NXD©
NEXT GENERATION OF AGRICULTURE

Presents

NXD© DRAIN

Product report
Industrial Design Master Thesis
Architecture & Design
Aalborg University
June 2018

NXD Drain
M.Sc.04 ID5
Jens Asmussen Hamann & Martin Juul Jensen

0.1 TITLE PAGE

Project title: NXD Drain

Type of report:
Master thesis - Product report

Time period:
01.02.2018 - 31.05.2018

Team:
M.Sc. 04 - ID5

Supervisor:
Finn Schou

Number of pages: 24

0.6 TABLE OF CONTENT

Martin Juul Jensen

Jens Asmussen Hamann

0.3 MASTER THESIS

This master thesis is compiled by M.Sc. 04 Team 5. It is a project made as a part of the education Industrial Design at Aalborg University. The topic of the project is self chosen. The project started 01/02/2018 and were handed in 31/05/2018.

The theme of this project is a drainage solution that is developed as a Business to Business product for the agricultural sector. Due to climate change, the amount rainwater is increased which creates problems on the arable fields. The thesis unfold a solution which handling the problems in proportion to drainage and the increased rainwater.

Many persons have participated though the project and the team would like to thank every persons who helped with expertise and supervision doing the project. A special acknowledgment to:

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Contractor - Skjoldager Dræn og Entræprænørforretning
Contractor - Langholt Maskinstation
Consultants SLF - Asger and Carsten
Consultant LandboNord - Christian Christensen
Consultants SEGES - Stinna Filsø and Eskild
Assistant professor - Ming Shen

0.2 ABSTRACT

The following master thesis is the result of a process of the development of a new drain aiming the agricultural sector. Drainage is heavy economically to the arable farmers. The investment is not without worries, as the farmer does not know if the new drainage field works as intended. A typical problem within drainage is a blockage by sand. The only way to spot a blockage is when the crops are flooded.

The outcome of the development is a drain, NXD Drain, which penetrates 60% more water and increases the water velocity by more than 15%. The increased velocity in combination with a filtering system makes the drain self-cleanable and thereby removes the problem of blocked drainage. Besides removing blockage problems, have arable farmers possibility to increase their yield by more than 30%. Further, is a concept; NXD Sight, unfolded which changes drainage from a passive tool to an active tool. NXD Sight provides knowledge of drain condition and soil moisture. The data is useful for predicting problems inside the drain. Furthermore does the knowledge of soil moisture enable arable farmers to see where he can operate with heavy machinery without compressing the soil, damaging his crops or getting stuck in a soft mud-spot.

