A MODEL COMPARISON BETWEEN WWL TABEL AND REGIONAAL FOR SETTING A WATER ORDINANCE.

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Summary

In the Netherlands, the water boards are the responsible authorities for regional water management. Their tasks include managing water ordinances which affect the hydrological conditions in soil. Mismanaged hydrological conditions in soils can cause yield losses in agricultural production. When developing water ordinances, it is important to understand their potential consequences for the yield, and specifically to predict yield losses. Tools, such as the Waterwijzer Landbouw (WWL) can be used to quantify yield losses under different scenarios. WWL contains three models for such assessments: Maatwerk, Tabel and Regionaal. Tabel and Regionaal can quantify the yield losses on a regional level.

The goal of this study is to judge the performance of Tabel and Regionaal and their (dis-)advantages.

Theory

Regionaal is a sophisticated, geo-referenced time series model that predicts yield loss based on plant growth. It models plant growth and related yield losses on daily or weekly intervals with situation-specific input data such as hydrological conditions, climate data and soil conditions. Tabel also estimates the yield losses but based on a combination of (limited) conditions that generate pre-determined outputs. The database for Tabel has been developed based on outputs of Regionaal. These outputs were created by running different scenarios for a standard 30-year period.

Methods

A multicriteria decision analysis supported by model runs and interviews were used for this study. The criteria covered result type, validity, verification, acceptability, practicality and effectiveness. The result type refers to the unit and dimensions of the model results, in this case both models output relative yield loss over a region for a certain period in years. Validity and verification represent the reliability of the models. Acceptability is the scope of approval of a model by the users and stakeholders. The practicality of the models is defined by the ease of use, understanding and computation time. Effectiveness covers how useful the results of a model are to formulate advice. The findings were used in a multicriteria decision analysis to conclude which model is more suitable for setting water ordinance policies.

Validity and verification

This study found that both models have no existing research validating the models against real-world measurements. Only that Tabel had been validated against Regionaal. The verification of both models however is different: Regionaal is more verified since it is a deduction model predicting yield loss by simulating plant growth. Tabel, on the contrary, predicts the yield loss by predicting what Regionaal would have simulated.

Acceptability

From the interviews it was concluded that interviewees felt more confident in the results of Regionaal than in Tabel. This was due to Regionaal simulating the plant growth daily or weekly instead of seasonally.

Practicality

The practicality of Tabel is significantly better than Regionaal. Tabel is easier to use and requires significantly less computational power. Regionaal needs to simulate the plant growth daily or weekly for each raster cell of the to-be-modelled region. This simulation requires significantly more computation, which is a drawback.

Effectiveness

Due to the longer computational time of Regionaal this research made a model run only for a dry period. These results are less useful when setting a water ordinance compared to yield losses over a

longer period such as from Tabel. This is due to water ordinance being set for general circumstances. This made Tabel scoring higher on the criterion of effectiveness.

Conclusion

This study recommends the use of Tabel when setting water ordinance, since Tabel is easier and more feasible to use when simulating a thirty-year period. Although Regionaal is more verifiable than Tabel – due to Regionaal simulating plant growth daily or weekly – there is no hard evidence for this. Tabel has been validated against Regionaal and it was shown that Tabel overestimates drought yield loss in heavy clays during wet periods. The ease of use and quicker computation time of Tabel outweighs the validity and verifiability of Regionaal. In more specific research cases, like an extreme drought period, Regionaal is recommended, since that would require simulations of shorter time periods.

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List of Abbreviations

Abbreviation	Meaning
AGOR	Actueel grond- en oppervlaktewater regime: current ground- and surfacewater regime
BOFEK	Bodem Fysiologische Eenheden Kaart: rastermap describing soil types
FIXED	Model that simulates yield of plants with fixed seasonal growth
GHG	Gemiddeld hoogste grondwaterstand: average highest groundwater table
GLG	Gemiddeld laagste grondwaterstand: average lowest groundwater table
HELP-tabellen	A predecessor of WWL Tabel and Regionaal
KNMI	Koninklijk Nederlands Meteorologisch Instituut: Dutch weather institute
LGN	Landelijk Grondgebruiksbestand Nederland: Dutch land-use map
MCDA	Multi-criteria decision analysis
NUSAP	Numerical, Unit, Spread, Assessment and Pedigree: a notational system to evaluate models
PV	Peilvoorstel: proposed water ordinance
RAMEC	Risk Assessment Method Evaluation Criteria
RQ	Research question
SWAP	Soil, water, atmosphere, plant: model to simulate hydrology in the soil
WOFOST	World Food Studies Simulation Model: model to simulate plant growth
WWL	Waterwijzer Landbouw

1 Introduction

On a global level, 70% of the available freshwater resources are used for agricultural production (Food and Agriculture Organization, 2023). Water is a vital resource for agricultural activity as it is necessary for the growth of crops. Meeting crops' water demand is relevant as excessive water leads to vegetation suffocating due to oxygen stress and water deficit causing drought stress (Mulder et al., 2018). Managing soil water for plant availability is complex and thus challenging, but necessary to keep potential damages minimal. To understand the impacts of hydrologic soil conditions on yield losses different approaches are used. In the present study, the Waterwijzer Landbouw (WWL) – a tool to simulate the growth of crops and quantify potential yield losses due to unsuitable hydrological soil and weather conditions (Martin Mulder et al., 2021) – is assessed .

In the Netherlands, the geographical context of the study, water resources are managed by waterboards that act upon water ordinances (*peilbesluiten*) (Groothuijse et al., 2016). A water ordinance establishes surface water levels for a certain region. These water levels are maintained with sluices, pumps, culverts and ditches for example (Groothuijse et al., 2016). The surface water levels affect groundwater tables. The ground water tables in an area determine the hydrological soil conditions which affect plant growth (De Wit & Boogaard, 2021). Thus, the water ordinance indirectly affects the plant growth in its region by affecting the hydrological soil conditions. Changes in the water ordinance can result in yield changes in agriculture. If the water boards want to know the effects of changing the water ordinance on the yield in agriculture, WWL can be a useful tool to predict/simulate these effects.

WWL contains three different models: Maatwerk, Regionaal and Tabel. Maatwerk and Regionaal both simulate the growth of crops in time intervals and compare them to the ideal growth. Maatwerk simulates the growth in a single point in a field whereas Regionaal assesses growth in a region. Regionaal and Tabel are both georeferenced models. Tabel, on the contrary to Regionaal, quantifies yield losses through derived metarelations[1], which links the yield losses of crops to the hydrological soil and weather conditions. Since water ordinances concern regions, both Tabel and Regionaal can be used by the waterboards to quantify the yield loss.

1.1 Research objective

The research aims to judge the performance of the two water-management models Tabel and Regionaal, including their respective (dis-)advantages, to inform decision-making in water ordinance.

The main research question to fulfil the research objective is:

> *How do the two models (Tabel and Regionaal) perform relative to each other in informing decision-making processes for water ordinances?*

The research questions to answer the main question are listed below. The first group of questions (RQ 1) are to test the models on their reliability. This is split into validity and verifiability. It is important to understand what theories the models use and how they are programmed as well as how valid the results are. The second group of research questions (RQ 2) are to compare the results either model gives and what they mean. Last group of questions (RQ 3) are about the type of results that is required for consulting in water ordinance. It aims to find out what results are needed for the policy-making process and what the implications of either model is in the policy-making process.

RQ 1. How do the validation and verification of either model compare to each other?

RQ 1.1. How valid and verified is each model?

[1] These metarelations were created with Regionaal. This is further explained in chapter 2.

RQ 1.1.1. For which purposes was the model developed?
RQ 1.1.2. Which assumptions were used in either method?
RQ 1.1.3. How is the conceptual model validity of either method?
RQ 1.1.4. How is the computerised model verification of either method? (Structure of model code, etc.)
RQ 1.1.5. What is the operational validity of either method?

RQ 2. How does the output of either method compare to each other?
RQ 2.1. How can the results of either model be classified?
RQ 2.2. What are the differences in the results of Regionaal and Tabel?
RQ 2.2.1. How could these be explained?
RQ 2.2.2. How should these be interpreted?
RQ 2.3. Are there any anomalies in the results of either model?
RQ 2.3.1. If so: how did these originate?

RQ 3. What kind of model results are needed for consultancy?
RQ 3.1. How had previous consultancy cases used WWL to analyse different measures?
RQ 3.2. How would the results affect the decision-making?
RQ 3.3. What type of results are preferred?

1.2 Report structure

Chapter 2 Waterwijzer Landbouw explains the background of quantifying the yield loss due to the hydrological soil conditions. It is clarified why WWL has been developed. This chapter also explains both models (Regionaal and Tabel) in detail and how they are operated. It is recommended to read the entire chapter if one is unfamiliar with the models.

Chapter 3 Research Methods explains the methods used in this project. These are a multi-criteria decision analysis (MCDA), model case study and an interview study.

Chapter 4 Results is the overview of the results of this research. This chapter is split into three parts. First is the model case study, second the interview study and last is the evaluation of the MCDA.

Chapter 5 Discussion comments on the results and research. Whether there were any issues or instants that should be mentioned and their possible implications within this research.

Chapter 6 Conclusion and Recommendations concludes the report by answering the research questions using the results. Besides the conclusions, recommendations for model usage, further research and projects are given.

2 Waterwijzer Landbouw

This chapter first explores the development of WWL itself. WWL is designed to be an improvement on the preexisting tools to determine yield loss due to hydrological soil conditions. The models incorporated in WWL are explained in the following chapters, first Regionaal then Tabel. The reason for this order is that Tabel is derived from Regionaal. Each model paragraph starts with the conceptual model followed by the model structure and properties. This is followed by how the models are operated. The chapter ends with a summarising comparison for those who are familiar with the models already.

2.1 Development Waterwijzer Landbouw

As explained in the Introduction it is necessary to quantify the yield losses due to weather and related hydrological conditions. The so-called HELP-tabellen - tables which quantified yield losses based on expert interpretation – were used in the past. These tables were based on weather conditions from 1951-1980 which were not up to date due to climate change (Martin Mulder et al., 2018). Consequently, these tables are not replicable for periods with different weather conditions. It was also debatable whether the expert interpretation in the HELP-tabellen was reliable (Martin Mulder et al., 2018).Thus a model – which could quantify the yield loss independent from expert judgement and fixed parameters – was needed since external changes such as weather or different soil types were not included in the tables. The tables had fixed parameters that would need to be adapted if conditions for crop growth changed.

The WWL models, Tabel, Maatwerk and Regionaal, were developed for this reason. These models were designed to quantify the yield loss by simulating plant growth. The advantage of these models is that parameters for weather, soil and hydrology can be adapted. In this way, climate and spatial changes can be considered (Martin Mulder et al., 2021).

The models can be used for studying the implications of water ordinances in agriculture. The yield losses due to the groundwater tables can be modelled in WWL Tabel and Regionaal. These models quantify the yield losses resulting from poor hydrological soil conditions for an area. The area is split into rasters with adjustable grid cell sizes. The models differentiate for multiple causes of yield losses, due to hydrological soil conditions: direct causalities such as drought, oversaturation and salinisation, as well as indirect causalities. These indirect causalities are the delay of seeding, ploughing and harvesting. The delay for seeding occurs if the soil is too dry or too wet for plants to root. Ploughing and harvesting delays occur if the soil is too wet, making the land inaccessible for machinery. This could lead to a shortened growth period for crops causing yield loss. The knowledge of where and why yield losses occur for certain water ordinances aid in the decision-making process in water ordinance implementation.

2.2 WWL Regionaal

Regionaal is a sophisticated, geo-referenced time series model that predicts yield loss based on plant growth. The growth of plants depends on the crop, soil type, hydrology and the weather (De Wit & Boogaard, 2021; Martin Mulder et al., 2021). The growth of the plant in turn affects the hydrology in the soil since growth requires water. Wet or dry conditions stress crop growth which lowers the demand for water at the roots. These growth reductions lead to yield loss. The yield losses due to growth reductions are classified as direct causes.

