefits of the project (Lely, 1901)[11].

The cost-benefit analysis in Lely's draft law of 1901 is summarized in table 2.1. The table shows that the costs for closing off the Zuiderzee were estimated to be 27 mln euro, of which half of the costs pertained to the enclosure dam. These costs include also the payment of compensation to fishermen for their loss of income and capital. The costs of land reclamation

[11] A major input for this law was also the study by van der Houven van Oordt and Vissering on the economic importance of the Zuiderzee (1898). Vissering was president of the Dutch central bank and chairman of the Zuiderzee association. They discussed various options how to organize the distribution of reclaimed land and the impact on the local economies along the coast of the Zuiderzee. As part of modern social liberal policy, they argued that fishermen were entitled for compensation. However, they also stressed that many villages along the Zuiderzee coast were 'dead villages', as poverty was widespread, houses badly maintained and the major source of income were very marginal revenues from fishing and fishing was a dangerous job. The land reclamation would provide many new opportunities for the people in these villages.

were estimated to be 17 mln euro. The total costs of 44 mln euro correspond to about 5% of Dutch national income in 1901 and about two-third of the budget of the central government. This illustrates the size and financial risks of this project for the Dutch central government.

Table 2.1 Overview of costs and benefits of closing off the Zuiderzee and land reclamation according to Lely's draft law of 1901 (mln euro, price-levels of 1901).

Costs				Benefits	
Costs for closing off	27			Benefits directly linked to closing off	
Costs for constructing 33 km enclosure dam		14		Saving in costs for drainage	10
Other costs directly linked to closing off		13		Saving in costs of maintenance of dikes more than costs of maintenance of enclosure dam	
Adjustments for the isle Wieringen			4.0	Extra safety	
New channels and adjustment of dikes			2.7	Extra fresh water for Northern provinces	
Adjustment of harbours			0.3	Extra shipping	
Compensation for fishermen			2.1	Benefit of traffic over enclosure dam	
Compensation for national defence reasons			4.0		
Compensation for Amsterdam's fresh water supply			0.1	Saving in future costs of land reclamation	30
Costs of land reclamation of two polders	17				
Annual burden of costs of reclamation	0.8			Annual rent of reclaimed land	1.3
Annual surplus from land reclamation	0.5				
P.M. Risk of malaria, but that can be contained by various policy measures					

The argument in favor of the project was based on two lines of reasoning. First, reclamation of two polders was considered to be a very profitable investment, resulting in an annual surplus of 0.5 million euro per year. Secondly, the closing off costs were substantial (27 million euro), but were offset by major savings. Two were explicitly calculated: the savings in terms of less drainage (10 million euro) and saving in future costs of land reclamation (30 million euro)[12]. In addition, there were savings, like extra safety (= less damage), extra fresh water supply for the Northern provinces, extra shipping and extra traffic over the enclosure dam.

Also this second effort of Lely as minister to realize his plan failed, as the cabinet fell and his successor had different ideas and priorities. In 1913, Lely became minister for the third time and in 1918 his law for closing off the Zuiderzee was approved by the Dutch parliament. This approval was not only due to the merits of the plan and the persistence of Lely. The storm surge of 1916 caused 51 victims and a lot of damage. This gave the government the urge to execute the difficult and expensive works for greater safety. Another new reason was the First World War and the rapidly growing population: this showed that it was important to be able to feed your own population.

[12] Land reclamation as such is cheaper with an enclosed Zuiderzee, because with an open Zuiderzee dikes need to be much higher and stronger and need more repairs. Limiting the project to only enclosure of the Zuiderzee and without any land reclamation would probably be suboptimal, as it would ignore the substantial net benefits of land reclamation.

Even after the official approval of the project, controversies remained and public debate continued. A former minister of Finance, van Gijn, caused a turbulent round of public debate in 1920. In a newspaper article, he claimed that the project would yield a loss of 400 million euro. This turned out to be based on assuming a relatively high rate of interest on government debt for those days (7 percent)[13].

Another issue was whether enough suitable clay would be available for the construction of the enclosure dam. This dispute was settled in 1921 by the discovery of boulder clay at the start of the first work of the Zuiderzee project. This glacial clay turned out to be very suitable for dike construction and was found in huge quantities.

There were also heated discussions about the extent to which closing off the Zuiderzee would cause a rise in the storm tide levels along the coasts of Friesland and North-Holland and lead to extra flooding risks. According to Lely, such risks would be very limited and would only occur in a small part of Friesland. A Royal Commission was installed to investigate this issue. It was headed by the famous physicist Lorentz; for him this was a totally new topic, which took him eight years of thorough and intense study.[14]

A major challenge was to reconcile the insights of meteorologists about the impact of wind on water waves above deep oceans with the insights of hydrologists about the impact of the resistance of the bottom of canals and rivers on tidal waves. Lorentz's solution was to split the problem into two parts: studying the impact of the dike on normal tidal waves and then studying the impact of incidental, irregular, storm surges. His theoretical analysis was calibrated and tested using new data on tidal waves, currents and wind set up in the Zuiderzee region and similar situations abroad, e.g. the Gulf of Suez and the channel of Bristol. The calculations were conducted by a large team of engineers. Also, all kind of scale models were used to decide on the details of the enclosure dam, e.g. what should be the capacity of the sluices and what is the best surface?

The Commission confirmed to a great extent Lely's assumption that the extra flooding risk was limited and confined to Friesland. The commission provided a concrete advice about how much and where the Frisian dikes were to be raised to keep water safety unchanged after closing off the Zuiderzee. They also suggested to move the enclosure dam a bit upwards, as according to the original plans the length of the area would be close to a quarter of the length of waves, which is the ideal length for resonance and would therefore lead to much larger tidal waves.

The Zuiderzee Works were completed in 1932, still mainly in line with Lely's plan of 1891. As a consequence, the Zuiderzee was split by the enclosure dam resulting in a large fresh water lake in the midst of the Netherlands, the IJsselmeer (Lake IJssel). This enclosure dam

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[13] All seemed to agree that the interest rate on government debt was the proper discount rate.

[14] At Lorentz' funeral, Einstein complained that this may have been a good service for Dutch society, but that it was a bad service for the advancement of physics, see Kox (2007). On Lorentz' work for the Zuiderzee Commission, see also Vreugdenhil, Alberts and van Gelder (2001).

separates this lake from the Waddenzee, the isles in the north of the Netherlands and the North sea.

The work by Lorentz' commission initiated hydraulic laboratory research in the Netherlands, which became famous all over the world. This new hydraulic engineering knowledge proved also to be very useful for constructing the Delta Works. The hydrological research and consultancy institute Deltares originated from this.

3 Tinbergen, Van Dantzig and the Delta commission

3.1 Introduction

In 1953, a combination of high spring tide and severe windstorm over the North Sea caused a major storm surge. In some locations, this pushed up the water level by 6 meters above mean sea level. The flood and waves overwhelmed Dutch dikes and caused extensive flooding in the south eastern part of the Netherlands[15] (about 1400 km2 of land, see figure 3.1). The death toll was 1,836 and 70,000 people had to be evacuated, whereas material damage was estimated to be 5% of Dutch national income; this mainly refers to damaged assets, like dwellings, farms, roads, dikes and cattle. In addition, there was a limited loss of agricultural production. Due to the Zuiderzee Works, major damage in the northern part of the Netherlands was avoided.

Figure 3.1 Extent of flooding during the North Sea Flood of 1953.

The death toll and damage could easily have been much larger. Only a heroic act of a shipper, who succeeded to maneuver his ship full of rubbish into a dike in the lowest and most densely populated part of the Netherlands, avoided that major cities like Rotterdam, Delft,

[15] The North Sea flood of 1953 was also one of the most devastating natural disasters ever recorded in the United Kingdom (UK). In the UK, over 1,600 km of coastline was damaged, and sea walls were breached, inundating 1,000 km². Flooding forced 30,000 people to be evacuated from their homes, and 24,000 properties were seriously damaged.

Gouda and The Hague were flooded and that the life of about 3 million people was endangered.

The risk of such a calamity was well-known in the Netherlands. One of the major engineers of the Dutch government, Johan van Veen, had warned that dikes in the south eastern part of the Netherlands were too low and not well maintained. Since the 1930s, this Dutch "doctor Cassandra" and his team had developed plans to shorten the coast by closing off all the river mouths and sea inlets by a number of dams. However, the scale of the project, the intervention of the Second World War and political priorities for reconstructing the economy afterwards, made that nothing happened.

This all changed after the North Sea Flood of 1953. A Delta Commission was installed to investigate the measures to be taken. The Delta Works could not be completed immediately and simultaneously. Priority was therefore given to the most urgent safety risks. The preferred sequence of investment was first small than big and, similarly first simple solutions than complex solutions. Within a year, the first new water construction work was under construction: new sluices and a storm surge barrier at the Hollandse IJssel; this is a region 7 meter below sea level and at the lowest point of Europe, near to Rotterdam and very important for shipping. This first urgent work was completed in 1958. The last part of the Delta Works was completed in 1997: the ingenious flexible storm surge barrier Maeslantkering, with doors larger than the Eiffel tower. It was the result of a prize contest organized by the Dutch government and it protects the harbour of Rotterdam without obstructing shipping traffic.