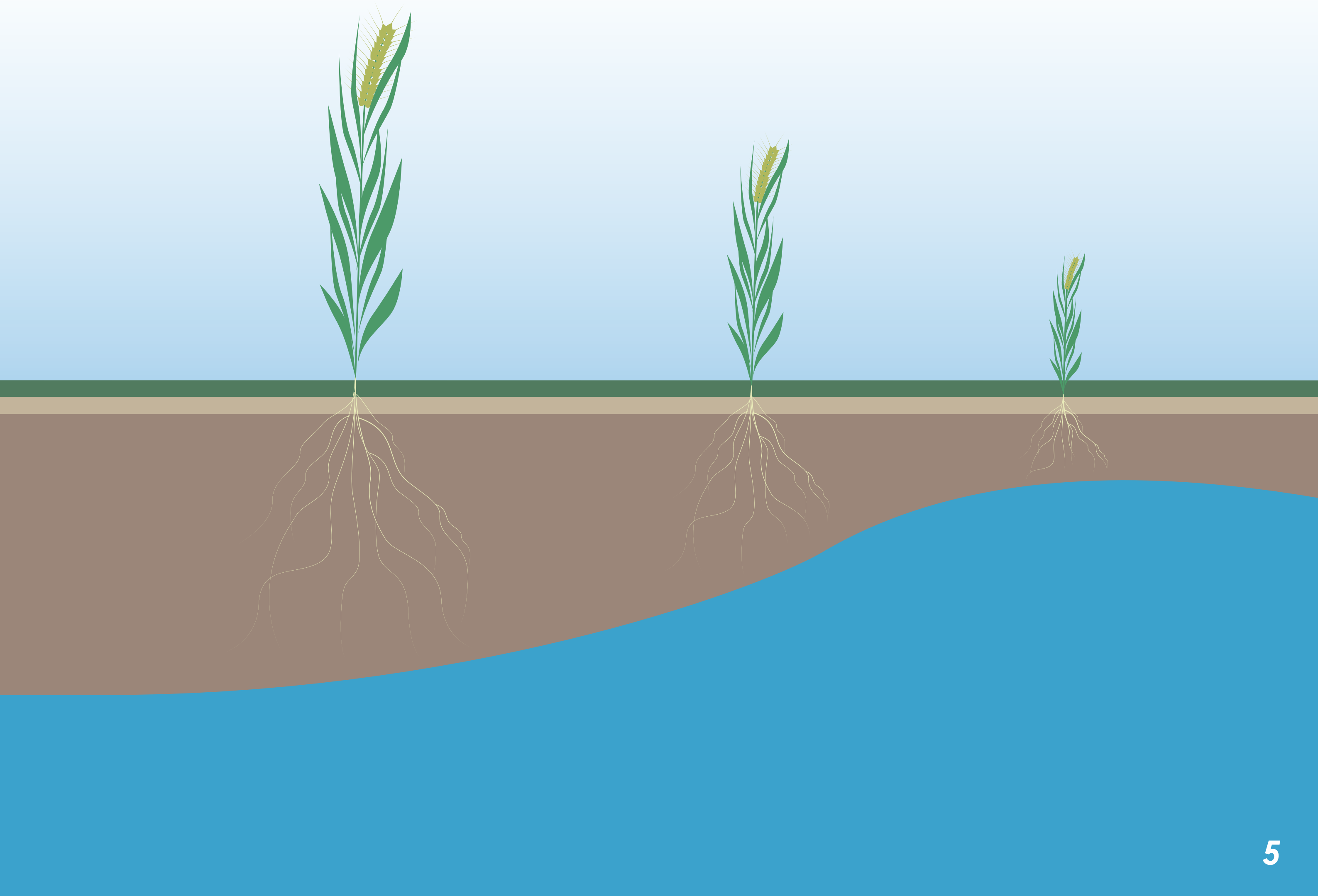
STOP FOODWASTE

START MAKING THE PERFECT CONDITIONS FOR YOUR PLANTS AND GET

Many think drainage is to avoid flooded field - and YES, it is! But it is not the only reason. Drainage is lowering the water table which allows the root-system of the plants to grow deeper and thereby bigger. This means the plant is able to obtain more nutrients and thereby grow larger and results in a larger yield for the farmer.

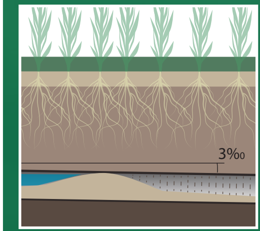
OVER 30% MORE YIELD

NXD DRAIN



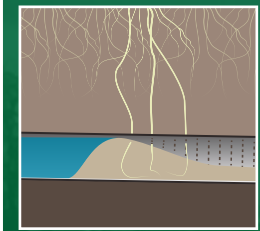
BLOCKED DRAIN
CREATES PROBLEMS FOR FARMERS

REASONS FOR BLOCKED DRAIN



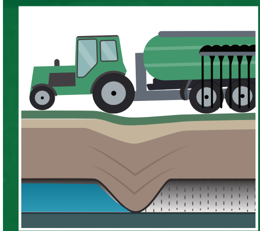
Problem 1 - Low water flow

The problem is represented when the slope of the drain not are high enough. Meaning the velocity of the water is to low which allows sand to drop to the bottom of the drain. Over time the sand accumulate which will create a blockage in the drain.



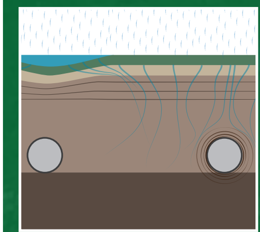
Problem 2 - Roots and sand

The root system of crops can grow into a depth of 2 meters. This means there are a risk of roots growing into the drain pipes. With roots inside the drain makes it easier for the sand to accumulate and thereby create a blockage.



Problem 3 - Heavy machinery

The daily used machinery in agriculture is growing larger and heavier. Due to time constraints from plants, the farmer cannot always wait to operate on the field before the soil is dry and strong. The consequence of driving in wet soil is a higher pressure to the drain which makes the drain collapse.