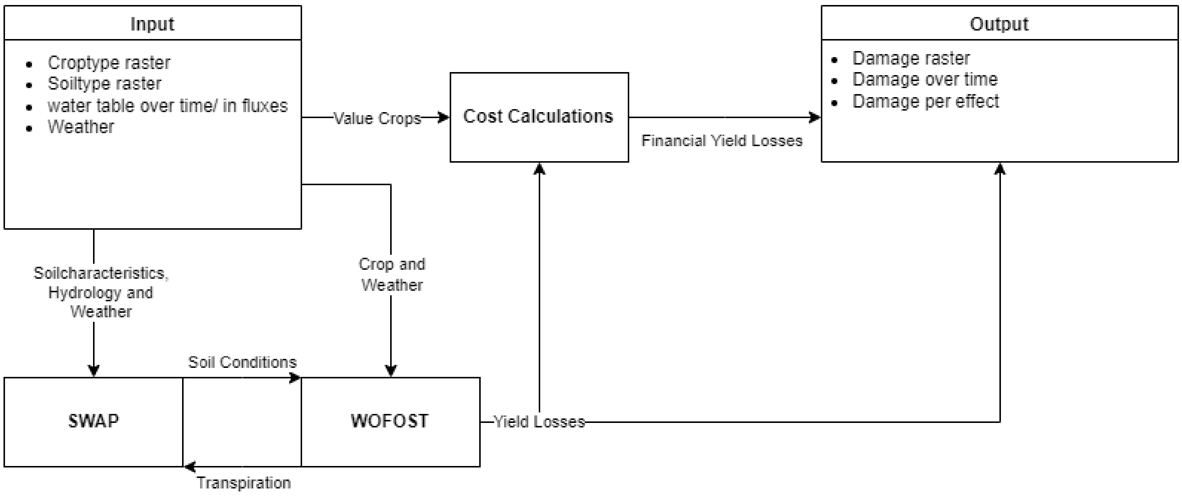


Figure 2-1: Conceptual Model WWL Regionaal

Figure 2-1 shows the conceptual model of WWL Regionaal. The crops and soil type need to be specified for each raster cell. The water tables can vary over time and can be given as head or height relative to the ground surface. The weather can be put in as a daily radar rain raster map or set for a weather station. In the latter case, the users set the weather station from which Regionaal should extract the weather data.

The relationship between the hydrological soil conditions and the growth of plants is modelled with SWAP and WOFOST. SWAP models the hydrological soil conditions and WOFOST the transpiration (the amount of water the roots absorb). WOFOST consists of three different models: WOFOST (for seasonal growing crops), GRASS (for grass-like plants which get mowed multiple times per season) and FIXED (for plants that have a fixed growth over different seasons (such as trees)). Indirect causes occur if the soil is not sufficiently wet or too wet which leads to delay the timing for ploughing, seeding, and harvesting. These causalities are returned to the growth calculations in the model.

SWAP-WOFOST is the heart of Regionaal, it determines the water flows and growth of crops. SWAP-WOFOST can keep track of (in-)direct causes reducing the plant growth during the simulation.

For the output, the yield losses are returned on a raster of total yield loss and per (in-)direct causality. The translation of yield loss to financial yield loss can be done with datasets that contain the price per kilogram for a given crop.

2.3 WWL Tabel

Tabel was developed to compute yield losses quicker than Regionaal (Martin Mulder et al., 2018). Tabel estimates the yield losses but based on a combination of (limited) conditions that generate pre-determined outputs. This database is called Tabel hence the name WWL Tabel. The database was made by running the sub-models SWAP and WOFOST for different scenarios; for each combination of crop, soil type, and weather type 100 simulations with and 700 without irrigation were conducted. This resulted in a database with over 2 million simulations per climate scenario each for 30 years (Mulder et al., 2018).

Meta-relations from the database have been derived with a random forest model (Breiman, 2001). This model is known for its predictive capabilities (Mulder et al., 2018). Forests –a group of regression trees resembling the causalities for the yield losses– predict the yield loss through ensemble modelling. The relations describe the yield loss per causality (total, (in)direct, oxygen stress, drought stress and salinisation stress) between average highest and lowest groundwater table. Per causality, a relation exists for the highest and lowest average groundwater table mapped with related damages.

Figure 2-2 shows the meta-relation for a field of potatoes in the current climate conditions. For a given GLG (average lowest groundwater table) and GHG (average highest groundwater table), the yield losses can be extracted from the database. Because WWL Tabel has such a large database it can apply or interpolate a meta-relation for any kind of combination of input.

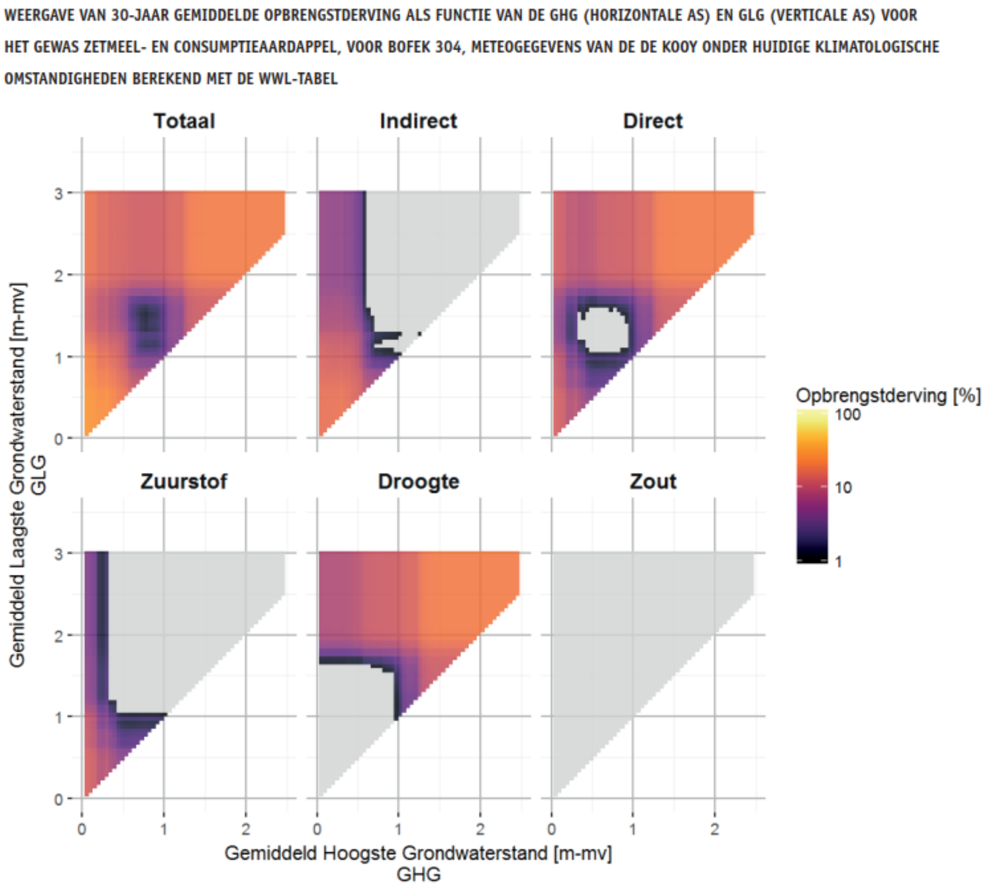


Figure 2-2: Meta-relation for potatoes for BOFEK 304 and METEO-data from De Kooy for current climate conditions Mulder et al. (2018)

Using the meta-relations between water tables and the yield losses, the complexity of the model has been reduced. Since the daily interaction between the hydrological soil conditions and plant growth is not modelled. Instead of modelling the daily development per crop, the average yield loss for a period is quantified immediately through these meta-relations.

2.4 Software Operation

Both models are scripted in the programming language R. The models are both structured in a folder containing subfolders for the input, (temporary) output, tools, and documentation. There are also *".inp"* files to control the settings for a model run and executable files to run the (sub-)models.

Regionaal has 5 sub-models. The initialisation submodel creates meteo-files if necessary (the input data for weather). In certain cases, one does not have these files as input. In this case, these files can be made by extracting data from nearby or similar weather stations (like a station with similar weather conditions). Having these meteo-files are necessary to run Regionaal.

Once the meteo-files are ready, the first sub-model can be used. Here the data files needed for the SWAP-WOFOST simulation are prepared. The next sub-model is the SWAP-WOFOST simulation itself which requires the most computation time to run. There is also a tool available to check whether the second sub-model successfully made all its runs. The third sub-model analyses all the SWAP-WOFOST runs for the yield losses. Like the second sub-model this part also has a tool to check if all its runs have been analysed successfully. The last sub-model is to aggregate the results into raster maps containing the yield losses.

Tabel uses its database to calculate the yield losses and therefore has only an executable file to run the model. Tabel first analyses a raster cell to look at the specific input for said cell, which are the hydrological soil and weather conditions, the soil type and the land-use. Then Tabel applies a meta-relationship to the specific raster cell inputs and estimates the yield losses for that cell. If this has been done for each cell, the raster maps containing the yield losses are made.

2.5 Comparison WWL Models

In Table 2-1 a comparison of the WWL models is given. It shows differences regarding model scope, input and methodology.

Regionaal uses SWAP-WOFOST to model the growth of plants per time step. The usage of SWAP-WOFOST makes the model complex and significantly increases computation(time). Tabel, unlike Regionaal, does not use the SWAP-WOFOST model each run but derived meta-relations making Tabel less complex and much quicker. Table 2-1 also shows that WWL-Tabel requires more standardised input data such as BOFEK, GHG and GLG and the weather data from 1 of the 5 main weather stations whereas Regionaal has more freedom in the type of input.

Table 2-1: Comparison Tabel and Regionaal (Mulder et al., 2021)

	WWL Tabel	WWL Regionaal
Core	WWL meta-relations, based on calculations with SWAP-WOFOST	SWAP-WOFOST and regional hydrology model
Scale of application	National and regional	regional
Soil Data	BOFEK	Regionally available soil data or common soil profiles
Hydrology	Water table/characteristics (GHG and GLG[2])	Water tables in time intervals
Meteorological Data	From 1 of the 5 main weather stations[3]	From any desired weather station
Climate Scenarios	Current climate (1981-2010) and climate scenario Wh[4] (2036-2065)	Any option is possible
Crop types	10 most common crop types	23 most common crop types

[3]The main weather stations are: de Kooy (235), De Bilt (260), Eelde (280), Vlissingen (310) en Maastricht (380).

[4] Climate Scenario with high rise in temperature (Kennisportaal Klimaat adaptie, 2022)

3 Research Methods

The main method used to evaluate Regionaal and Tabel is through a multi-criteria decision analysis (MCDA). A model case study and interview study are used to support evaluating the criteria of the MCDA. This chapter first explains the MCDA and its criteria then the model case and interview study.

3.1 Multi-Criteria Decision Analysis

To evaluate both models, Tabel and Regionaal, a MCDA was conducted. The models are compared with each other on different criteria. These criteria were set up at the beginning of the research and evaluated through interviews, literature and model usage. The total score for either model can be determined after criteria have been evaluated. The model with the highest score is the most appropriate model according to the MCDA.

Formulation of the Criteria

The analysis starts with the establishment of the criteria to assess the model methods. These criteria should cover the research questions and were based on *"Risk Assessment Method Evaluation Criteria"* (RAMEC) and *"NUSAP"* (Numerical, Unit, Spread, Assessment and Pedigree: a notational system to evaluate models)(Covello & Merkhofer, 1993; Janssen & Sluijs, 2004). These reports have been peer reviewed and cover the important aspects of model design and usage.