3.2 Tinbergen's CBA of the Delta Works (1954)

As part of the activities of the Delta commission, Tinbergen made a cost-benefit analysis of the Delta Works (Tinbergen, 1954, see table 3.1). In fact, he focused on comparing two alternatives: raising and strengthening dikes all along the waterways versus Delta Works including the construction of barrier dams. Shortening the coastline by blocking the estuary mouths of the Oosterschelde, the Haringvliet and the Grevelingen would reduce the length of the dikes exposed to the sea by 700 kilometers. As a consequence, much fewer dikes would have to be reinforced. Like the analysis in Lely's draft law of 1901, the analysis of costs and benefits was broken down into those directly linked to increasing safety and supplementary costs and benefits. Looking only at the direct costs and benefits, raising dikes seemed to be the cheapest alternative. However, by taking into account the various other costs and benefits, the Delta Works turned out to be the cheapest alternative. Furthermore, the Delta Works were considered to be superior in terms of extra safety.

The importance of several supplementary benefits were quantified in monetary terms, e.g. benefits due to saving in travelling and transportation cost, benefits for fishing, benefits for agriculture due to reduction of salination and extra fresh water and new opportunities for leisure activities. In addition, several other supplementary benefits were briefly mentioned but not quantified, e.g. stimulus for hydraulic and engineering science, stimulus for exporting such hydraulic and engineering knowledge, spreading of industrial activities over a larger area in order to relieve the crowded Rotterdam area, unlocking the economy of some isolated islands and a boost for national pride. But also a major issue was totally ignored: closing off the estuary mouths by barrier dams would turn tidal salt water areas into fresh water lakes like the IJsselmeer. This had major environmental consequences.

Table 3.1 Tinbergen's cost-benefit analysis of the Delta Works (mln euro, price level of 1954; original figures in Dutch guilders translated into euros by the standard conversion rate in 2002, i.e. 2.2; Tinbergen, 1954).

Costs			Benefits		
	Raising dikes Mln euro	Delta-works		Raising dikes	Delta-works
A. Costs for increasing safety	720	820	A. Benefits directly linked to the costs of increasing safety	730	820
- Construction costs	680	750	- A.1 Saving in costs of maintenance	10	40
- Other costs, e.g. loss of salt water fishing	40	70	- A.2 Residual: Costs for extra safety and other benefits	720	780
B.1 Costs not related to increasing safety	15	70	B. Supplementary benefits	25	200
B.2. Net supplementary benefits (residual)	10	130	- Reclamation of land	10	60
			- Time saved in transport	10	60
			- Reduction of salination reduces damage to vegetables and fruit	0	70
			- Benefits for fresh water fishing and public utilities	5	20
C. Total costs	735	890	C.1 Total benefits solidly quantified (=A.1 + B.2)	35	240
			C.2 Net benefits for agriculture from less dehydration (tentative estimate)	0	90
			C.3 Net benefits from new opportunities for leisure activities (tentative estimate)		45
			C.4 Residual: Net costs for extra safety and other non-quantified benefits	700	515
P.M. Net material damage North Sea Flood 1953: 500					

Tinbergen not only compared two alternatives to increase safety, i.e. Delta Works versus raising dikes. He also discussed whether such investments would be superior to not increasing safety at all. He concluded: "The net costs .... represent the price the Dutch nation will have to pay for the improvement of the security of life and property in the Delta area and for such imponderable assets as obtaining more space for the overcrowded Rotterdam area and a world-wide shop window of Dutch know-how in civil engineering. The net costs … involved are equal to the material damage of the 1953 floods. So if after completion of the works only one disaster of a similar extent is prevented in the near future, they will have already fully paid their way. As nobody knows when the next floods will strike, this possibility must be taken into heavy account."

Ex post evaluation

Half a century later, to commemorate the Delta Works, an ex post evaluation was made of Tinbergen's ex ante analysis (see Don and Stolwijk, 2003). According to this study, both costs and benefits had been underestimated.

Costs turned out to be much larger than estimated by Tinbergen: about 5 billion euro instead of 1 billion euro[16]. By far the major reason[17] for this was that the Delta Works were drastically redesigned after intense public debate. In order to protect the unique salt water environment and to help fishing industry, the Eastern Schelde would not be fully closed by a dam. Instead, an open barrier was built, containing a number of sluices that are only closed during heavy storms and high water levels. This increase in costs reflects a change in environmental preferences in Dutch society. With the benefit of hindsight, three alternatives should have been compared in Tinbergen's cost-benefit analysis:

- Raising and strengthening dikes all along the waterways;
- Delta Works with closed barrier dams;
- Delta Works with an open barrier for the Eastern Schelde.

Furthermore, the major environmental costs of closed barrier dams should have been included in the analysis.

Also, some benefits were underestimated. The Delta Works, including the improved transport links, helped the province of Zeeland to benefit from economic developments in Rotterdam and Antwerp.

Another issue[18] is prevented damage and economic growth; this issue was not raised in the ex post evaluation study[19]. Tinbergen argued that when a disaster of a similar extent could be prevented in the near future, the discounted value of this damage is close to its current estimate. He assumed that future economic growth was substantially smaller (between 1.5 and 2.5 per cent per year) than the real interest rate (between 3.5 and 4.5 per cent per year)[20]. However, Dutch economic growth in the period 1950-1980 was 4% per year.[21] This implies that expected economic damage also grows with 4% per year. Discounting with a

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16 This excludes the costs of the Maeslant-kering. Mid 1980s, it became clear that the dikes in the Nieuwe Waterweg (the channel serving as the major entrance to Rotterdam harbour) did not provide sufficient safety for the very densely populated region of Rotterdam. Raising the dikes further would have been very expensive. Alternative solutions were therefore sought. The problem was that shipping traffic to and from Rotterdam harbour should not be obstructed. An award was granted by the government for the best and cheapest solution. This resulted in the ingenious flexible storm surge barrier Maeslant-kering.
17 Another reason for higher costs was a rise in wage rates not anticipated by Tinbergen.
18 Another issue not discussed in the ex post evaluation study were the benefits from exporting the new hydraulic and engineering knowledge. This was mentioned by Tinbergen as one of the possible benefits. The expensive but innovative shift towards Delta Works with an open barrier for the Eastern Schelde and the ingenious flexible storm surge barrier Maeslantkering turned out to be very suitable investments for exporting such knowledge. For example, similar flexible storm surge barriers are now also constructed near London, New Orleans and Sint-Petersburg and other areas, like Venice, are now also considering this.
19 This argument is in Drees and Gubbi (1968, pp. 170-171) and not in Don and Stolwijk (2003).
20 See Tinbergen (1954, p. 73, note 1) and Van Dantzig (1956), p. 281).
21 This is the result of 1% population growth and 3% productivity growth; employment growth per capita slightly declined (see Bos, 2006).

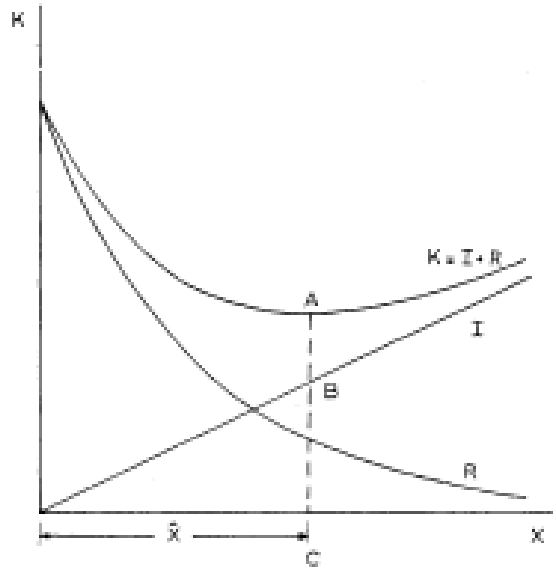
somewhat similar real interest rate implies that also in the longer run the discounted value of expected future damage is close to the current estimate of damage. So, even when the disaster of a similar extent would have occurred for the first time in a much more distant future, an investment in extra safety by amount of the current estimate of damage would have been attractive.

3.3 Van Dantzig's formula for optimal strength of dikes (1956)

From observed maximum flood levels to probabilistic thinking

For centuries, engineers were used to build dikes to such a height that they were safe against the highest flood observed at that place. However, in 1939 the Dutch engineer Wemelsfelder introduced probabilistic thinking for determining limits for the height of a flood (Wemelsfelder, 1939)[22]. He estimated statistically the cumulative distribution of sea level heights and to every height there belongs a positive exceedance probability. If the height is very large, the exceedance probability becomes very small, but in theory there will always be a risk that flooding occurs. Wemelsfelder found that the annual exceedance frequencies during high tide at Hoek van Holland during the period 1888-1937 followed very closely a straight line when plotted on logarithmic paper. In another paper, he found that in the estuary mouths the situation is different.

Figure 3.2 Minimizing total costs (K) from raising a dike (I) and expected economic damage (R) (figure 3.1.3 in Dantzig and Kriens, 1961).



From probabilistic thinking to an economic decision problem

As part of the work of the Delta Commission, the mathematician Van Dantzig (see Van Dantzig, 1956) formulated the problem of water safety in mathematical terms as an economic decision problem about finding the optimal water safety level. This optimum was

[22] The old method was to design the height of dikes on the basis of the highest recorded water level plus some margin of safety. Wemelsfelder refused to accept that the highest recorded water level was the highest possible water level. On the basis of a very long time frame, spanning 10,000 years, he estimated the statistical probability of various high water levels. He concluded that there was a reasonable chance that the highest recorded water level would be surpassed within a century.

determined by comparing the extra costs of raising dike heights with the benefits from the reduction in expected damage due to raising dike heights[23]. As long as the extra costs are smaller than the concomitant benefits, it is profitable to continue raising the dikes. This could also be expressed as looking for the minimum of the sum of the costs for raising dike heights and the expected damage (see figure 3.2).

What is the value of loss of human life and other imponderabilia?