Problem 4 - Compressed soil

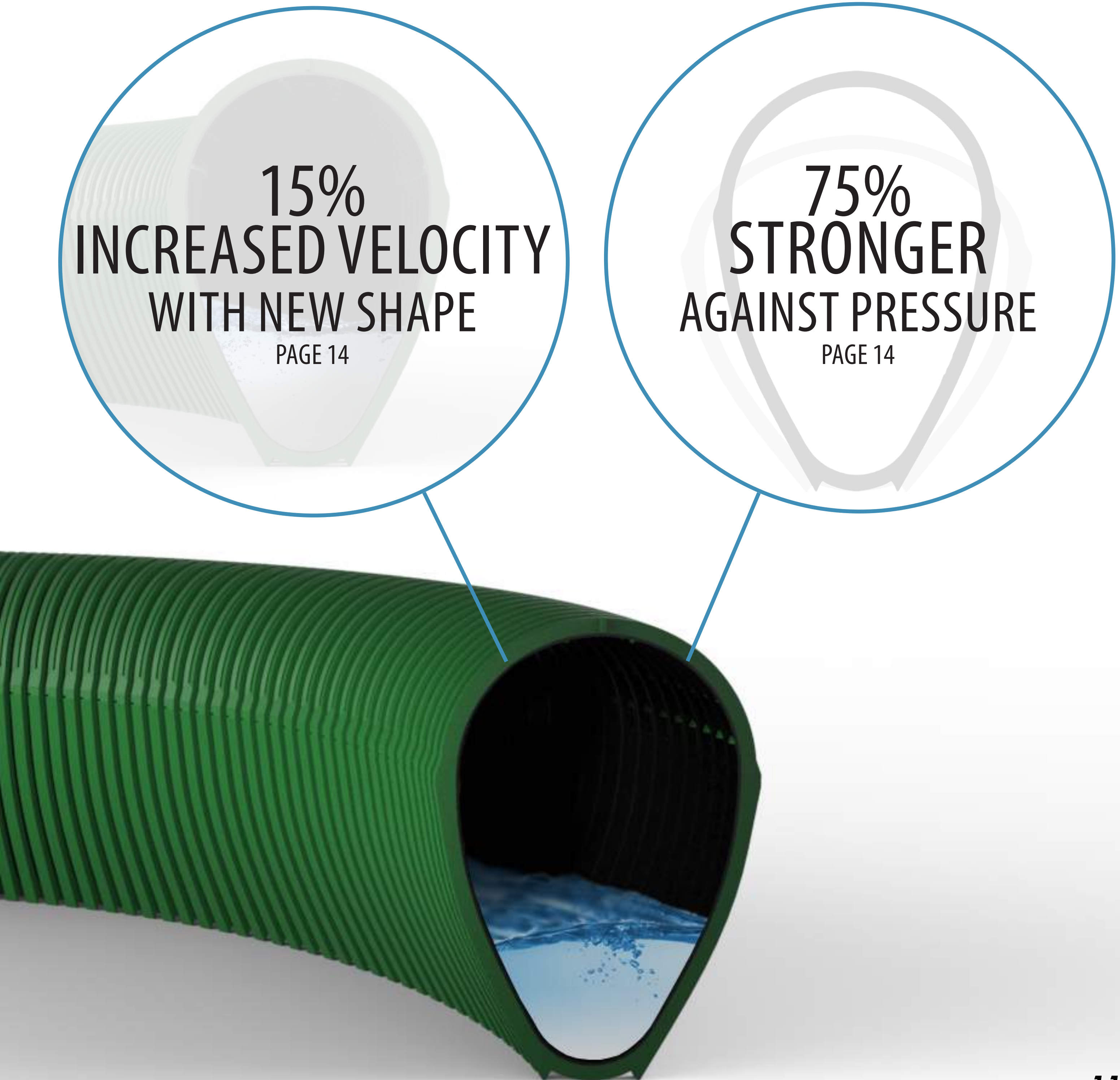
As described in problem 3, is the result of driving in wet soil a higher pressure from the machinery to the soil. This further results in compressed soil which means all the pores in the soil disappears. This creates a film, that the water cannot penetrate trough, resulting in the water laying on top of the soil.