RAMEC addresses criteria about the model internally and externally. The internal criteria are logical soundness, completeness, and accuracy. Logical soundness addresses the theories, methods and assumptions that are used. Completeness tests whether the model method is complete and whether certain aspects are left out. Last, the accuracy is about the precision of the model. The external criteria of RAMEC are acceptability, practicality, and effectiveness. Acceptability focuses on the compatibility with existing institutes and whether clients accept the method. The practicality looks at the expertise required to operate the model and how much time and computation is required to run the model. Third is effectiveness, which reflects on the usefulness of the model output for decision-making processes.

The second evaluation method, NUSAP, is a notational system which aims to evaluate models for policy making. NUSAP is an abbreviation of Numerical, Unit, Spread, Assessment and Pedigree. Numerical, Unit and Spread are respectively the output with a specific unit and statistical spread. The Assessment reflects on the Number, Unit and Spread as a whole. Last is the Pedigree which is a matrix which describes several criteria. A pedigree matrix is an evaluation tool which looks at the proxy representation, empirical basis, theoretical understanding, methodology and validation of the model. Proxy representation means how well the output fits the knowledge gap in the decision-making. The empirical basis represents the empirical foundation of the parameters within the model. The theoretical understanding reflects how well-established the theory behind the model is. The methodology is to reflect on the method to implement the theory in the model. Last, is the validation which addresses the validity of the output of the model.

The NUSAP evaluation covers the two internal criteria from RAMEC about the logical soundness and the accuracy of the model. The criteria for the MCDA have been formulated and listed in Table 3-1.

Table 3-1: Criteria for the Multi Criteria Decision Analysis

Scope	Category	Code	Criterion
Internal	Assessment	IA1	The model method outputs a raster map showing the yield losses for a certain period
		IA2	Does the model method outperform the other method during the case study?
	Pedigree Matrix	IP1	The model method outputs an exact measure of the desired quantity
		IP2	The empirical basis consists of controlled experiments and large samples of direct measurements
		IP3	The theory behind the model method is well established
		IP4	The methodology used is the best available in a well-established discipline
		IP5	The model method output can be validated with independent measurements of the same variable over a longer period
	Completeness	IC	The model covers as many aspects as possible
External	Acceptability	EA1	The model method is accepted by waterboards and other institutes
		EA2	Users and experts are confident in the model
	Practicality	EP1	The model method can be used by an inexpert
		EP2	The model method has a low demand for computational power and time to run
		EP3	The input data is easily attainable
	Effectiveness	EE	The model is useful for decision making

The research questions and criteria have been pairwise matched to show that the research questions are covered by all the criteria. This is shown in appendix A**.** The matching confirms that the criteria cover all the research questions.

The criteria are scored by comparing Regionaal relative to Tabel. The scoring can be *"++", "+", "0", "-"* and *"--"* indicating Regionaal's performance compared to Tabel. The meaning of the scoring in the same order is: *"significantly better"*, *"better"*, *"no clear/significant distinction which performs better"*, *"worse"* and *"significantly worse"*.

3.2 Model Case Study

To further gain insight into the model performances, a model case study is conducted. The case study gives insight into the scope and unit of the results of both models. This insight is needed to know whether either model outputs can be used for consultancy in water ordinance. The case study covers the internal assessment (IA2), external practicality (EP2 and EP3) and the external effectiveness of the MCDA.

Case study Groesbeek and Ooijpolder

This paragraph first describes the study area. Then the scenarios modelled in Tabel and in Regionaal. A scenario is defined by its simulation period, region and set water ordinance. The data collection and visualisation are explained at the end.

The case study area is Groesbeek & Ooijpolder, which is marked by a red border in Figure 3-1 (Peilbesluitgebied means water ordinance area and Gemeentegrenzen municipality borders). The yield losses are quantified from 1991 to 2020 with the GHG and GLG data. The input data used for this research are:

- Soil characteristics: BOFEK2012 and BOFEK 2020 raster maps
- Crop types: Land-use raster maps from LGN (institute mapping land-use in the Netherlands)
- Hydrology of 2011-2019 (hydrological years):
  - AGOR GHG and GLG (AGOR refers to the current scenario)[5]
  - PV GHG and GLG (PV stands for "peilsvoorstel" meaning proposed water ordinance)
  - AGOR daily groundwater tables
  - PV daily groundwater tables

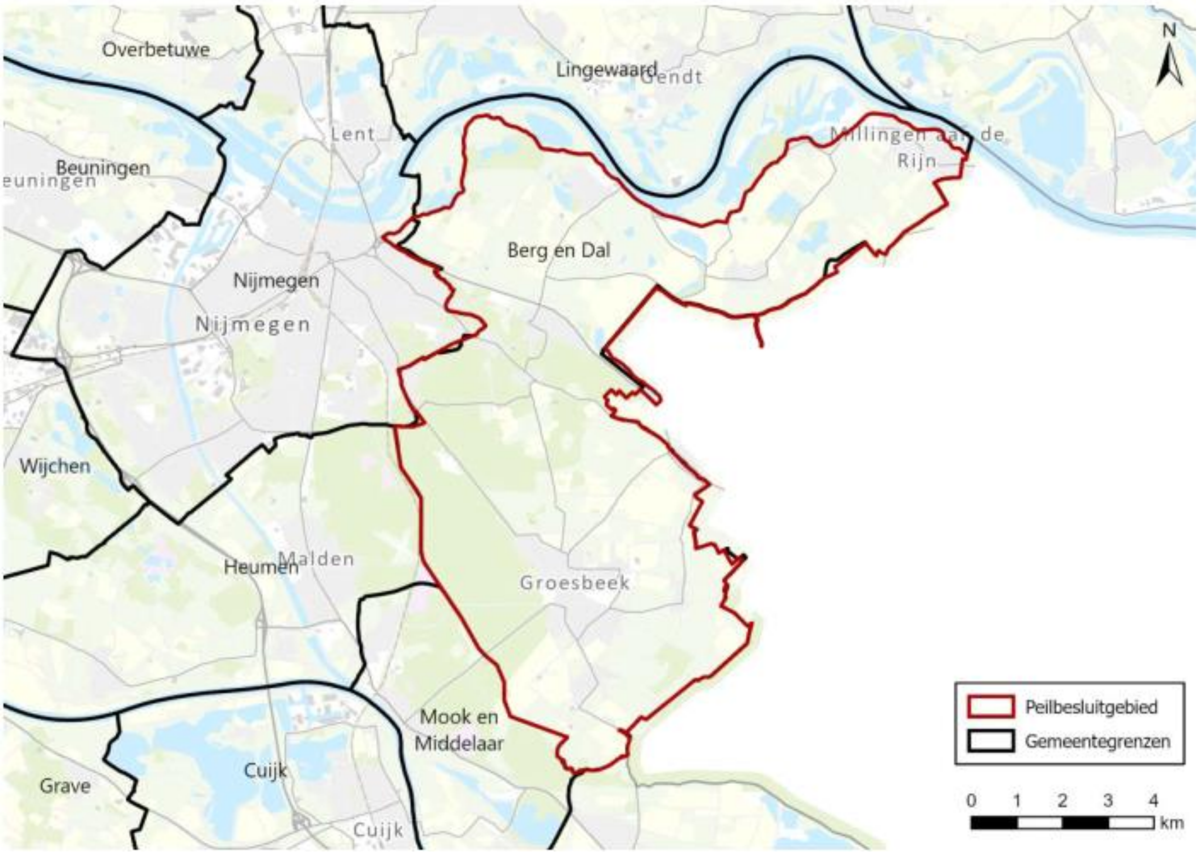


Figure 3-1: Framework water ordinance Groesbeek & Ooijpolder (Zalm, 2021)

The raster maps' grid size used in this study is 25 by 25 metres. Further input is which weather station to use and the period to model. The weather station used is station 260, which is "De Bilt".

The years 2017-2018 were chosen for Regionaal because 2018 is an extremely dry year and 2017 was slightly wetter than normal (Adrie Huiskamp, 2018; Adrie Huiskamp, 2019).. To reduce simulation time, the simulation period is limited to two years.

[5] AGOR is an Dutch abbreviation for "actueel grond- en oppervlaktewater regime" which translates to current ground- and surface water regime.

The data from the case study is collected as rasters showing the yield losses in total and split up into the respective causalities causing the yield losses. The overall yield losses for the entire region will also be given per scenario (e.g.: total yield loss is 40%, from which indirect causes are 10% and direct 30%. For direct causes, the yield losses from dry causes are 20% and wet 10%).

3.3 Interview Study

The interview study is to evaluate the internal assessment criterion 2 (IA2) and all the external criteria. The interviews are conducted with different participants; the model developer, a consultant and the waterboard. These are relevant since the model developer can give insights about the model itself and its mechanics and the waterboard must use the results for setting the water ordinances. The consultant applies the model and could help understand the integration between using the model and interpreting the results. For this reason, there are three different interviews prepared each with a different objective. The interviews use open questions (see appendix C) and were recorded. Open questions are used to enable interviewees to give extra information that could be useful to the study.

Model developer interview

The objective is to gain insight into the internal criteria of the models. For this, the interviewee is asked to assess the model, go through the pedigree matrix and reflect on the completeness of the model (see internal criteria in chapter 3.1). Model results from the case study are reviewed here as well. In the model case study, Tabel and Regionaal are compared and differences in the model results need to be understood. The expertise and experience of the interviewee is helpful to understand the differences between the model results.

Waterboard interview

The objective is to gain insight into the external criteria of the models. For this, the interviewee is asked to reflect on the acceptability, practicality, and effectiveness of the model (see external criteria in chapter 3.1). The model results from the case study are reviewed as well. The questions here focus on the implications of the differences in results between Tabel and Regionaal and how they could impact decision-making.

Consultant interview

The objective is a combination of the interviews of the model developer and the waterboard. The interview focuses on all criteria (internal and external) and whether this set of criteria fits the assessment of this model study. Here the differences between the model results from the case study are reviewed as well, on a technical level and the impacts on decision-making processes.

4 Results

This chapter provides the comparison between the Regionaal and Tabel based on data from the case study and interviews. In the end, the evaluation with the MCDA is given.

4.1 Results: Case Study

In this paragraph, the results from the model case study are presented. Table 4-1 lists the modelled scenarios.

Table 4-1: Scenarios model case study. AGOR refers to the current scenario and PV to a scenario with the proposed water ordinance. If the database of Tabel was set to 2.0.0, BOFEK 2012 was used and BOFEK 2020 for 3.0.0.

Scenario	Model	Period	Figure (see appendix B)	Computation Time [h:min:s]
AGOR	Tabel	1981-2010	Figure B-6	00:01:46
		1991-2020	Figure B-1	00:01:37
			Figure B-6	
	Regionaal BOFEK 2020	2017-2018	Figure B-2	57:30:53
			Figure B-3	
			Figure B-4	
PV	Tabel	1991-2020	Figure B-5	00:01:38

The figures in Table 4-1 can be found in appendix B. Figure 4-1, Figure 4-2 and Figure 4-3 show the expected yield losses according to Tabel and Regionaal. Figure 4-1 shows that Regionaal outputs a higher yield loss on average for the region than Tabel. Regionaal estimates the yield loss for 2017-2018 at 22,6% whereas Tabel estimates the yield loss for 1991-2020 at 9,0%. Tabel does not provide the yield loss per year, but Regionaal does. The total yield loss for 2017 and 2018 are respectively 16% and 28,7%, see appendix B Figure B-3 and Figure B-4. This is due to 2018 being a drought year and 2017 a slightly wet year.

Regionaal estimates significantly higher yield losses compared to Tabel. Especially in the southern parts of the study area. According to Regionaal the main contributor to these yield losses is drought. This area has more hills and thus more sloped fields. Due to the runoff of sloped area these may be more vulnerable to drought damages (van Oort et al., 2023).