Van Dantzig argued that for determining the optimal strength of dikes not only material damage should be taken into account. Also losses of human lives should be incorporated, but the problem is how this should be done: what should be the value attached to saving a human life? Van Dantzig and Kriens (1961) first discussed three approaches:

- Net life time income lost due to loss of life.
- Expenditure by the government to reduce the loss of life.
- Insured value of the life of high ranked civil servants.

Net life time income is the income earned during a life time minus the goods and services consumed. Looking at the figures in a study on car accidents by Reynolds (1956), it was concluded that that net life time income lost would give quite different valuations to the lives lost of different persons. E.g. it would be even substantially negative for elderly people and nearly all women. The highest amount would be for a man between 15-20 years: 71 thousand euro; for women of the similar age group it would be 6 thousand euro. The average figure for all lives lost (due to a car accident) was 14 thousand euro. [24]

The second measure for human life was hidden in the expenditure by the government, e.g. the costs of abolition of unguarded railway crossings, the prevention of factory incidents and the prevention of road traffic accidents. However, “these amounts, if taken per head, vary greatly and become large when they appeal greatly to public imagination, but in many other casus, where this is not the case … relatively small amounts which could have prevented the loss of many human lives are refused. For this reason it seems undesirable … as … a guiding norm for future cases” (Van Dantzig, 1956, p. 285).

The third measure for human life was the insured value of high ranked civil servants travelling by airplane. However, this was not to be regarded as an indicator of value of the human life lost, but of the protection against claims by the relatives. Furthermore, it would not be suited as an average for all civil servants and even less as an average for the whole population. Finally, only few could afford to buy a life insurance with an insured value of e.g. 45 thousand euro.

[23] He looked only at exceedance probability of dikes and assumed that the strength of a dike could be indicated by its height. He did not look at other failure mechanisms, e.g. piping.
[24] Assuming also an exchange rate of 10 guilders for 1 pound (see Harten et al. 2001) and using also the standard euro-guilder conversion rate of 2.2.

However, even this last high insured value was considered to be far too low by Van Dantzig and Kriens. To judge the plausibility of this value, they looked at the material damage and human lives lost during the 1953 North Sea Flood:

- 1800 lives lost multiplied by 45 thousand euro per life amounts to a value of 90 million euro. This would be sufficient to raise the dikes in the south-western part of the Netherlands with only 3 cm.
- Giving human lives lost an equal value as the material damage during this flooding would imply that the value of the 1800 lives lost reflected an amount of about 450 thousand euro per head.

They concluded that both calculations illustrated that 45 thousand euro per life was a major underestimate of the value of the human lives lost. They therefore preferred a pragmatic approach to valuing human lives lost and any other *imponderabilia*. The benefits of extra safety were estimated as the expected value of the reduction in material damage multiplied by a pragmatic factor 2. The latter was regarded as a rough minimum estimate of the value of the loss of life, the costs of chaos and shock and the value of cultural assets damaged or lost.

Benefits of extra safety increase due to economic growth and sinking of land

The benefits of extra safety were not assumed to be constant over time. Adjustments were made for economic growth and wealth and for sinking of land. Economic growth and the increase in national wealth and material damage were assumed to be 2% per year, while the discount rate is 4% per year. These assumptions have been copied from the CBA on the Delta Works by Tinbergen. The failure rates[25] of dikes increase over time due to sinking of the land relative to the sea level. This was estimated as 0.7 meters per century. The provided motivation still looks quite modern:

“For about 9 thousand years the Netherlands have been slowly sinking into the sea. This is … an equilibrating readjustment of the earth crust to the loss of load caused by the melting away of the Fennoscandian icecap about 10,000 years ago. … It is counteracted partly by a rising of the Alpine Foreland. Moreover, the sea level is constantly rising because of the melting away of the Greenland icecap.” (Dantzig, 1956, p. 281)

New official water safety norms based on cost-benefit principles

This new method was applied with new data to the dike ring Central Holland and further analysis of the Delta Works (Dantzig and Kriens, 1961). Following this study, it was decided to introduce an official water safety norm: in the economic heart and most populated part of the Netherlands, the risk of flooding (exceedance probability) should be once every 10,000 years. For other -generally much less densely populated- regions, later also official water safety norms were developed, ranging from once every 1250 years to once every 4,000 years.

[25] Put more accurately: the exceedance probability distributions of the dikes (see footnote 12).

4 Guidelines & More room for water

4.1 Introduction

This section discusses two topics:

- The guidelines on cost-benefit analysis (Eijgenraam et al., 2000): this implied the introduction of cost-benefit analysis as formal and obligatory tool for deciding on major public investments in infrastructure;
- The cost-benefit analyses related to the projects 'Room for water' (Verrips and Stolwijk, 2000) and 'More room for Rivers' (Ebregt et al, 2005, Eijgenraam, 2005 and 2006).

4.2 CBA-guidelines on infrastructure (2000)

Since 2000, there are national guidelines on CBA's in the Netherlands (see Eijgenraam et al. 2000). These guidelines guarantee that all CBA's are based on the same assumptions and methodology, e.g. same discount rate, treatment of indirect effects and avoidance of double counting. All major infrastructure projects financed by the Dutch central government are now subject to CBA's based on these guidelines. Furthermore, also many much smaller projects and many projects on other topics (e.g. investments in scientific knowledge or historic monuments) are accommodated by CBA's that should comply with these guidelines.

The guidelines could be regarded as a response to a - by many considered as failed - decision-making process about a freight railway-track from the Rotterdam harbour to Germany. Government plan's in the mid-1990s about this railway-track, reintroduced cost-benefit analysis (CBA) at CPB, the government's official but independent bureau for economic policy analysis.[26] The government initiated a large research project on cost-benefit analysis and asked CPB and Ecorys, a private economic consultancy firm, to develop guidelines together with other economic research organizations.

The first guidelines focused on evaluating transport infrastructure. Over the years, these guidelines have been supplemented with all kinds of more specific guidelines, e.g. about how to use transport models, how to use CBA in the planning stage and about how to apply the guidelines to specific cases like for water construction works, for revitalizing urban areas and improving the environment. In 2013, an updated guideline was drafted under the supervision of CPB and PBL (Romijn and Renes, 2013) to include new insights and to widen the scope of application, e.g. covering also issues like education, labour market and health care.

[26] Under the supervision of Tinbergen, CPB made a cost-benefit analysis of the Delta Works in 1954 (see section 3.2). After budget cuts in the early eighties, such project appraisals were scrapped at CPB.

4.3 CBA for More room for water (2000 and 2005)

In 1993 and 1995, the water levels in the major Dutch rivers Rhine, Meuse, Waal and IJssel became very high and a serious breaching of river dikes was feared. Out of precaution 250,000 people were evacuated in 1995. These rising water levels seemed to confirm the climate change predictions about rising sea levels and higher river water discharges.

For many decades, the standard Dutch response to such threats was to strengthen dikes and to add all kinds of technical barriers. However, the problems with the river-regions were partly the direct consequence of previous water management policies: taming the Dutch rivers by deepening, straightening and shortening the river flows and building dikes along these more and more canal-like rivers was key to making Rotterdam Europe's major harbor. However, it created also less and less space for river water discharge.

The projects 'Room for water' and 'More room for rivers' meant a new flavour on the Dutch menu of preventive water management policies: spatial adjustments to increase safety. As part of this project, many options to increase safety by giving more room for rivers were investigated over a long range of years. The project also induced a reconsideration and extension of Van Dantzig's method to analyse optimal failure rates of dikes.

Quick-scan cost-effectiveness analysis

In 2000, a first set of projects for improving safety along the rivers and coast were investigated by a quick-scan cost-effectiveness analysis (see Stolwijk and Verrips, 2000). Much more than previous cost-benefit analyses, all kinds of non-monetary costs and benefits were taken into account. Four projects were considered for the lower river-region. Table 4.1 provides an overview of the costs and benefits.

All four projects substantially increase safety in case of an extreme river discharge: they all reduce expected material damage by about 1 bln euro and ¼% of Dutch GDP in 2000; the costs of any human suffering were ignored. In the reference scenario in which no policy measures are taken, the likelihood of flooding is once every 100 years and leads to an expected annual material damage of 2.4 bln guilders. In all four projects, this likelihood of flooding is reduced to once every 2000 years, which corresponds to an expected material damage of 0.12 bln guilders.

The monetary costs for the projects include the purchase of land, costs of constructing and maintaining dikes and other water works and the costs of land use restrictions. In case of raising dikes, there are no new land use restrictions, no loss of agricultural production, no social consequences for farmers and no revenue for farmers due to the sale of land. The three alternatives proposing spatial adjustment (rerouting of the river Meuse, rerouting of the river Waal and changing the discharge distribution over various rivers) are in particular attractive in terms of quality of landscape, quality of the environment and possibility of flexible water management. The expected annual expenses for the government for the spatial adjustment alternatives are slightly higher than the annual costs, as the purchase of land is a government expense which is only partly (by amount of the loss of agricultural income) a cost for Dutch society.