Samson


NO
MORE
FLOODED
FIELDS
AND INCREASE YOUR YIELD


WITH
NXD DRAIN


FILTERING
1 MILLIMETER SAND
PAGE 12
60%
MORE WATER
PENETRATION
PAGE 13

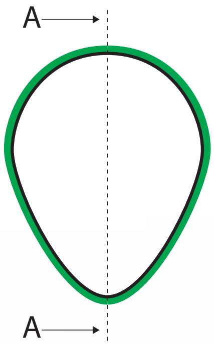

15%
INCREASED VELOCITY
WITH NEW SHAPE
PAGE 14
75%
STRONGER
AGAINST PRESSURE
PAGE 14

WE DO IT DIFFERENT

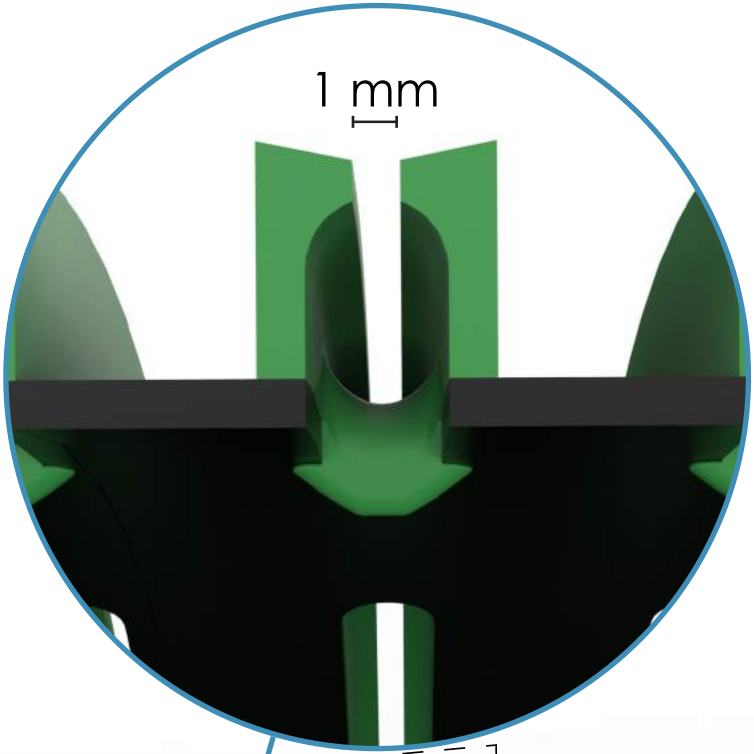
The strategy has always been to keep the sand out of the drain. It has been an issue how to make a filter that separate the sand from the water and still allow a high amount of water to penetrate. NXD are looking at the problem in a different way.