In Tabel, the yield losses near the river in the northern region are higher due to wet damages see Figure 4-3. The wet yield losses seem to match the total yield loss in Figure 4-1. Unlike Regionaal, in which drought is the leading contributor of the yield loss, which is likely due to Regionaal simulating 2018 which is a dry year (Adrie Huiskamp, 2019).

A consultant would focus on setting a water ordinance to mitigate the drought damages in the south on the hilly area and near the river area in the north when using the results of Regionaal. Whereas the results of Tabel would shift the focus on maintaining the current scenario since the yield loss is only 9%. Some mitigations in the water ordinance may be made to reduce the wet yield losses, from Tabel, near the river in the north.

This also shows the key-difference between the results of both models. With the results from Tabel a consultant would find their conclusion on an average period based on the timespan 1991-2020 in which drought is not the main issue whereas a consultant would focus on drought scenarios with Regionaal since Regionaal modelled a dry year (2018) and thus drought yield losses are prominent.

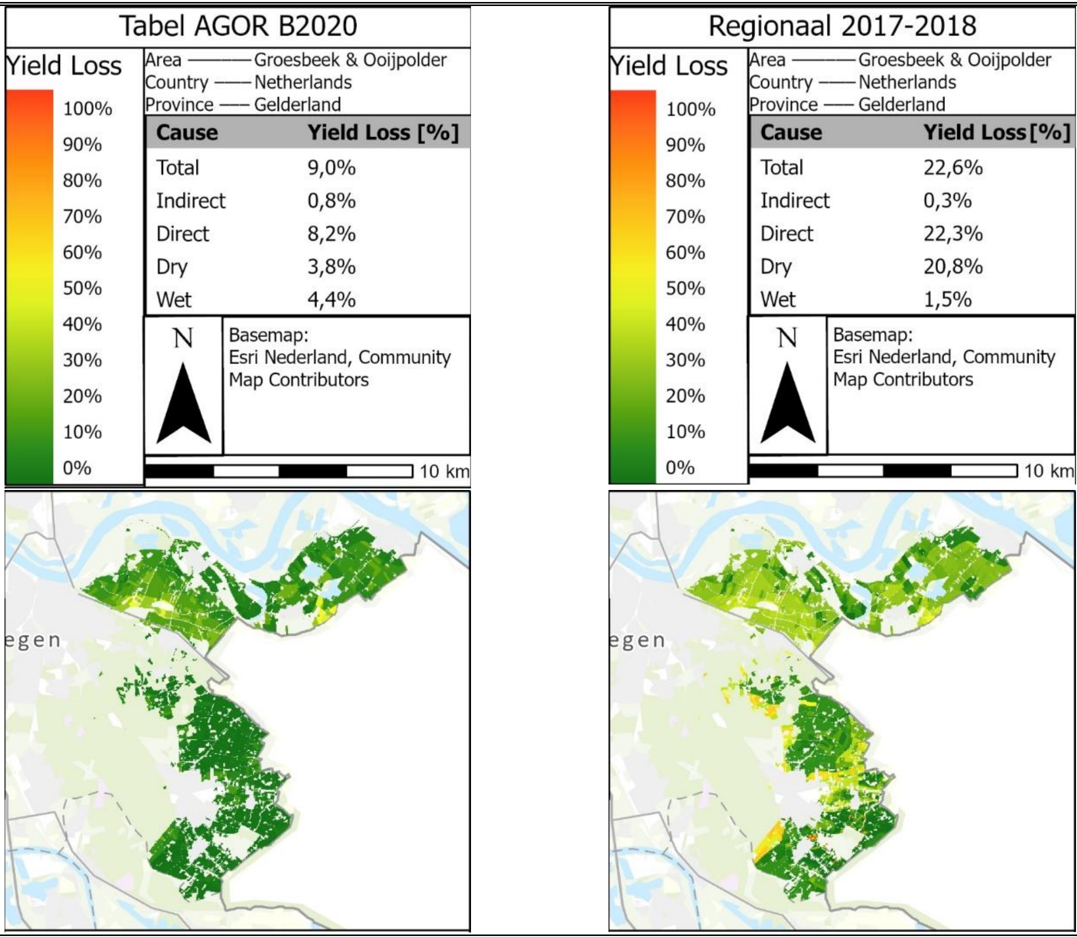


Figure 4-1: Shows the total yield loss modelled by Tabel and Regionaal for Groesbeek & Ooijpolder. The upper figures show the legends applicable to Figure 4-1, Figure 4-2 and Figure 4-3.

Tabel	Regionaal

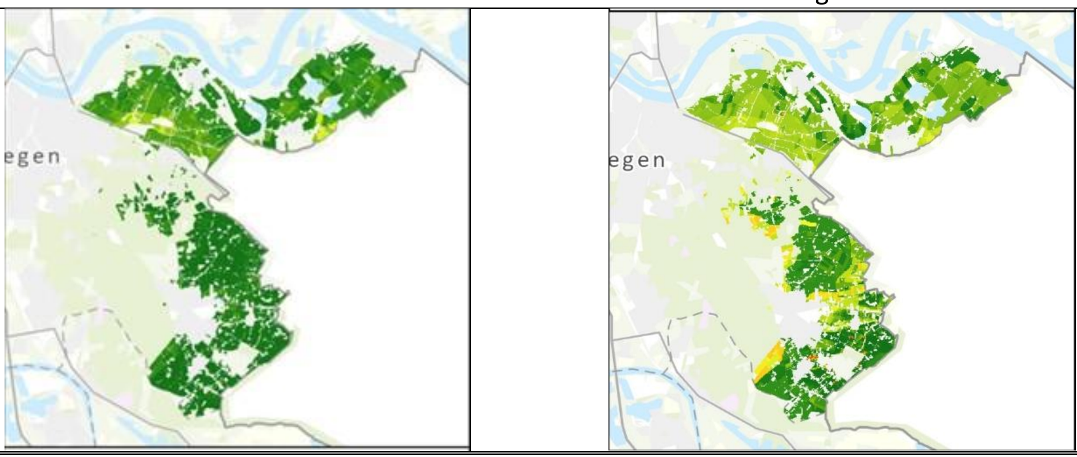


Figure 4-2: Shows the direct yield loss modelled by Tabel and Regionaal for Groesbeek & Ooijpolder.

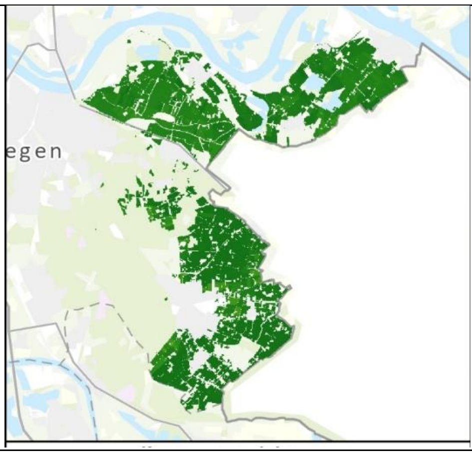
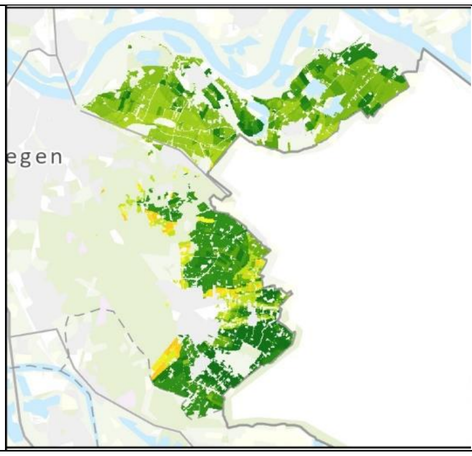
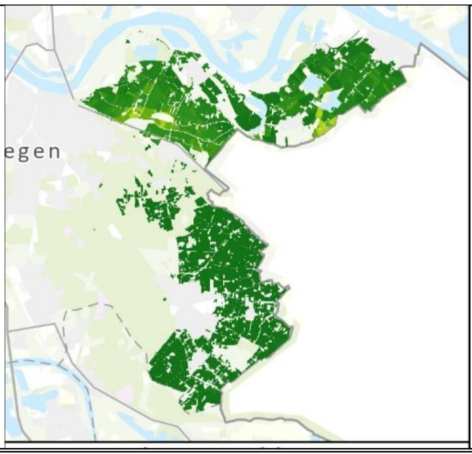
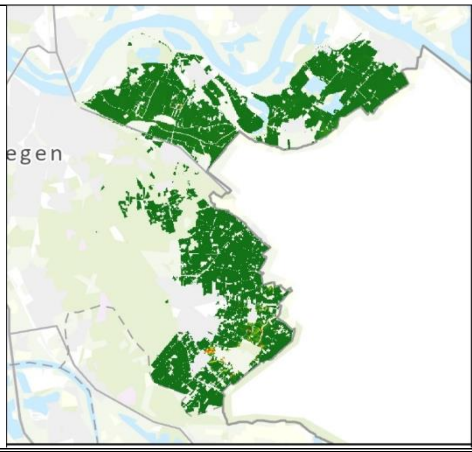
Tabel	Regionaal
Dry yield loss	
	
Wet yield loss	
	

Figure 4-3: Shows the dry and wet yield loss modelled by Tabel and Regionaal for Groesbeek & Ooijpolder.

4.2 Results: Interviews

The results from the interviews can be found in Appendix C. The interviewees were the model developer, waterboard and consultant. The three interviewees had more confidence in the model results of Regionaal compared to Tabel. This is due to Regionaal simulating growth instead of using meta-relations. But the time required to model in Regionaal was considered a disadvantage justifying the use of Tabel. The interviewees from the waterboard and consultant said that a simulation for a longer period with average conditions is more fitting when looking at the overall performance of a water ordinance. However, a simulation in Regionaal with drought can be useful to test an area against drought resilience. The waterboard noted that such results could aid in taking measures against droughts within a study area. The consultant also noted that studying the impacts on yield during droughts is useful for water ordinances since droughts have become more common.

4.3 Results: MCDA Evaluation

This paragraph evaluates the criteria of the MCDA which are shown in Table 4-2. The paragraphs below explain each category of the MCDA. The MCDA scores Regionaal relative to Tabel, see Table 4-2. First paragraphs cover the internal criteria the latter paragraphs the external criteria. Key-words of the criteria in Table 4-2 are made bold such that they can be referred to in the paragraphs.

Table 4-2: Relative scoring of the criteria of the Multi-Criteria Decision Analysis. The scoring can be "++", "+", "0", "-" and "--" indicating Regionaal's performance compared to Tabel. The meaning of the scoring in the same order is: "significantly better", "better", "no clear/significant distinction which performs better", "worse" and "significantly worse".

Scope	Category	Criterion	Score
Internal	Assessment	The model method **outputs** a raster map showing the yield losses for a certain period	0
		The model method **outperforms** the other method during the case study	-
	Pedigree Matrix	The model method outputs an **exact measure** of the desired quantity	0
		The **empirical basis** consists of controlled experiments and large samples of direct measurements	+
		The **theory** behind the model method is well established	0
		The **methodology** used is the best available in a well-established discipline	+
		The model method output can be **validated** with independent measurements of the same variable over a longer period	0
	Completeness	The model **covers** as many aspects as possible	+
External	Acceptability	The model method is **accepted** by waterboards and other institutes	0
		Users and experts are **confident** in the model	+
	Practicality	The model method can be used by an **inexpert**	-
		The model method has a low demand for computational power and **time** to run	--
		The **input data** is easily attainable	-
	Effectiveness	The model is **useful** for decision making	-
Total Score			--

Assessment

For the assessment, there are two criteria. The first criterion is that the model **outputs** a raster with the yield losses for a certain period. Both models output raster maps with yield losses for a given period. The periods are however restricted to years, as in from January the 1st until December the 31st. Since both models fulfil the criteria, it is scored with a *"0"*.