Table 4.1 A cost-effectiveness analysis of four projects in the lower river-region for increasing safety, assuming an extreme river discharge of 18,000 m3 per second (Stolwijk and Verrips, 2000, table 8, p. 55)

	Rerouting of Meuse	Rerouteing of Waal	Changing discharge distribution	Raising dikes
Total annual monetary costs (bln euro)	0.15	0.14	0.11	more than 0.11
New land use restrictions (hectares)	1982	3253	2308	0
Total annual monetary benefits by reduction of expected material damage (bln euro) guilders)	1.04	1.04	1.04	1.04
Net annual monetary benefits (bln euro)	0.88	0.90	0.93	less than 0.93
Non-monetary effects				
quality of landscape (spatial beauty)	+	+	++	-
quality of environment	+	+	++	
social consequences for farmers	-	-	-	
flexible water management	+	+	++	-
Annual distributional effects				
farmers (bln euro)	0.002	0.003	0.002	
government (bln euro)	-0.152	-0.143	-0.112	more negative than -0.11

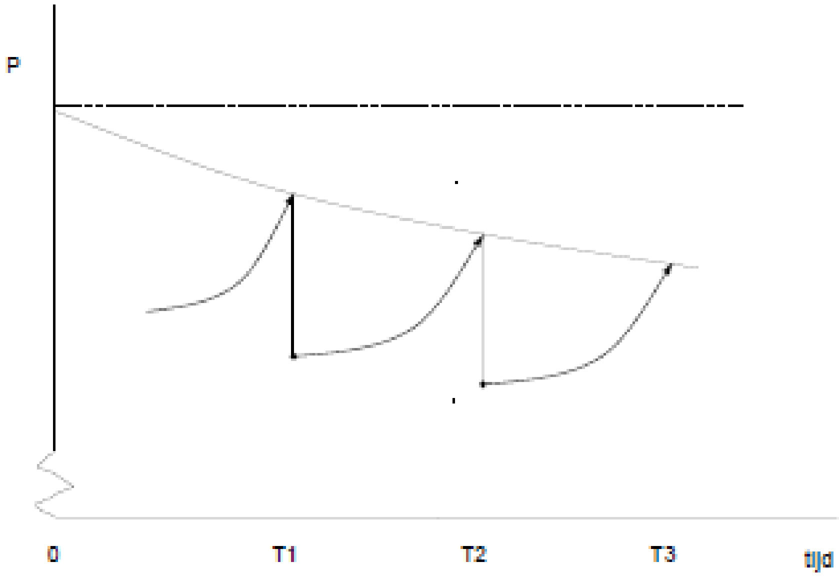
In 2005, two new cost-benefit analyses were published by CPB. The first one focused on the methodology of optimal safety standards for dike-ring areas and applied this to the dike-ring areas along the river Rhine (see Eijgenraam, 2005 and Eijgenraam, 2006). The second was a multi-dimensional cost-effectiveness analysis of more than 600 specific policy measures and four packages of policy measures (see Ebregt, Eijgenraam and Stolwijk, 2005).

Optimal failure rates of dike-rings revisited

Van Dantzig's formula for optimal safety standards for dike rings failure was static, i.e. it did not consider the optimal timing of investments. Therefore, optimal safety standards did not change over time. However, the potential damage increases over time by economic growth. Hence, it is optimal to lower flooding probability over time.

Eijgenraam (2005 and 2006) therefore elaborated Van Dantzig's optimal dike-strength approach to account for such more complicated dynamic situations. A major part of investment costs in strengthening dikes consist of fixed costs. It is therefore efficient to strengthen dikes in major steps, i.e. not by many small and frequent investments but by large incidental investments. As a consequence, the optimal flooding probability should fall over time following a saw tooth-pattern (see figure 4.1.). The exact optimal pattern depends on expected damage, investments costs (and the relative size of fixed versus variable costs) and external developments, like the speed of the rise in the sea level, the increase in river discharges, the speed of land subsidence and economic and demographic growth.

Figure 4.1 Optimal flooding probability should fall over time in line with economic growth and following a saw tooth-pattern (figure 2.4, p. 41 in Eijgenraam, 2005). Three lines are shown: 1) constant flooding probability, 2) flooding probability falling in time because economic growth leads to extra safety benefits and 3) optimal flooding probability which is falling over time and with a saw tooth-pattern: directly after the investment flood probability substantially drops, but after some time with economic growth this flood probability rises and then new investments in safety are needed.



This new method was used to recalculate Van Dantzig's analysis for dike ring Central Holland, by far the most important dike ring in the Netherlands. The developments during the past five decades were in line with Van Dantzig's pessimistic scenario for flooding risk. Van Dantzig's conclusion that the safety level chosen for Central Holland was too low was confirmed.

The new method (excluding any loss of lives and other serious personal damage[27]) was also applied to the dike ring areas along the river Rhine. In general, the official safety norms were in the middle of the figures calculated for the individual dike rings, but they showed an enormous spread.

Multi-dimensional cost-effectiveness analysis

As part of the project More room for rivers, CPB was asked to assess 600 specific policy measures and four packages of policy measures. These policy measures were very heterogeneous, ranging from deepening trenches, moving dikes further away from the river, introducing extra channels, rerouting rivers and raising dikes. These policy measures have all types of consequences, which cannot be well translated into monetary terms. In Stolwijk and Verrips (2000), this was analysed by a one-dimensional cost-effectiveness analysis focusing on the effectiveness in terms of safety and adding some non-monetary effects like the quality of the landscape and environment. A different approach was developed and

[27] Excluding loss of lives is a plausible assumption if flooding can be predicted well. Allowing sufficient time for evacuation is in generally true in case of higher river discharge rates.

applied by Ebregt, Eijgenraam and Stolwijk (2005). This could be labelled multi-dimensional cost-effectiveness analysis.

For all investigated measures, four types of benefits are distinguished:
- Extra safety in terms of reduction of high water level in m^2;
- Extra landscape with high environmental quality (biodiversity) in hectares;
- Extra landscape with spatial beauty per kilometer along the river;
- Extra landscape attractive for leisure activities per kilometer along the river.

So, for all 600 measures, information was available of their impact on these four types of benefits. Furthermore, there was information on their estimated costs. These costs were then compared to the average cost per benefit. The latter are based on an extended data base of policy measures and their costs and effects.

The typical cost rate for reducing high water levels varies between river branches of river and sometimes even by parts within each river branch. It ranges from 8 thousand euro per m2 in the river Maas to 26 thousand euro in the river Waal.

The typical cost rate for an extra hectare of landscape with high environmental quality is 230 thousand euro. This is much higher than the average costs per ha for increasing environmental quality ('Ecologische Hoofdstructuur'). Hence, combining extra safety with environmental development therefore does not seem not to be very cost-effective.

The typical cost rate for extra landscape with spatial beauty is 2.5 million euro per kilometer along the river. Similarly, the extra cost for extra landscape attractive for leisure activities is 3.2 million euro per kilometer higher than landscape not rated as attractive for leisure activities.

Table 4.2 Multi-dimensional cost-effectiveness of the 'proposed package' of policy measures for More room for rivers (see Ebregt, Eijgenraam and Stolwijk, 2005, p. 15)

Branch of the river	Costs: estimated	Costs: estimated using standard cost-effectiveness-prices	Difference in costs	Difference in costs	Cost-effectiveness-label
	mln euro			%	
IJssel	660	605	55	9	Average
Nederrijn-Lek	409	311	98	32	Expensive
Waal	1025	858	167	19	Average
Maas	121	125	-4	-3	Cheap
Total	2215	1899	316	17	Average

Table 4.2 illustrates the multidimensional cost-effectiveness method. It compares the cost-effectiveness of a certain 'proposed package' with a certain 'standard package'. The proposed measures for the Nederrijn-Lek are labeled expensive, as the estimated costs are 32% higher

than those using the standard cost measures. In contrast, the policy measures for the river Maas are relatively cheap.

This elaborate study on the cost-effectiveness of 600 policy measures played a major role in the negotiation process of the Dutch central government with its local public and private partners in the regions. In 2006, the Dutch central government decided to invest 2.3 billion euro in the river-regions (0.3% GDP; Dutch Ministry of Infrastructure and Environment, 2006). These works were completed a decade later, i.e. in 2015.

5 CBA for the next century

5.1 Introduction

The first Delta Commission was a direct response to the North Sea Flood of 1953. In 2007, a second Delta Commission was installed (Deltacommissie, 2008). Their mandate was to formulate in a very short time span of one year a long term vision on the protection of the Dutch coast and its hinterland. This Commission could be regarded as a response to the warnings of climate change and their implications for water management systems, the economy and the environment. The Commission concluded that the Netherlands should accelerate its efforts, because at present even the current standards of flood protection were not being met everywhere. Moreover, the current standards are out of date and must be raised by a factor ten. The climate is changing rapidly, the sea level is probably rising faster than has been assumed, and more extreme variations in river discharge are expected. The economic, societal and physical stakes in the Netherlands are great and growing; a breach in a dike has seriously disruptive consequences for the entire country.

Following the report by the second Delta Commission, a 'Delta Program' (Alphen, 2015) was started to further develop and investigate the best set of policy measures for making the Netherlands climate-proof for the next decades and century; the major reference years are 2050 and 2100. A 'Delta Fund', i.e. a separate item in the central government's budget, was started to finance the expenditure. Its budget is about 1 billion euro per year[28]. A 'Delta Commissioner' was appointed to organize and supervise the 'Delta Program'. According to plan, policy decisions were taken in 2015.

The 'Delta Program' is good example of the Dutch consensus type of decision-making based on expert advice and a wide consultation of stakeholders. In the successive rounds of discussion and decision-making, many different types of local government (provinces, municipalities and water boards) and private organisations (e.g. local entrepreneurs and ecological groups) participated. Citizens were also asked to express their opinion.

To investigate the various issues, a whole range of consultancy firms and official expert institutes were recruited. This included conducting cost-benefit analyses. Four of these cost-benefit analyses, in particular those that focus on safety norms, will be discussed first (section 5.2-5.5).

[28] A separate fund in the central government's budget was also used for the major flood risk project of a century ago: a Zuiderzeefund for the Zuiderzee Works (enclosure of the Zuiderzee, see section 2).