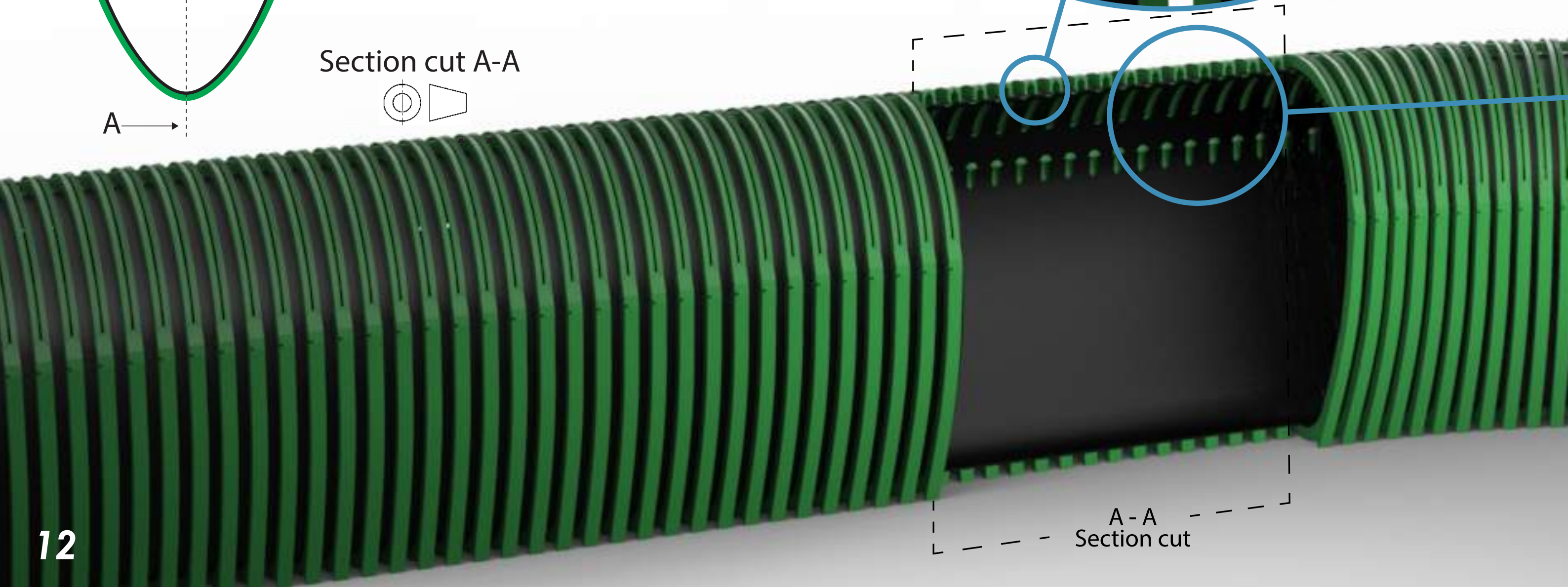
FILTERING SAND
FROM 1 MILLIMETER

NXD Drain are filtering sand from 1 millimeter. This means that when the water penetrate through the rib, corns from 1 millimeter and below will have access to the drain.
With the smooth inner pipe and increased flow the fine corns is acceptable to lead in, because, it will be lead away with the increased flow. Removing the corns below 1 millimeter around the drain means that it will create its own filter grit over time. This will increase the pores in the soil that lead the water to the drain.