The second criterion is which model **outperforms** the other in the model case study. The interviews determined that the results from Tabel were most useful for decision-making regarding water ordinance, because the water ordinances are designed for standard conditions. In Regionaal the simulation was done for the years 2017 and 2018 in which 2018 was a dry year. Although Regionaal showed the most affected locations during a drought it does not show the performance of a water ordinance for general circumstances over a longer period. Regionaal thus scored *"-"*.

Pedigree
For the first criterion is that a model outputs an **exact measure** of the desired quantity. The models have no clear distinction in how fitting the model results are. Both models' output raster maps relative yield losses for a certain period. One advantage of Regionaal is however that it also provides the yield losses of each year within the period. As already mentioned in the assessment, the yield losses over a longer period are more relevant than those of a single year. Since both models can output the same type of results the score is *"0"*.

Regionaal performs better on the **empirical basis.** Since Tabel's empirical basis is completely extrapolated from Regionaal. Meaning that the empirical basis supporting Tabel is always less based on measurements than Regionaal. The less the empirical basis relies on derived and speculated data the better. Regionaal's empirical basis is thus better and scores *"+".*

For the third criterion, both models perform the same since they both rely on the same **theory**. The theory describes the relationship between plant growth and hydrological soil and weather conditions. Thus, the score is *"0".*

The fourth criterion is about the **methodology**. The methods to implement the theory between the models are different. The purpose for the WWL models is to quantify the yield losses in agriculture due to the meteorological and hydrological soil conditions. The objectives of Regionaal and Tabel differ if one only looks at the way the models have been designed. Regionaal outputs the yield loss by simulating the plant growth whereas Tabel attempts to predict the yield loss that Regionaal would have simulated in the same conditions through its meta-relations (Martin Mulder et al., 2021). Since the goal is to quantify the yield losses of the crops it is better to model the growth of the crops themselves rather than what Regionaal would predict. Therefore, Regionaal scores better and the score is *"+"*.

For the last criterion, both models perform the same. WWL Regionaal is not **validated** with measurements from the real world. It is difficult to measure yield losses specifically due to the hydrological soil and weather conditions. Tabel has been validated against Regionaal since it models yield losses by estimating the results from Regionaal (Martin Mulder et al., 2021). Although Tabel has been validated against Regionaal it also has not been validated against measurements from the real world. It is very hard to measure yield loss, and it is even harder to measure the specific yield losses due to the water ordinance. Thus, both models score the same and the score is set at *"0".*

Completeness
Since the growth of plants is quite complex there have been made several assumptions in WWL Regionaal to reduce complexity. Important assumptions made in Regionaal are listed below (Martin Mulder et al., 2018):

- Water flows only vertically (1 dimensional)
- Interventions against diseases and pests are not considered for indirect causes
- Automatic irrigation is based on drought stress
- Root development is not modelled

The impact of the assumptions is unknown since there has no sensitivity analysis been performed. However, in the interview with the model expert, it was said that root development was currently the most important assumption, since the root development determines the absorption of water in the soil which in turn determines the growth of the crop.

The assumptions of Regionaal directly translate into the database of Tabel. Tabel assumes however that the results of Regionaal are reliable to quantify the yield losses and that the meta relations can be used to model Regionaal. Regionaal scores a *"+"* on completeness since Tabel **covers** less aspects in its modelling process by using its meta-relations.

Acceptability
There are two criteria assessed regarding the acceptance of the models. The first is whether the model is **accepted** by the waterboards and other institutes. From the interviews with the model developer and the waterboard, it became apparent that both models are acceptable. Therefore, both models showed no clear distinction in which performed better. Since both models are accepted the score is set at *"0".*

The second is whether users and experts are **confident** in using the model. The interviewees stated that they had more confidence in Regionaal than Tabel when looking at the validity. Thus, the score is *"+"*.

Practicality
The three criteria of the practicality are that the model can be used by an inexpert, has a low demand for computation and has easily attainable input data.

Concerning the ease of use and whether the model could be used by an **inexpert**, Tabel performs better. Even though Regionaal and Tabel are very similar regarding the input and model usage. Regionaal is a little bit more complex since you must use multiple executable files for each run. Also, the consequences of mistakes are potentially worse in Regionaal. If you make mistake in the input in Tabel, then you will know you made this mistake within minutes due to the model time of Tabel. If you make a mistake however in Regionaal it could take a few days before it becomes apparent. The first two sub-models may run correctly in Regionaal but when running the third sub-model issues may arise. This means that mistakes are discovered later in Regionaal than in Tabel. And if Regionaal requires a rerun due to the mistake the costs in time are even longer. The consequences of mistakes in Regionaal are more time demanding than in Tabel. Thus, Tabel scores better than Regionaal regarding ease of use and the score is *"-".*

It became apparent that Regionaal demand in computational **time** is 2135 times longer than Tabel during the case study. Even though Regionaal only modelled a period of 2 years and Tabel did 30 years. Meaning that Regionaal requires much more computational time. Regionaal thus scores significantly worse with *"--"*.

The third criterion is the attainability of the **input data**. The differences between the input data are the data for the water table in the soil and the weather conditions. In Regionaal the water tables need to be specified per time interval resulting in a set of raster maps for each timestep. In Tabel regardless of the period to be modelled only two raster maps for the water tables are necessary which are the GHG and GLG maps. Because of this, the required input maps for Regionaal are significantly larger than those of Tabel. In the study case, the raw input for Regionaal was 26,7 GB (after filtering the input it was 2,7 GB) and for Tabel 67 MB. If the input files need to be transferred or downloaded, it is generally harder to do so for larger files. Another difference between the models is the input for the weather data, Tabel only requires a station from which to extract the data. Whereas Regionaal either requires radar data for each time step or an initialisation run to prepare the weather data. This again makes attaining the input for Regionaal harder. Thus, the input for Tabel is easier to attain than for Regionaal and the score is *"-".*

Effectiveness

It was said that Tabel offered more **useful** data, during the interview with the waterboard, since it gave results for a longer period. It is possible to use Regionaal to attain results for a longer period as well. This would however require more computation time which is not always an option. Therefore, the usefulness of Tabel is considered better than Regionaal and the score is *"-"*.

Overall score

Table 4-2 shows that Tabel scores better in general. Although Regionaal scores better for the internal criteria, in the external criteria it significantly scores worse. This is mainly due to Tabel scoring much better on the practicality of the model. It is far quicker to use Tabel and much easier.

5 Discussion

5.1 Literature

Most of the available literature could be considered grey literature since most of it is in Dutch. This is due to the models being Dutch. Besides, specific literature concerning WWL often came from the developers themselves. There were some publications from alternative authors. The downside of this is that the sources could provide a narrow perspective on the models. Meaning that this report could share the same perspective.

5.2 Case Study

Tabel overestimates the wet damages in clays with the BOFEK 2012 database (Martin Mulder et al., 2021). The difference between BOFEK 2012 and 2020 has been modelled as well. It is interesting to see how the two databases can differ. Figure B-6 in appendix B shows that the differences in between the yield loss calculations of the two databases can go up to 30% for the study area at Groesbeek and Ooijpolder. It shows that in the river area with clays the wetter damages are less for BOFEK 2020 which is in line with the literature. Where it was mentioned that Tabel overestimated wet damages in clays. This shows the vulnerability of Tabel when it comes down to soil type in the input files.

To make the comparison between Tabel and Regionaal it would be interesting to see whether policymakers would make different decisions depending on the information they have been given. The new water ordinance simulation (PV) has not been modelled in Regionaal. A set-up to study this could be to give some policymakers the results in yield loss for the AGOR and PV from Tabel and others from Regionaal. In chapter 6 in recommendations this is further explored.

The simulation in Tabel was from 1991 to 2020 but the groundwater data from 2011-2019. These periods are different which might be incorrect, since the input data does not share the same timeline as the database from which Tabel draws its meta-relations. Still, the groundwater data in GLG and GHG rasters are averages for a longer period and, therefore, this should not have significant consequences.

Regionaal was used to model for a shorter period and Tabel a longer period. This was because Regionaal would take too much computation time for this study time frame. In the past, yield losses were modelled for a longer period since a water ordinance was set for general conditions. Due to more frequent extreme weather conditions due to climate change however, it may be more useful to study yield losses for more extreme scenarios. The case study shows that Regionaal can do so. The simulation of 2018 shows the areas that are vulnerable to drought scenarios that are not visible from the simulation of Tabel. Meaning that in the future Tabel might not be the best tool to assess water ordinances that need to be resilient against extreme scenarios.

5.3 Interview Study

There were only three interviewees which is a small sample size. If one of the interviews was biased that has a large impact on the results. The interviews themselves were conducted through a combination of open questions and discussion. The advantage of this set-up is that there is a lot of freedom on which topic to focus on. There is room to talk about topics that have not explicitly been included in the questions. This freedom, however, is also sensitive to bias and tunnel vision. Possible biases could be the focus on using the models for water ordinance assessment and from the previous interviews.

5.4 Evaluation

The idea of MCDA is to compare the models more objectively. How an MCDA is conducted however is subjective to the researchers. Also, in this case there were no weights applied. Criteria may differ depending on who set up the MCDA. If conducted by a different researcher, the results of the evaluation may have been different. Since weights might have been applied together with different criteria. It is important to use the results of the MCDA to understand the differences between the models and how they translate into the usage of the models.

The context in which the MCDA is applied influences the outcome. In this case, the models were evaluated in the context of water ordinances. If the focus had been on drought studies, Regionaal might have performed better, as it can model shorter drought periods. This implies that a study using the same MCDA could yield different results if the criteria are assessed in a different context.

The consequence of Regionaal requiring a lot of computation is quite big. If a consultant has access to a lot of computational power for a model (a computational server for example), then the MCDA may not reflect their needs properly. Regionaal would have been able to run the same time-period as Tabel in the case study and it would have scored better on the external criteria regarding practicality. Meaning that the MCDA would have outputted a more positive score for Regionaal

5.5 Recent studies

Since the initial study, a new study has emerged comparing the Regionaal and Tabel models. This more recent research found both similarities and contrasts between the two (Bor, 2023). It concluded that Tabel is quicker and easier to use than Regionaal, but Regionaal is more accurate for calculating dry yield losses. BIJ12, a consultancy working with provinces on nature conservation and nitrate policy transitions, used this report to advocate for using Regionaal when studying yield losses (BIJ12, 2023). These findings partially contradict those of the this study; however, Regionaal is not recommended unless a computational server is available Since this study only used a laptop and not a server, this could explain the differences in the results.

6 Conclusion and Recommendations

The research objective of this study is to judge the performance of two water management models, Waterwijzer Landbouw Tabel and Regionaal, including their respective (dis-)advantages, to inform decision-making in water ordinance. Both models were studied on their validity, verification, acceptability, practicality and effectiveness.

Through an MCDA it was shown that Tabel is more suitable than Regionaal when considering the practicality of the model. Regionaal requires more expertise and computational power than Tabel. This outweighs that Regionaal is more verifiable than Tabel due to Tabel being a derivative of Regionaal. The interviews and case study showed that the output of Tabel is sufficient for studying standard weather conditions, which is what is needed for water ordinance studies. Regionaal has the option to generate output for general study cases, but this would demand significantly more computational time.

Thus, in conclusion, when looking at the combined outcomes for verifiability, validity, performance, expectations and practicality, Tabel is more suitable for consultancy studies regarding water ordinances.

6.1 Recommendations

The recommendations are split into several parts. The first two parts are about Tabel and Regionaal. Next are some suggestions for further research. The last part is about alternative methods to use the models. Instead of using one model, they could be used combined.

Tabel and Regionaal

Regionaal is useful to mark locations where yield losses occur during extreme conditions. Understanding the yield losses during dry or wet periods could help to set up measures within an area to mitigate dry or wet yield losses. An example could be installing terraces or ridges to reduce run-off on slopes.