5.2 Optimal safety norms for Dutch dikes (2011)[29]

Before discussing the CBA on optimal safety norms, we start by providing some background information. What were the current safety standards? And what was the advice by the Second Delta Commission for increasing the safety standards?

Current safety norms for Dutch dikes

Current Dutch flood protection standards range from an admissible flood probability of 1/1,250 per year for dike-ring areas along the Rhine and Meuse rivers, to 1/10,000 per year for the most important dike-ring areas along the coast. These are the highest protection standards in the world, e.g. much higher than the well-known U.S. standard of 1/100 per year and exceeding the standard of 1/500 per year which Galloway et al. (2006) recommend for densely populated or vulnerable areas.

The flood protection standard of 1/10,000 per year for dike ring 14 ('Central Holland'), the dike ring area with the highest economic value and population size, is based on the cost-benefit analysis by Van Danzig in the 1950's (see section 3.3). However, standards for the other dike ring areas were not based on a cost-benefit analysis. For other dike ring areas along the coast, the first Delta Commission compared only estimates of potential flood damage in these dike ring areas with the potential damage in dike ring area 14. The investment costs of reaching these standards in the other dike ring areas were fully ignored; this amounts to assuming that they are roughly the same as in dike ring area 14. The current flood protection standards for dike ring areas along the rivers Rhine and Meuse (1/1,250) are based on advice of a separate Commission in 1993. They placed a high value on the environmental damage caused by dike improvement projects along the rivers in the preceding decennia. Furthermore, they took account of the fact that flooding from the North Sea is difficult to anticipate, whereas flooding by rivers can be anticipated in many cases. Hence, evacuation is possible. This explains why protection standards for river flooding are much lower. This Commission chose to analyse only protection standards of 1/500 and 1/1,250 per year and not higher.

Advice without further investigations

In 2008, the Second Delta Commission advised to increase the protection standards of all dike-ring areas tenfold. This seemed intuitively logical, because GDP was five times as large as in the 1950s and the climate is changing rapidly. But this would require huge investments by the Dutch government.

A cost-benefit analysis for new safety norms

Some years before, in 2006, the Dutch government had launched a big multi-year project to update the flood protection standards. This included a cost-benefit analysis for flood protection standards for all dike rings in the Netherlands. In order to assess new optimal safety norms, a lot of new, better and more up-to-date information was needed:

[29] See Kind et al. (2011), Kind (2014) and Eijgenraam et al. (2014).

- What are the costs of raising dikes in various parts of the Netherlands?
- What are the current flooding risks and to what extent will they be influenced by changes in climate and land subsidence?
- What is the effect of raising dikes on flooding risks?
- What is the expected material damage and number of victims in case of flooding?
- How can the value of reducing the number of victims be assessed in monetary terms?

By substantial research effort during five years, information was compiled and brought together. This was organized by Deltares, an independent Dutch research institute in the field of water, subsurface and infrastructure. Key-elements of the approach were:

- Water boards and provinces were asked to provide Deltares with basic information on dikes and inundation scenarios.
- In contrast to the 1960 analysis more than one safety norm per dike ring was allowed due to local differences.
- Not only failure of dikes due to overtopping, but also due to 'piping', i.e. groundwater transport under the dike that weakens its foundation, was taken into account.
- To be more flexible and to include more detailed information, the mathematical model for determining optimal safety norms by Van Dantzig and Eijgenraam had to be modified (see Brekelmans, et al. 2012).
- The value of statistical life for flood risk management was investigated on the basis of a Dutch survey on the value of housing with different flood risk values (see Bockarajova, et al., 2012). This value was set at 7 million euro, which is three times as large as the value of statistical life used in the Netherlands for measuring the value of road traffic safety (see Schroten et al, 2014).
- Monte Carlo analysis with different values and assumptions for key-variables was used to assess the uncertainty of the results.

According to this very extended and detailed cost-benefit analysis, it is wise to raise safety standards especially along the rivers Rhine and Meuse. However, for many dike ring areas in coastal regions, current flood protection standards were already relatively high. This implies also that the advice by the second Delta Commission to increase all safety standards tenfold was not needed from a cost-benefits point of view.

The new flood risk safety norms

In 2015, the Dutch government agreed on new official flood risk safety norms. About 70%[30] of these new norms are based on the cost-benefit analysis on optimal safety norms. In

[30] About 20% of this new norm was based on a study on individual (or location-related) casualty risk and incident-related group (or societal) risk (see Beckers and de Bruijn, 2011). This provided insight in the risk indicators to determine flood protection standards from the perspective of becoming a flood victim. Every inhabitant should have a probability of drowning due to a flood of no more than 10^{-5}/year. This probability of drowning is the result of dike failure probability, evacuation rate, flood pattern and the fatality function of those who remain. When the latter three are known, the required level of flood protection (design probability of the flood defence) can be derived to meet this 10^{-5}/year norm. This norm was a political choice, a level of 10^{-6}/year would require 5 billion euro extra investments (see Alphen, 2015). In addition to the cost-benefit analysis on optimal safety norms and individual flood risk analysis, also specific regional arguments played in role in agreeing on the new flood risk safety norms.

comparison with a tenfold increase of safety norms, this led to a saving of investment costs by 8 billion euro[31] while maintaining a substantial safety increase.

5.3 CBA for renovating the Zuiderzee enclosure dam (2011)

Eighty years ago, the Zuiderzee was closed off by a 33 km long barrier dam ('Afsluitdijk') (see section 2). In order to meet its legal safety standards of flooding once every 1/10.000 years, this Zuiderzee enclosure dam needs fundamental reconstruction. The dam should also continue to meet two other functions: managing the water level in the IJsselmeer and providing good connections for transport by car and by ship. This renovation could be combined with new functions with respect to energy (e.g. solar energy, tidal energy and wind energy), environment (e.g. green dikes and special sluices for fish), local economic development (e.g. leisure activities) and mobility (e.g. roads for bikes, bigger sluices to accommodate ships, public transport). In order to evaluate the various proposals, a cost-effectiveness analysis was conducted by CPB (Grevers and Zwaneveld, 2011).

All alternatives assumed that legal safety standards should be met during the next century. A complete cost-benefit analysis would require that also different safety standards were investigated. For example, what would have been the optimal safety standards? What are the costs and benefits of the no renovation alternative? These issues were investigated later (see section 5.5). This sequence was in line with the schedule of political decision-making: they first wanted to decide about the best alternative to meet current safety standards; decision-making about changing safety standards was a separate issue that would be decided much later.

Analysis of the water management issue showed that in case of a pessimistic climate change scenario (a rise in the sea level of 25 cm in 2035) managing the water level in the IJsselmeer ('Lake IJssel') would become difficult. At that time, policy makers were only thinking of one solution to this problem: raising the water level in the IJsselmeer in line with the rise in the sea level.

An overlooked alternative: massive pumps

However, a non-considered alternative was installing massive pumps at the Zuiderzee Enclosure dam ('Afsluitdijk'). This alternative was previously claimed to be much more expensive, e.g. due to high costs of energy. But the conventional solution of raising the water level in IJsselmeer requires that dikes surrounding IJsselmeer should be raised and that new drainage sluice were to be added. This is also very costly. Furthermore, an advantage of pumps would be extra safety, as pumps are more effective for managing water levels under various circumstances. For example, the effectiveness of drainage sluices directly depends on the strength and direction of the wind. The costs and benefits of drainage sluices and pumps would be further investigated in two other cost-benefit analyses (see 5.4 and 5.5).

[31] The investment was reduced from 12 billion euro to 4 billion euro (Eijgenraam et al., 2014).

In addition to putting the spot lights on the option of pumps, this cost-effectiveness analysis was innovative in assessing the effects on the environment and the treatment of flexibility.

Reporting of environmental effects

The effects on the environment were shown in two different ways: the extent to which legal environmental protection standards were met and the score in biodiversity points. In contrast to the perspective of minimal legal standards for the environment, the score in biodiversity points does not only look at negative effects on the environment, but also takes into account positive effects. The biodiversity points are assessed by expert opinions of ecologists, which take account of the rarity of ecotypes and the effects on the quality and quantity of these ecotypes. The analysis showed that the so-called option Green Afsluitdijk resulted in a clear positive effect on the biodiversity. The additional costs of this option were estimated to be 700 million euro. According to the biodiversity points, similar positive effects on biodiversity can be obtained by constructing a fish sluice in the Afsluitdijk; this costs only 10 million euro. Hence, fish sluices were much more cost-effective.

The benefits of flexibility

In case of large uncertainties about the future, flexibility should also be taken into account as an important quality of alternatives. From an economic theoretic perspective, a real options approach can be considered. This allows estimating the value of flexibility. However, in cost-benefit practice of water management, the real options approach is hardly ever applied. For this cost-effectiveness analysis, flexibility was not expressed by one figure, but by calculating and showing the size of additional costs in case of a fast or slow rise in the sea level (see figure 5.1). A plausible bandwidth of the sea level rise was assessed in terms of two climate scenarios: in the moderate climate scenario the sea level will be in 2100 35-60 centimeters higher, while in the most extreme climate scenario ('W+ scenario') it will be 40-85 centimeters.

Figure 5.1 Sensitivity of the costs of six basic alternatives for renovating the Afsluitdijk (Zuiderzee-enclosure dam) for different assumption about the rise in the sea level.