Tabel also offers the option to quantify the yield losses for a single year in the period 1991-2020 or 1981-2010. This could be used to gain more insight into specific years. It can be useful to compare the results with Regionaal to better understand the differences in results between Tabel and Regionaal. Also, this function could be used to make 30 different simulations in Tabel to model each year in 1991-2020 and see how the yield losses behave over the years.

Further research

It would be interesting to study the effects of spatial resolution chosen for the assessment. If the amount of raster cells is reduced, then the computation time of Regionaal would significantly reduce as well. It might be possible to get useful insight into the yield losses with larger raster cells.

To better understand how Regionaal or Tabel would affect decision making in water ordinance a study with policymakers is recommended. By giving yield losses of a case study for a proposed water ordinance to two groups of policymakers. One group is given yield losses made with Regionaal and one group is given yield losses made with Tabel. This gives insight on how either model affects the policy-making process better.

Another interesting study could be to study which specific years represent specific climate conditions in the Netherlands. The KNMI papers used as reference in this report show what kind of weather 2017 and 2018 had compared to the current climate in the Netherlands (Adrie Huiskamp, 2018; Adrie Huiskamp, 2019). Then a consultant can choose specific years to model specific scenarios. In this way

Regionaal only must model a single year or a few years to study yield loss in dry, wet or normal conditions.

No weights were applied in the MCDA. Weights can be used to assign greater importance to certain criteria within an MCDA, potentially influencing the outcome. Further research could explore whether weights should be applied to this MCDA. One method for determining weights could involve pairwise ranking of the criteria, combined with interviews with relevant stakeholders.

Combined usage

Tabel and Regionaal could be used in an integrated approach. First, the general yield losses can be determined in Tabel. This is quick and easy. Then, these yield losses can be studied to identify locations where the yield losses seem of interest. For example, cells where yield losses are significantly higher than neighbouring cells or areas. Or locations with heavier clays. Then a mask can be made to act as an input for Regionaal. Regionaal has a function to only quantify yield losses in raster cells marked by a mask. This could reduce the computation time in Regionaal significantly.

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Appendix A. Pairwise matching of the MCDA criteria onto the research questions

The pairwise matching of the MCDA criteria onto the research questions is shown in Table A-1. The table shows that all research questions are at least related to one of the criteria. The research questions are listed below Table A-1 and the criteria of the MCDA are listed in Table A-2. The table proves that all the research questions are covered by the criteria.

Table A-1: Relations between Criteria and Research Questions. A green box means that a criterion a research question.

Research Questions	Criteria													
	IA1	IA2	IP1	IP2	IP3	IP4	IP5	IC	EA1	EA2	EP1	EP2	EP3	EE
1	■	■	■		■	■	■	■	■	■		■		■
1.1	■	■	■		■	■	■	■	■	■		■		■
1.1.1	■		■						■	■				■
1.1.2				■	■	■		■						
1.1.3				■	■	■		■						
1.1.4	■					■						■		
1.1.5	■	■		■			■			■	■	■	■	
2	■	■	■											■
2.1	■	■	■											■
2.2		■												
2.2.1		■			■	■								
2.2.2		■			■	■								■
2.3		■												
2.3.1		■				■								
3	■	■	■						■		■			■
3.1					■				■					
3.2		■								■				■
3.3	■	■	■					■		■	■	■	■	■

List of research questions:

RQ 1. How do the validation and verification of either model compare to each other?
- RQ 1.1. How valid and verified is each model?
  - RQ 1.1.1. For which purposes was the model developed?
  - RQ 1.1.2. Which assumptions were used in either method?
  - RQ 1.1.3. How is the conceptual model validity of either method?
  - RQ 1.1.4. How is the computerised model verification of either method? (Structure of model code, etc.)
  - RQ 1.1.5. What is the operational validity of either method?

RQ 2. How does the output of either method compare to each other?
- RQ 2.1. How can the results of either model be classified?
- RQ 2.2. What are the differences in the results of Regionaal and Tabel?
  - RQ 2.2.1. How could these be explained?
  - RQ 2.2.2. How should these be interpreted?
- RQ 2.3. Are there any anomalies in the results of either model?

RQ 2.3.1. If so: how did these originate?

RQ 3. What kind of model results are needed for consultancy?

RQ 3.1. How had previous consultancy cases used WWL to analyse different measures?

RQ 3.2. How would the results affect the decision-making?

RQ 3.3. What type of results are preferred?

Table A-2: Criteria for the Multi Criteria Decision Analysis

Scope	Category	Code	Criterion
Internal	Assessment	IA1	The model method outputs a raster map showing the yield losses for a certain period
		IA2	Does the model method outperform the other method during the case study?
	Pedigree Matrix	IP1	The model method outputs an exact measure of the desired quantity
		IP2	The empirical basis consists of controlled experiments and large samples of direct measurements
		IP3	The theory behind the model method is well established
		IP4	The methodology used is the best available in a well-established discipline
		IP5	The model method output can be validated with independent measurements of the same variable over a longer period
	Completeness	IC	The model covers as many aspects as possible
External	Acceptability	EA1	The model method is accepted by waterboards and other institutes
		EA2	Users and experts are confident in the model
	Practicality	EP1	The model method can be used by an inexpert
		EP2	The model method has a low demand for computational power and time to run
		EP3	The input data is easily attainable
	Effectiveness	EE	The model is useful for decision making

Appendix B. Model case study results

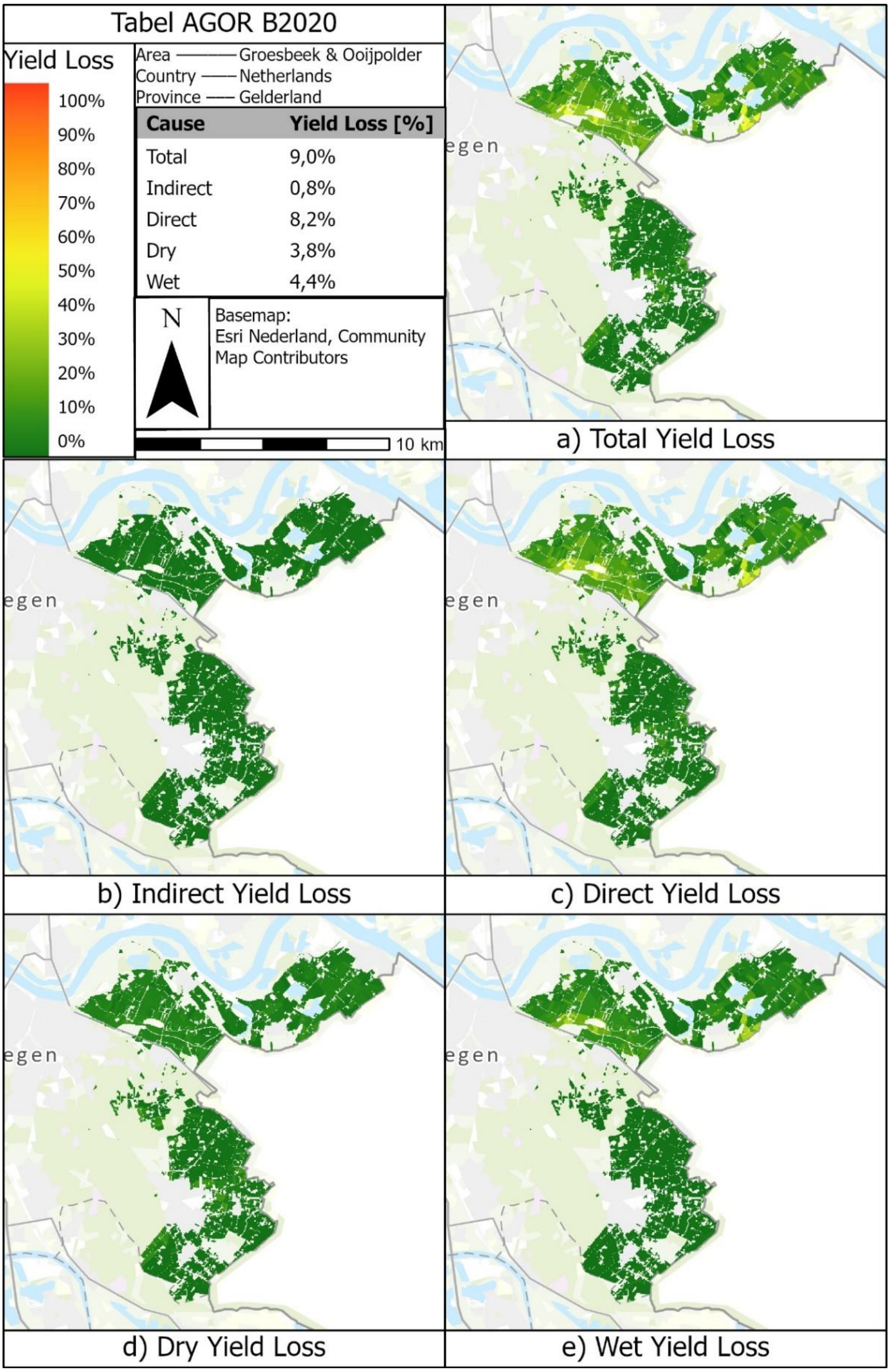

Figure B-1: WWL Tabel AGOR 1991-2020. The expected yield loss for the current scenario is according to Tabel a total of 9%. The direct yield losses contribute 8,2% to the total from which 4,4% are wet yield losses. The period for these yield losses is modelled for 1991-2020.

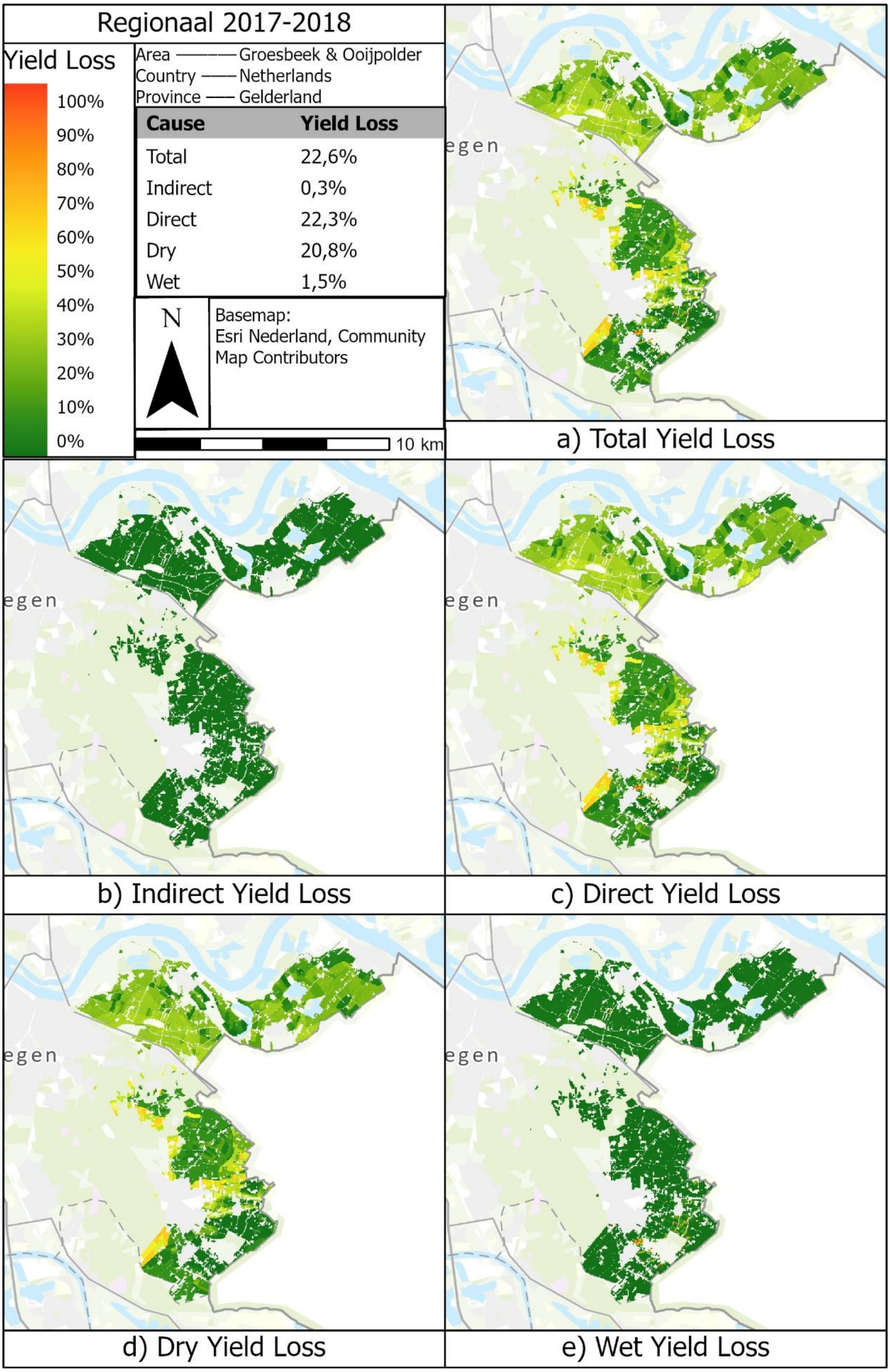

Figure B-2: WWL Regionaal AGOR 2017-2018. The expected yield loss for the current scenario is according to Regionaal 22,6% for the period 2017-2018. The direct yield loss contributes 22,3% from which 20,8% is from dry yield losses.

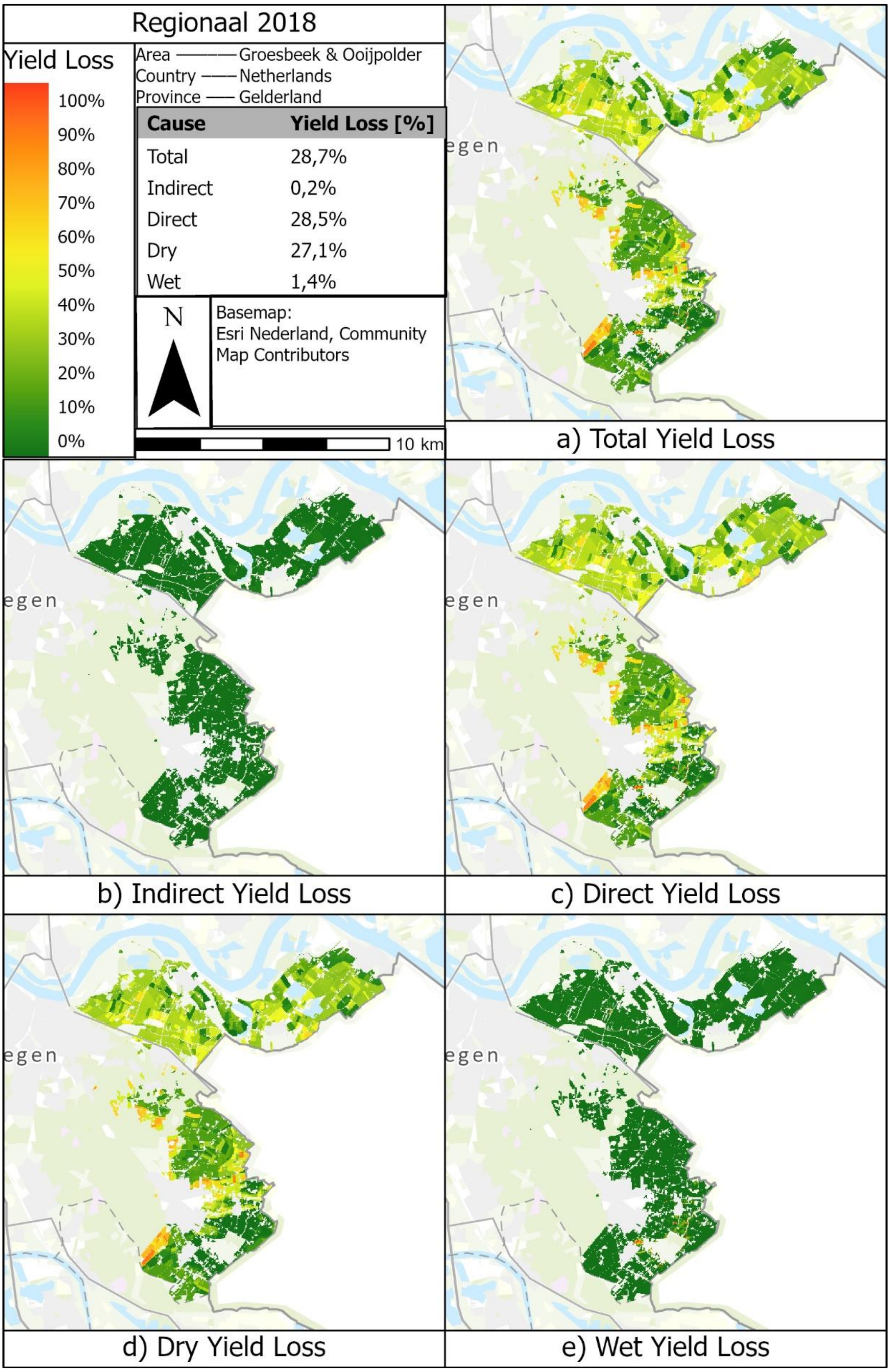

Figure B-3: WWL Regionaal AGOR 2018. The expected yield loss for the current scenario is according to Regionaal 28,7% for 2018. The direct yield loss contributes 28,5% of which 27,1% is from dry yield losses.

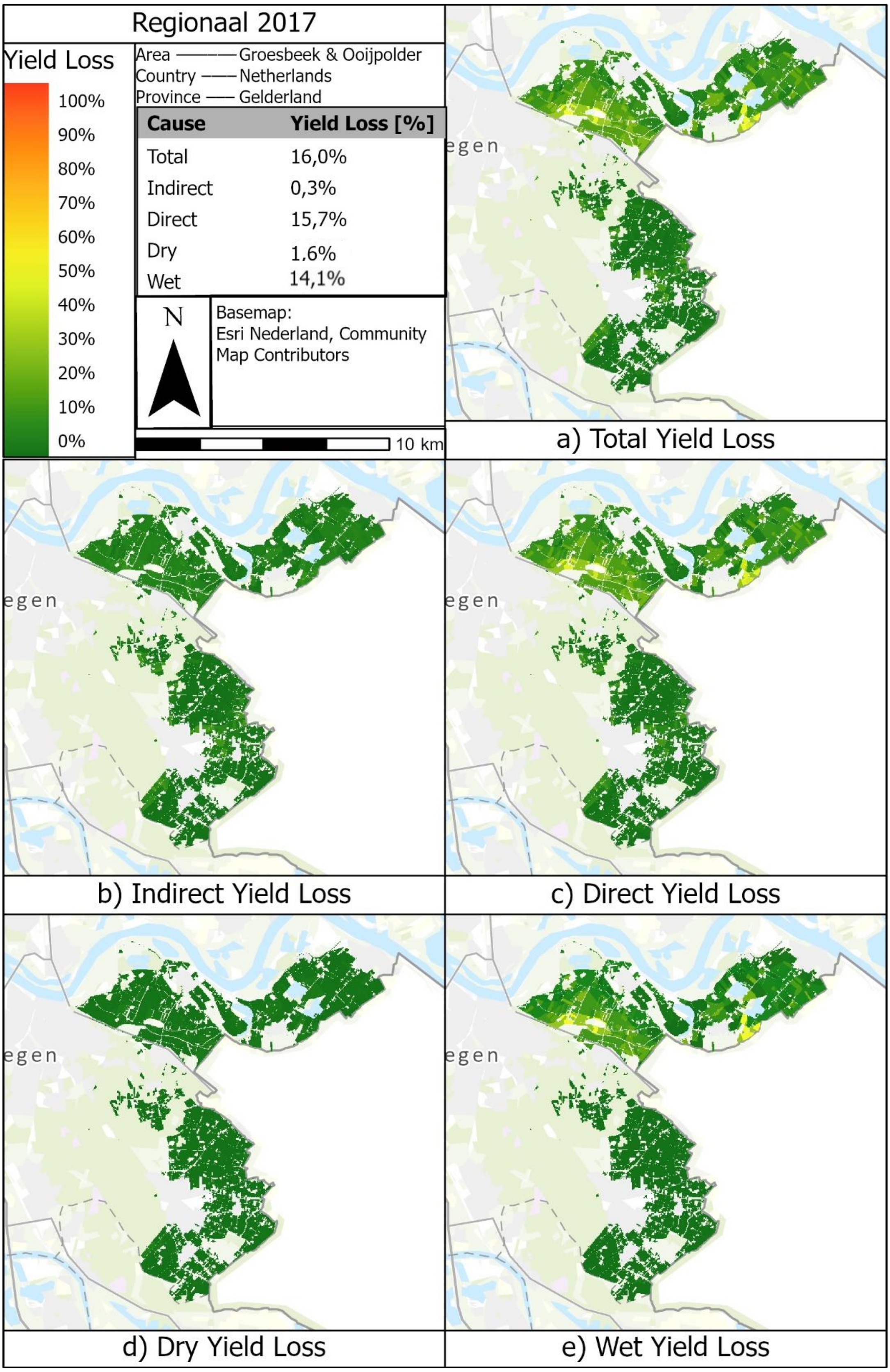

Figure B-4: WWL Regionaal AGOR 2017. The expected yield loss for the current scenario is according to Regionaal 16% for 2017. The direct yield loss contributes 15,7% of which 14,1% is from dry yield losses.