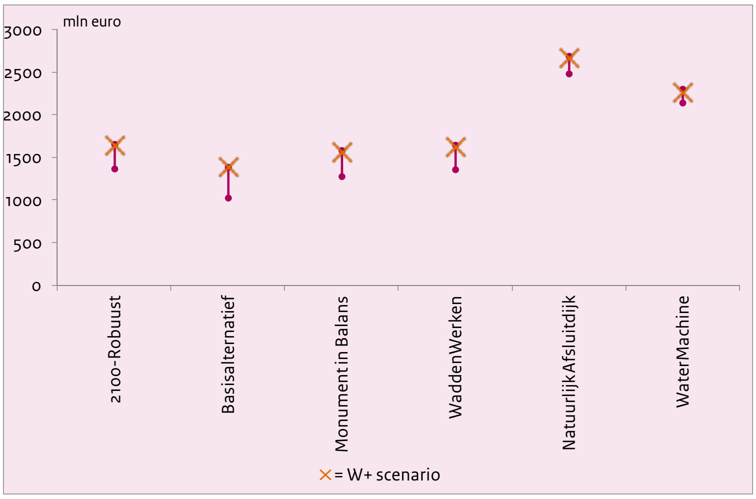


Figure 5.1 shows that all six alternatives are flexible and can be adjusted with limited extra costs for a higher than expected rise in sea level. In case of a lower than expected rise of sea level, considerable costs can also be saved. The basic alternative ('basisalternatief') is the most flexible alternative due to its phased approach by first renovating and then building new constructions.

Impact on public decision-making

This CBA was well received by policy makers (Zwaneveld et al. 2012). The CBA identified the most cost-efficient elements for the renovation of the Afsluitdijk. These elements included improving safety, water management (e.g. installing pumps), energy options and the environment. The authors of the CBA worked closely together with the responsible civil servants to present the results of the CBA to decision makers. Looking back, the civil servant and authors of the CBA (Zwaneveld et al., 2012) conclude that the results of the cost benefit analysis ware almost completely adopted in the final decision of the Dutch Cabinet.

5.4 CBA for safety & fresh water in the IJsselmeer-region (2012)

According to the second Delta Commission, the water level in IJsselmeer should rise in line with the sea level to enhance safety and secure fresh water supply. In case of a pessimistic climate change scenario, this would imply a water level rise of 1.5 meter. In a cost-effectiveness analysis (see Bos, Zwaneveld and Puijenbroek, 2012), this strategy was compared with a strategy of installing giant pumps at the Afsluitdijk, i.e. the Zuiderzee enclosure dam. In addition, various alternative options to increase the fresh water supply were assessed.

To account for climate change uncertainty, effects were calculated for two distinct climate change scenarios (see table 5.1). In the Netherlands, four climate change scenarios are available (KNMI, 201?)[32]. From these scenarios, the most moderate ('G') scenario and the most extreme ('W+') were used. In the most moderate scenario, the sea level will have increased by 35 cm in 2050. In the most extreme scenario, it would be 85 cm. The costs of raising dikes and safety benefits were calculated using the Diqe-Opt model (see section 5.5). In addition, all kinds of additional costs and benefits were investigated, e.g. the effects of changing water levels for the natural environment, shipping, agriculture and historic monuments.

The effects on the natural environment were incorporated by several approaches. One approach was to estimate the costs of preventing any environmental damage. The shallow parts of the IJsselmeer are important for biodiversity. These parts can be protected against a rising water level by constructing a sand barrier. An alternative option is to transform agricultural land into an area with natural value. In addition to these cost-based compensation measures, the effects on biodiversity without any additional policy measures were investigated. Similar to the costs-effectiveness analysis for the Afsluitdijk (see section

[32] On long term scenario analysis in the Netherlands, see Bos and Teulings (2013b).

5.3), biodiversity was measured in as follows: the extent to which legal environmental protection standards were met and biodiversity points.

Table 5.1 Two climate scenarios for the Netherlands in 2100 in comparison to base year 1990 (based on figures from 1976-2005). 'Winter' refers to December, January and February; 'Summer' refers to June, July and August.

		Moderate climate scenario (G)	Hottest climate scenario (W+)
Universal increase in temperature in 2050		+1°C	+2°C
Universal increase in temperature in 2100		+2°C	+4°C
Change in wind in Western Europe		no	yes
Winter	average temperature	+1.8°C	+4.6°C
	coldest annual winter day	+2.1°C	+5.8°C
	average rainfall	+7%	+28%
	number of rainy days (≥0.1 mm)	0%	+4%
	10 year return period of 10 day annual maximum rainfall	+8%	+24%
	maximum annual day average of wind speed	-1%	+8%
Summer	average temperature	+1.7°C	+5.6°C
	warmest annual summer day	+2.1°C	+7.6°C
	average rainfall	+6%	-38%
	number of rainy days (≥0.1 mm)	-3%	-38%
	10 year return period of 10 day annual maximum rainfall	+27%	+20%
	Potential evaporation	+7%	+30%
Increase in sea level	increase in cm in 2050	15-25	20-35
	2100	35-60	40-85

Source: KNMI (2006). G = Moderate climate scenario, W+ = Hottest climate scenario

Table 5.2 CBA for safety and fresh water in the IJsselmeerregion (Bos and Zwaneveld, 2012), costs (discounted value with 5.5% discount rate) and fresh water supply for seven alternatives for the more extreme climate change scenario.

	L.1	L.2a	L.2b	L.2c	L.3a	L.3b	L.4
	Mln euro						
Investments in safety	1094	1094	1094	1094	1882	1882	1882
Residual damage	971	1008	1094	971	1381	1628	1256
Other costs	4	22	98	74	256	296	132
Total costs	2069	2124	2286	2139	3519	3806	3270
Difference in costs with L.1		55	217	70	1450	1737	1201
Fresh water buffer, million m^3	600	1000	1480	1400	1600	1960	1000
Difference with L.1		400	880	800	1000	1360	400
Extra costs of extra fresh water buffer, euro/m^3		0.14	0.25	0.09	1.45	1.28	3.00

Reference alternative L1: pumps and no change in water level; L.2a, b and c: like L.1 but with additional options for increasing the fresh water buffer during summer time L.4: the water level increases in line with the sea level; L.3a and b: like L.4 but including additional options for increasing the fresh water buffer

According to this cost-effectiveness analysis (see table 5.2), the option to install giant pumps at the Afsluitdijk is over one billion euro (in net present value) cheaper than allowing the water level to rise with the sea level. This conclusion still holds when the differences in fresh water buffer are taken into account. Another conclusion of this analysis was that with limited investments (about 25 million euro), the fresh water buffer in the IJsselmeer-region could be tripled in about a decade. This should be more than sufficient to meet fresh water demands in the next decades. In 2015, the Dutch government decided –fully in line with this analysis- to install pumps at the Afsluitdijk and to triple the fresh water buffer.

Opening the black box

Dutch government took her decision after comprehensive consultation of stakeholders in the region, e.g. several provinces, several water boards, many municipalities and many local citizens, local entrepreneurs and local organizations. The results of the CBA for safety & fresh water in the IJsselmeer region had to be discussed with these stakeholders. The problems arose that cost-benefit analysis is generally reviewed as a black box (see Huizinga, 2012; see also section 4.2). For this CBA, the methods used for calculating the safety cost and benefits are complex and specific assumptions may easily put off decision makers.

To cater criticism, many efforts have been made to enhance transparency and accessibility of this cost-benefit analysis. This was done in various ways:

- Presenting safety costs and benefits for each local dike ring separately.
- The effects of non-safety policy measures were shown on maps of the IJsselmeer-region;
- Explicitly describing and discussing the various assumptions and their impact on the results.
- Presenting and discussing provisional and final results with various groups of stakeholders.
- Active participation in the process of performing the CBA by the Ministry's project organization for the IJsselmeer region, including the project leader and the project director. They helped to formulate project alternatives and checked methods and texts comprehensibility and plausibility. A dedicated policy summary was written and distributed by the project organization.

5.5 Optimal safety norms for the Zuiderzee-region (2014)

The CBA for new optimal safety norms for dikes in the Netherlands (2010, see section 5.2) did not investigate the safety norms for barrier dams like the Afsluitdijk, i.e. the enclosure dam for the Zuiderzee. It also did not investigate the consequences for safety of installing giant pumps at the Afsluitdijk. Furthermore, optimal safety at the Afsluitdijk interacts with optimal safety of dikes surrounding the IJsselmeer. If during a storm surge the Afsluitdijk fails, severe safety effects occur on dikes surrounding IJsselmeer.

Apart from the Afsluitdijk, a second barrier dam is located in the region, the 'Houtribdijk'. This barrier dam subdivides the former Zuiderzee into two separate lakes: IJsselmeer ('Lake IJssel') and Markermeer ('Lake Marken'). The optimal safety levels for the Afsluitdijk and the

Houtribdijk interact. In addition, optimal safety levels of dikes surrounding Markermeer depend on the safety levels of both barrier dams. Therefore, a new CBA was launched which focused on assessing optimal safety norms for the Zuiderzee-region (see Zwaneveld and Verweij, 2014; Zwaneveld and Verweij, 2017).

This CBA could benefit from the data compiled for the previous CBA on optimal safety norms for dikes in the Netherlands, e.g. the costs of raising dikes and damage in case of flooding.

A challenge in this CBA was how to model mathematically the interdependence between safety of the Afsluitdijk, the safety of the Houtribdijk and safety of the dikes around the IJsselmeer and the Markermeer. This was solved by identifying six additional failure probabilities and building a new graph-based mathematical model (Diqe-Opt; Zwaneveld and Verweij, 2014, 2017). For each specific dike ring, this model investigates whether it is a good investment to raise the dike: if the costs are smaller than the benefits, the dike should be raised.

An important feature of this model is its flexibility. This implies that the model can not only be used for analysing optimal safety norms and the related optimal investment patterns. It can also be used when restrictions apply. These restrictions can be added easily in the model. For example, the safety of a specific dike ring can be restricted to be larger than the current official safety norm. Another useful application could be determining the optimal overall investment pattern assuming a specific annual maximum budget set by the central government. This new model also played a major role in a cost-effectiveness analysis for the IJsselmeer-region (see section 5.4).