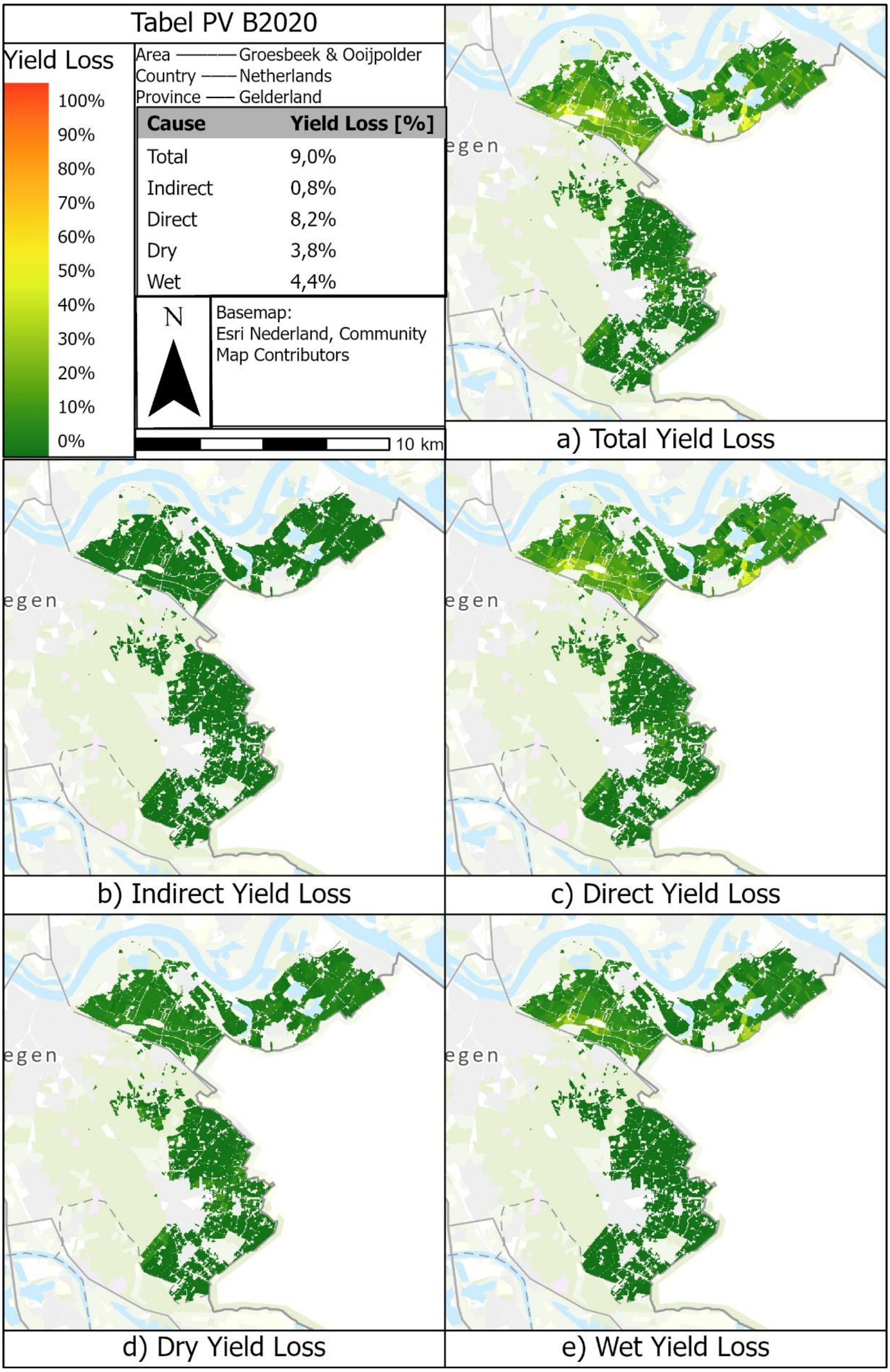

Figure B-5:WWL Tabel PV B2020. The expected yield loss for the new scenario is according to Tabel 9,0% for the period 1991-2020. The direct yield loss contributes 8,2% from which 4,4% is from wet yield losses.

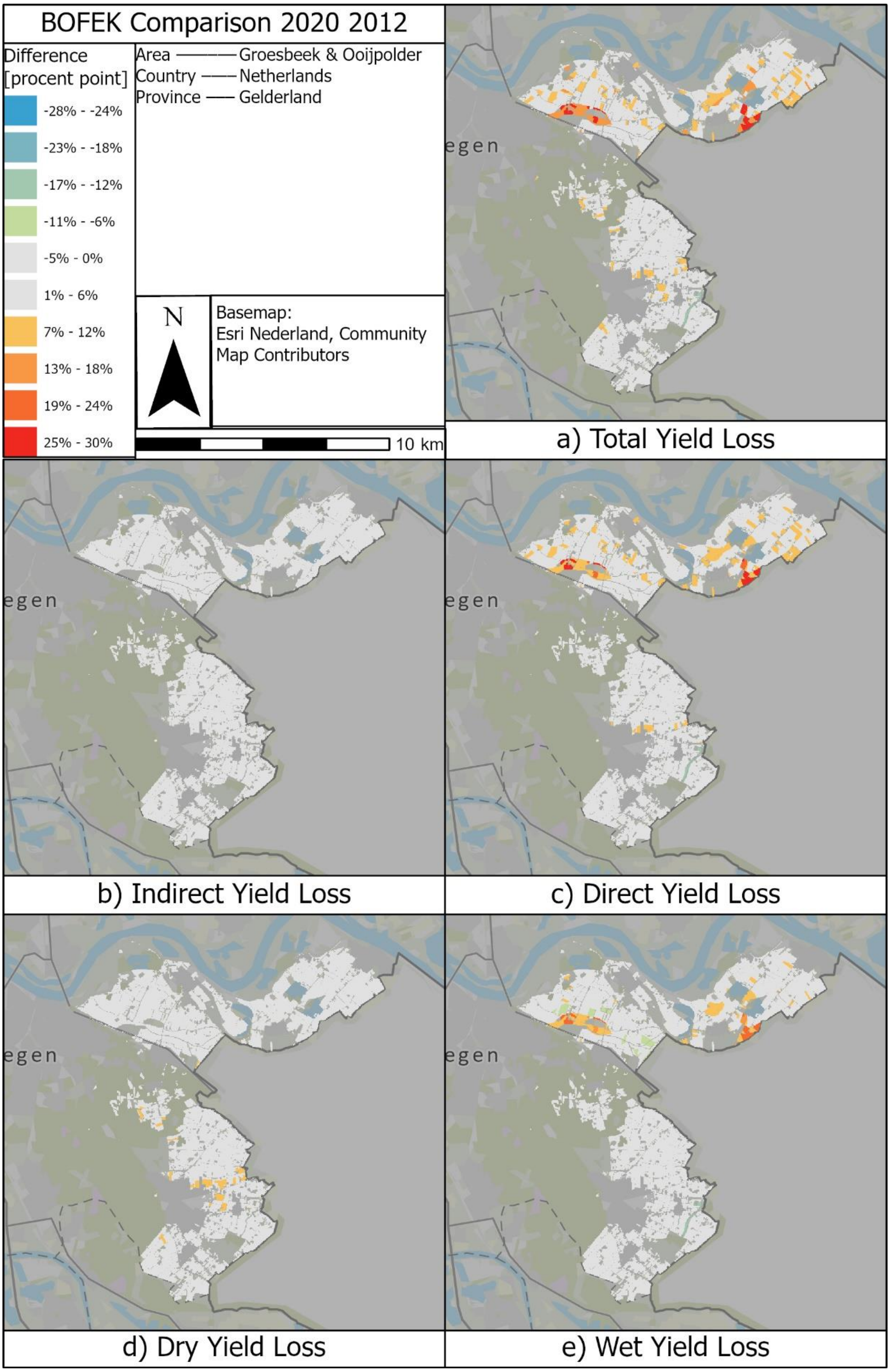

Figure B-6: BOFEK comparison. For the AGOR scenario, a model run has been done for BOFEK 2012 and 2020. Then the yield losses from BOFEK 2012 have been subtracted from BOFEK 2020. It is shown that specific areas in the north can deviate up to 30%.

Appendix C Interview Set-Up

The different interviews are listed below. The answers are not shown due to privacy concerns.

C.1 Interview Model Expert

The goal of this research is to compare the models WWL Tabel and Regionaal on their impact on the decision-making process in water ordinance. The models are tested in their performance regarding certainty, their ease of use and their contribution to the decision-making process. This interview focuses on performance and ease of use. First, the model case study is going to be presented to talk about the differences in the model results. Second, both models are assessed on their technical details. Third, open questions based on the pedigree matrix are asked (Janssen & Sluijs, 2004). This is followed by filling out the pedigree matrix itself. Fourth, questions regarding the practicality of the model are asked.

Model Case Study

Since the Regionaal did not work yet there were no questions covering the model case studies. The model expert did help with making sure that Regionaal would work. He also explained how to use the multi-core function of the model.

Assessment

For the assessment the following questions are asked:

1. Do you think that the concept behind WWL Regionaal is a fitting representation of the reality of agricultural yield losses?
2. Do you think that the usage of meta-relations based on SWAP-WOFOST is a justified method to model agricultural yield losses?
3. And why do you think it is (not) a justified method?
4. Which of the assumptions from Regionaal threaten the certainty and validity of the model most?
5. Are there any important assumptions that I have not listed above?
6. How would these assumptions translate into WWL Tabel due to the meta-relations?.

The questions for the meta-relations are:

1. How was the number of simulation runs needed to build the database for the meta-relations determined?
2. Do you think that the number of replications is sufficient to have built the database of the meta-relations?

Questions regarding the structure properties:

1. Why were R and Rtools chosen as software to run the models?
2. What are the advantages of using R and Rtools?
3. And what are the disadvantages?

Questions regarding the validity and verification of the models:

1. Although the validation of both models is hard, what can you say about the certainty of using WWL Regionaal?
2. Although the validation of both models is hard, what can you say about the certainty of using the WWL Tabel?
3. Has a sensitivity analysis been performed on WWL Regionaal?
4. Do you think either of the models outputs more valid/ certain results than the other?

External Criteria: practicality
Questions about the practicality of the models (ease of use refers to the difficulty of preparing the input for the model and using the model to get the results):

1. Do you think that WWL Regionaal can be used by laymen/ inexperienced people?
2. Do you think that WWL Tabel can be used by laymen/ inexperienced people?

C.2 Interview Waterboard

Interview waterboard set-up

1. Start by explaining the purpose of this research and interview
2. Model Case study and assessment
    a. No results yet so I cannot set up the questions
    b. Sub Objectives/ Questions
        i. Identify differences in model results
        ii. Find out how Martin explains these differences
            1. What do these differences mean for the certainty of the models

The goal of this research is to compare the models WWL Tabel and Regionaal on their impact on the decision-making process in water ordinance. The models are tested in their performance regarding certainty, their ease of use and in their contribution to the decision-making process. This interview focuses on the model's contributions to the decision-making process. First, the model case study is going to be presented to talk about the differences in the model results. Second, open questions based on the pedigree matrix are asked which is followed by filling out the pedigree matrix itself (Janssen & Sluijs, 2004). Third, questions regarding the external criteria of the models are asked.

Model Case Study
The results from the model case study are presented. In an open discussion, the following question should be answered:

1. How should the differences in the results be interpreted?
2. How would these results affect the decision-making process

External Criteria
For the external criteria, this interview focuses on the acceptability and effectiveness of both models. The questions are:

1. In your opinion is WWL Tabel an acceptable tool for quantifying yield losses due to hydrological soil and weather conditions?
2. In your opinion is WWL Regionaal an acceptable tool for quantifying yield losses due to hydrological soil and weather conditions?
3. Do you think that the results of WWL Tabel are useful for water ordinance?
4. Do you think that the results from WWL Regionaal are more useful than WWL Tabel?

C.3 Interview Consultant

1. Start by explaining the purpose of this research and interview
2. Initial assessment and pedigree
3. Model Case study
4. Assessment
5. Pedigree
6. External Qualities

The goal of this research is to compare the models WWL Tabel and Regionaal on their impact on the decision-making process in water ordinance. The models are tested in their performance regarding certainty, their ease of use and in their contribution to the decision-making process. This interview focuses on performance and ease of use. First, the model case study is going to be presented to talk about the differences in the model results. Second, both models are assessed on their technical details. Third, open questions based on the pedigree matrix are asked (Janssen & Sluijs, 2004). This is followed by filling out the pedigree matrix itself. Fourth, questions regarding the practicality of the model are asked.

Model Case Study
The results from the model case study are presented. In an open discussion, the following question should be answered:

1. How could the differences in results from Regionaal and Tabel be interpreted?

Assessment
For the assessment the following questions are asked:

1. Do you think that the concept behind WWL Regionaal is a fitting representation of the reality of agricultural yield losses?
2. Do you think that the usage of meta-relations based on SWAP-WOFOST is a justified method to model agricultural yield losses?
3. And why do you think it is (not) a justified method?

Questions regarding the validity and verification of the models:

1. Do you think either of the models outputs more valid/ certain results than the other?

External Criteria: practicality
Questions about the practicality of the models (ease of use refers to the difficulty of preparing the input for the model and using the model to get the results):

1. Do you think that WWL Regionaal can be used by laymen/ inexperienced people?
2. Do you think that WWL Tabel can be used by laymen/ inexperienced people?

For the external criteria, this interview focuses on the acceptability and effectiveness of both models. The questions are:

1. In your opinion is WWL Regionaal an acceptable tool for quantifying yield losses due to hydrological soil and weather conditions?
2. Do you think that the results of WWL Regionaal fit the decision-making process?