The CBA on optimal safety norms for the Zuiderzee-region model has major policy implications, as many optimal safety norms calculated differ substantially from current safety norms. In one important case (the Houtribdijk), the current safety norm is 1/10000 years, while 1/300 years seems optimal. For this and some other dikes, major investments in order to increase safety are already scheduled, but not yet formally agreed upon. Reconsidering or at least postponing such investments would therefore be wise. By a request of the Ministry of Infrastructure and the Environment, the quality of this CBA was assessed by a commission of four professors (Ierland et al., 2014). They concluded that 'it was an impressive study in which very many hydrological and economic aspects were combined in a wonderful way. In general, a good research question, appropriate methods and the best possible data were used'.

The proposed safety norm from this study for the Afsluitdijk was embraced. The CBA provided also two major new insights for the safety norms of dikes surrounding the IJsselmeer. Firstly, it showed that the additional failing probabilities connected to the Afsluitdijk had very significant impact on safety norms of the dikes surrounding IJsselmeer. Secondly, it suggested that installing pumps at the Afsluitdijk would significantly change the economical optimal safety norms. Both aspects were not taken up in the proposed new safety standards for the dikes surrounding IJsselmeer and Markermeer.

References

Acemoglu, D. and J.A. Robinson, 2013, *Rise and fall of nations; the origins of power, prosperity and poverty*, Profile Books, London.

Alphen, J. van, 2015, The Delta Programme and updated flood risk management policies in the Netherlands, *Journal of Flood Risk Management*, vol. 9 (4): 1-10.

Beckers, J.V.L, and K.M. de Bruijn, 2011, Analyse van slachtofferrisico's waterveiligheid 21[e] eeuw, Deltares, Delft.

Bockarjova M., Rietveld P. and Verhoef E, 2009, *First results immaterial damage valuation: value of statistical life (VOSL), value of evacuation (VOE) and value of injury (VOI) in flood risk context*, *a stated preference study (III)*, VU Amsterdam: Department of Spatial Economics.

Bos, F., 2006, Nederlandse collectieve uitgaven in historisch perspectief (Dutch Public Expenditure in Historical Perspective), CPB Document 109.

Bos, F., 2008, The Dutch fiscal framework; history, current practice and the role of the Central Planning Bureau, *OECD Journal on Budgeting*, vol. 8(1): 7-48. Also published as CPB Document 150.

Bos, F., P. Zwaneveld and P. Puijenbroek, 2012, Een snelle kosten-effectiviteitanalyse voor het Deltaprogramma IJsselmeergebied: wat zijn de kosten en veiligheidsbaten van wel of niet meestijgen met de zeespiegel en diverse opties voor het vergroten van de zoetwaterbuffer? (A quick cost-effectiveness analysis for the Deltaprogram IJsselmeer-region: what are the costs and safety benefits of raising the water level with the sea level and of various options to increase fresh water supply?), CPB Achtergronddocument.

Bos, F. and C. Teulings, 2013a, Netherlands: Fostering Consensus on Fiscal Policy, in G. Kopits (ed.), *Restoring Public Debt Sustainability: the Role of Independent Fiscal Institutions*, Oxford University Press, Chapter 7, 121-141.

Bos, F. and C. Teulings, 2013b, Short and long-term forecasting by the Netherlands Bureau for Economic Policy Analysis (CPB): science, witchcraft or practical tool for policy?, *OECD Journal of Budgeting* 2013, Volume 13 (1): 45-56.

Brekelmans, R., D. den Hertog, K. Roos and C.J.J. Eijgenraam, 2012, Safe Dike Heights At Minimal costs: The nonhomogeneous Case, *Operations Research*, vol. 60(6): 1342-1355.

Brouwer, R. and J. Kind, 2005, Cost-benefit analysis and flood control policy in The Netherlands, chapter 5 in: R. Brouwer and D. Pearce (eds), 2005, *Cost-Benefit Analysis and Water Resources Management* (Edgar Elgar, Cheltenham), 93-123.

CPB, 1959, Rapport over de rentabiliteitsverwachtingen van de Coen- en IJ-tunnelprojecten.

CPB, 1975, Kosten-batenanalyse tweede nationale luchthaven, monografie nr. 18, Deel 1 Hoofdrapport, Deel 2 Deelstudies.

Dantzig, D. van, 1956, Economic decision problems for flood prevention, *Econometrica*, vol. 24: 276-287.

Dantzig, D. van, and Kriens, 1960, The economic decision problem concerning the security of the Netherlands against storm surges, Report of the Delta commission, contributions II.

Deltacommissie, 2008, Samen werken met water; een land dat leeft bouwt aan zijn toekomst.

Deltaprogramma, 2012, Deltaprogramma 2013: Werk aan de delta; de weg naar deltabeslissingen.

Don, F.J.H. and H.J.J. Stolwijk, 2003, Investeren in veiligheid: de watersnoodramp en de kosten en baten van het Deltaplan, in: H.W. Lintsen (ed.), *Terugblik en toekomst, 50 jaar na stormvloed 1953,* Waterbouwdag 2003, *CUR*, Gouda.

Drees, W. and F. Th. Gubbi, 1967, *Overheidsuitgaven in theorie en praktijk,* Wolters Noordhoff, Groningen.

Dutch Ministry of Finance, 1971, Rapport betreffende het karakter en de betekenis van de beleidsanalyse en de kosten-batenanalyse.

Dutch Ministry of Infrastructure and Environment, 2006, Planologische Kernbeslissing Ruimte voor de Rivier, 19 december 2006.

Ebregt, J., C.J.J. Eijgenraam and H.J.J. Stolwijk, 2005, Kosteneffectiviteit van maatregelen en pakketten; kosten-batenanalyse voor Ruimt voor de Rivier, deel 2, CPB, The Hague.

Eijgenraam, C.J.J., 2005, Veiligheid tegen overstromen, Kosten-batenanalyse voor Ruimte voor de Rivier deel 1, *CPB Document* 82, CPB, The Hague.

Eijgenraam, C.J.J., 2006, Optimal safety standards for dike-ring areas, *CPB Discussion paper* 62, CPB, The Hague.

Eijgenraam, C.J.J., J. Kind, C. Bak, R. Brekelmans, D. den Hartog, M. Duits, K. Roos, P. Vermeer en W. Kuijken, 2014, Economically efficient standards to protect the Netherlands against flooding, *Interfaces*, vol. 44(1): 7-21.

Eijgenraam, C.J.J., C.C. Koopmans, P.J.G. Tang and A.C.P. Verster, 2000, *Evaluatie van infrastructuurprojecten; leidraad voor kosten-batenanalyse*, SDU, Den Haag.

Etzkowitz, H. and L. Leydesdorff, 1995, The Triple Helix: University - Industry - Government Relations: A Laboratory for Knowledge-Based Economic Development. *EASST Review* 14, 14 - 19.

Franklin, B., 1772, Letter to Benjamin Priestly, quoted in Gramlich, E. M. 1981, *Benefit-Cost Analysis of Government Programs*, Prentice-Hall, New Jersey, USA.

Filarski, R., 1995, Kanalen van de koning-koopman; goederenvervoer, binnenscheepvaart en kanalenbouw in Nederland en België in de eerste helft van de negentiende eeuw, Nederlands Economisch Historisch Archief NEHA, Amsterdam.

Fukuyama, F., 2011, *The origins of political order, from prehuman times to the French revolution*, Profile Books, London.

Galloway, G.E., G.B. Baecher, D. Plasencia, K.G. Coulton, J. Louthain, M. Bagha and A.R. Levy, 2006, Assessing the adequacy of the national flood insurance program's 1 percent flood standard, Report, American Institutes for Research, Washington, DC.

Geest, L. van der, M. Berkhof and M. Meijer, 2008, Het hoofd boven water; tweehonderd jaar investeren in waterwerken, Essay in opdracht van de Deltacommissie, Nyfer, Utrecht.

Gorter, H.P., 1965, Verlies en winst bij eventuele indijking van de Waddenzee, *Kwartaalblad van de commissie voor natuur en landschap*, pp. 173-183.

Grevers, W. and P. Zwaneveld, 2011, *Een kosten-effectiviteitsanalyse naar de toekomstige inrichting van de Afsluitdijk*, CPB Boek 2.

Ham, W. van der, 2007, *Verover mij dat land, Lely en de* Zuiderzeewerken, Uitgeverij, Uitgeverij Boom, Amsterdam.

Ham, W. van der, 2009, *Hollandse polders*, Uitgeverij Boom, Amsterdam.

Harten, M.C. van, W.L. Korthals Altes en C.G. de Vries, 2001, Een gulden geschiedenis, ESB, jaargang 86 (4340): 997.

Houven van Oordt, H.C. van der and G. Vissering, 1901, *De economische betekenis van de afsluiting en drooglegging der Zuiderzee*, Drukkerij Brill, Leiden.

Huizinga, F., 2012, The economics of flood prevention, a Dutch perspective. Keynote speech at symposium on flood management in Houston, *CPB Background Document*.

Ierland, E. van, C. Koopmans, P. Rietveld, A. van der Veen, 2014, Advies van de commissie van economische deskundigen over de CPB studie "Economisch optimale waterveiligheid in het IJsselmeergebied", SEO-report nr. 2014-01, SEO Amsterdam.

Kind, J., 2011, Maatschappelijke kosten-batenanalyse waterveiligheid 21e eeuw, Deltares, Delft.

Kind, J.J., 2014, Economically efficient flood protection standards for the Netherlands, *Journal of Flood Risk Management,* vol. 7(2): 103-117.

Kind, J., J. Gauderis, M. Duits and C. Bak, 2011, Economisch optimale niveaus voor de bescherming van dijkringen tegen grootschalige overstromingen, *H2O Tijdschrift voor watervoorziening en waterbeheer*, vol. 25/26: 10-12.

KNMI, 2006, KNMI Climate change scenarios 2006 for the Netherlands, KNMI Scientific report 2006-1.

Koopmans, C., 2010, Kosten en baten van het Centraal Planbureau: verleden, heden en toekomst, *Tijdschrift voor Politieke Economie digitaal*, jaar 4, vol. 3, pp. 19-30.

Kox, A.J., 2007, Uit de hand gelopen onderzoek in opdracht: H.A. Lorentz' werk in de Zuiderzeecommissie, in L.J. Dorsman and P.J. Knegtmans, 2007, *Onderzoek in opdracht; de publieke functie van het universitaire onderzoek in Nederland sedert 1876*, Verloren, Hilversum, pp. 39-52.

Laar, van de, P.T., 1999, Het rendement van de Rotterdamse haven ca. 1870-1940, in: A.J. Bindenga, M.A. van Hoepen en J. Maat (eds), 1999, *Bericht gegeven*, opstellenbundel bij afscheid Prof. F. Krens, Kluwer Rotterdam, pp. 259-271.

Lely, C., 1901*, Ontwerp van wet tot afsluiting en droogmaking van de Zuiderzee met toelichtende memorie*, Text downloadable via www.gutenberg.org, eBook 36317.

Marsman, H., 1936, Denkend aan Holland, Thinking of Holland, Poem of the century in the Netherlands, translation by Max Birkin.

Ministry of Mobility and Water, 2006, *De strategische MKBA voor de Europese Kaderrichtlijn Water*.

Mol van Otterloo, H.A. de, 1970, Schiphollijn, Eindrapport van de werkgroep spoorlijn Amsterdam-Den Haag, Ministerie van Verkeer en Waterstaat.

OECD, 2010, *OECD Economic Surveys Netherlands*, vol. 2010/10, June 2010, OECD Publishing.

OECD, 2011, Water Governance in OECD Countries: A Multi-Level Approach, *OECD Studies on Water.*

OECD, 2014, Water Governance in the Netherlands: Fit for the Future?, *OECD Studies on Water.*

Olson, M., 1971, *The logic of collective action; public goods and the theory of groups*, Harvard University Press, London.

Olson, M., 1982, *The rise and decline of nations: economic growth, stagflation and social rigidities*, Yale University Press, New Haven.

Ossokina, I. and C. Eijgenraam, 2010, Probleemanalyse en daaruitvolgende project- en nulalternatieven in KBA's, *CPB Memorandum* 234.

Ostrom, E., 1990, *Governing the commons; the evolution of institutions for collective Action*, Cambridge University Press.

Ostrom, E., 2005, *Understanding institutional diversity*, Princeton University Press, Princeton.

Pol, T. van der, F. Bos and P. Zwaneveld, 2017, Real options and cost-benefit analysis of public infrastructure, forthcoming as CPB Discussion Paper.

Porter, T.M., 1995, *Trust in numbers; the pursuit of objectivity in science and public life*, Princeton University Press, in particular chapter 7: U.S. Army Engineers and the rise of cost-benefit analysis, pp. 148-190.

Reynolds, D.J., 1956, The Cost of Road Accidents, *Journal of the Royal Statistical Society A*, vol. 119(4): 393-408.

Romijn, G. and G. Renes, 2013a, *General guidance for cost-benefit analysis*, CPB and PBL http://www.pbl.nl/sites/default/files/cms/publicaties/pbl-cpb-2015-general-guidance-for-cost-benefit-analysis_01512.pdf

Second Delta Commission, 2008, Samen werken met water; een land dat leeft, bouwt aan zijn toekomst; Bevindingen van de Deltacommissie 2008.

Schroten, A., H.P. van Essen, S.J. Aarnink, E. Verhoef and J. Knockaert, 2014, Externe en infrastructuurkosten van verkeer: Een overzicht voor Nederland in 2010, Delft, CE Delft & VU.)

Stolwijk, H. and A. Verrips, 2000, Ruimte voor water; kosten en baten van zes projecten en enige alternatieven, *CPB Werkdocument* 130.

SWOV, 2014, Kosten van verkeersongevallen, SWOV-factsheet, maart 2014, Den Haag.

Thijsse, J.Th., 1972, *Een halve eeuw Zuiderzeewerken 1920-1970*, Tjeenk Willink, Groningen.

Tinbergen, J., 1954, De economische balans van het Deltaplan, bijlage bij het rapport van de Deltacommissie.

Toonen, T.A.J., G.S.A. Dijkstra and F. van der Meer, 2006, Modernization of Dutch water boards: resilience or change?, *Journal of institutional economics*, vol. 2, issue 2, 181-201.

Ven, G.P. van de (ed.), 2004, *Man-made lowlands; history of water management and land reclamation in the Netherlands*, International Commision on Irrigation and Drainage, ICID, Uitgeverij Matrijs, Utrecht.

Ven, G.P. van de, 2008, *De Nieuwe Waterweg en het Noordzeekanaal; een waagstuk*. Onderzoek in opdracht van de Deltacommissie.

Vreugdenhil, K., G. Alberts and P. van Gelder, 2001, Een eeuw wiskunde en werkelijkheid: waterloopkunde, *Nieuw Archief voor Wiskunde* (NAW) 5/2, vol. 3: 267-276.

Wemelsfelder, P.J., 1939, Wetmatigheden in het optreden van stormvloeden, *De ingenieur*, 3 maart 1939, 31-35.

Woud, A. van der, 1987, *Het lege land; de ruimtelijke orde van Nederland 1798-1848*, Olympus, Uitgeverij Contact, Amsterdam.

Woud, A. van der, 1992, De Kanalenkoning en zijn reputatie, in C.A. Tamse, E. Witte (red.), *Staats- en natievorming in Willem I's koninkrijk (1815-1830)*, Brussel/Baarn, pp. 237-260.

Zanden, J.L. and van Riel, 2000, *Nederland 1780-1914; staat, instituties en economische ontwikkeling,* Uitgeverij Balans.

Zwaneveld, P., W. Grevers, C. Eijgenraam, Y. van der Meulen, Z. Pluut, N. Hoefsloot and M. de Pater, 2012, De kosten en baten van de Toekomst van de Afsluitdijk; Economisch onderzoek, gebruik daarvan en invloed op het uiteindelijke kabinetsbesluit, *Water Governance*, Vol. 2 (2), 23-34.

Zwaneveld P. and G. Verweij, 2014, Economisch optimale waterveiligheid in het IJsselmeergebied. CPB Communication 14 January 2014. The Hague, The Netherlands

Zwaneveld P. and G. Verweij, 2014a, Safe dike-heights at minimal costs; an integer programming approach, CPB Discussion Paper 277.

Zwaneveld P. and G. Verweij, 2017, Economic Decision Problems in Multi-Level Flood Prevention. Draft CPB Discussion paper. The Hague, The Netherlands.

Annex A: The history of Dutch CBA for other public expenditure

In the Netherlands, CBA application is closely linked to major investments in flood risk management (see table below). Up to the 1970s, CBA's for other public investments were quite limited. Exceptions were a CBA for a railway track from Amsterdam to the Hague and a two tunnel highways near Amsterdam. Following a European Act[33], reporting environmental effects of public investments started in the 1980s.

At present, most CBA's in the Netherlands are confined to one of the following policy themes: water safety, mobility, energy, healthcare, social security and natural environment. On occasions, CBA's were also made of organizing major events, like the Olympic Games. The application of CBA to other social policy themes, like education and employment policy, is rare. Unlike in the USA, in the Netherlands CBA of new regulations and laws is also very limited. A major exception is the CBA of the European water quality regulation in 2006 (Ministry of Mobility and Water, 2006).

Table A1 The history of Dutch CBA

1901	CBA enclosure of the Zuiderzee and land reclamation
1954	CBA Delta Works by Tinbergen
1956	Economic analysis of optimal strength of dikes by van Dantzig
1959	CBA of two tunnel highway under a channel and river near Amsterdam
1965	CBA land reclamation of the Waddenzee
1969	CBA Schiphollijn, a railway track from Amsterdam to The Hague
1971	Official report by the government recommending cost-benefit analysis:
1975	CBA second national airport in the Netherlands
1976	CBA extending the harbour of IJmuiden/Amsterdam
1985	European act on reporting environmental effects of public and private investments: start of environmental effect reporting in the Netherlands
1993-1995	Reports by CPB on freight railway track Betuwelijn from Rotterdam harbour to Germany
2000	National guidelines on cost-benefit analysis for infrastructure projects
2013	National guidelines on cost-benefit analysis in general
2016-2017	Guidelines on CBA for specific policy themes

The first official report by the Dutch government recommending cost-benefit analysis was published in 1971 (Dutch Ministry of Finance, 1971). That report discussed the relevance and basic principles of cost-benefit analysis in very general terms and described applications to roads and rail tracks, land development and reorganisation and investments for outdoor recreation. The first set of national CBA guidelines was published in 2000 and focused on infrastructure projects (Eijgenraam et al, 2000, see section 4.2). In 2013, a revised and much general guideline (Romijn and Renes, 2013a) was published. Currently, for various specific policy themes, supplementary and more detailed CBA guidelines are being developed, e.g. for social policy, environment, nature and infrastructure.

[33] Act on environmental impact assessment, Directive 85/337 EEC.

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