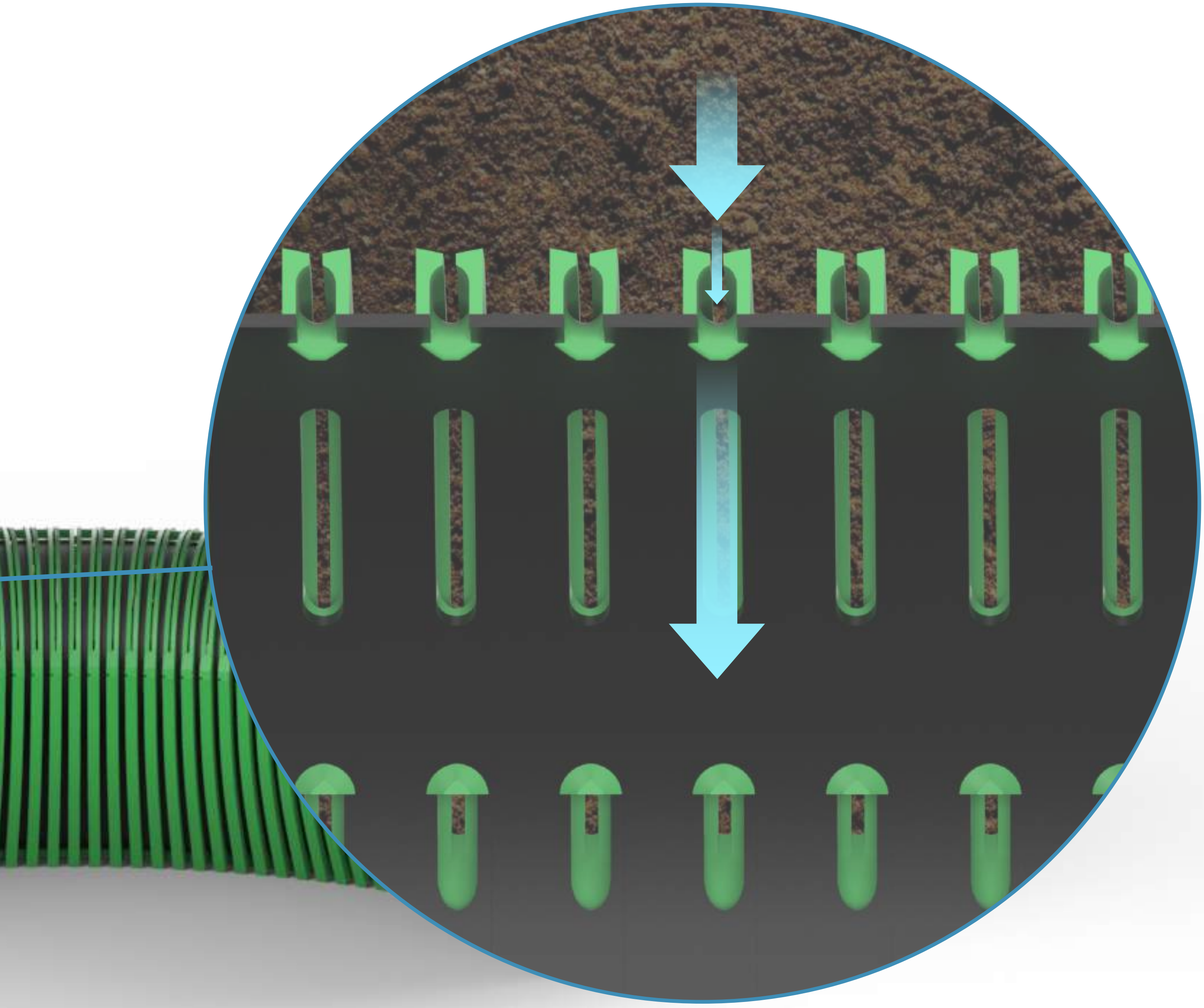
Section cut A-A

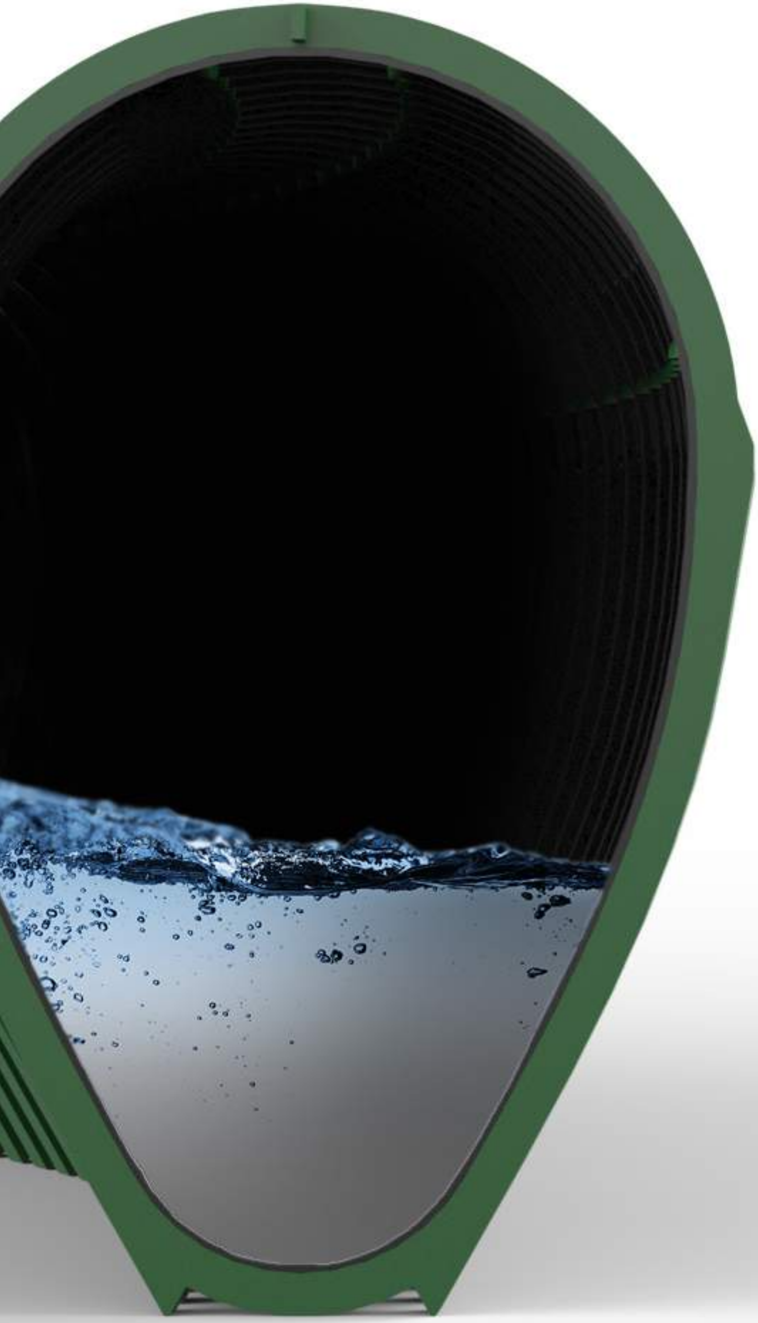




60% MORE
WATER PENETRATION

By filtering on top of the penetration holes, allows NXD Drain to increase the penetration area without taking corns from above 1 millimeter. Compared with a regular drain NXD Drain has a 60% increased area for water to penetrate into the drain. This will drain the field more effective and give a higher flow on the outgoing water.





SELF PURIFYING

15 % INCREASED VELOCITY

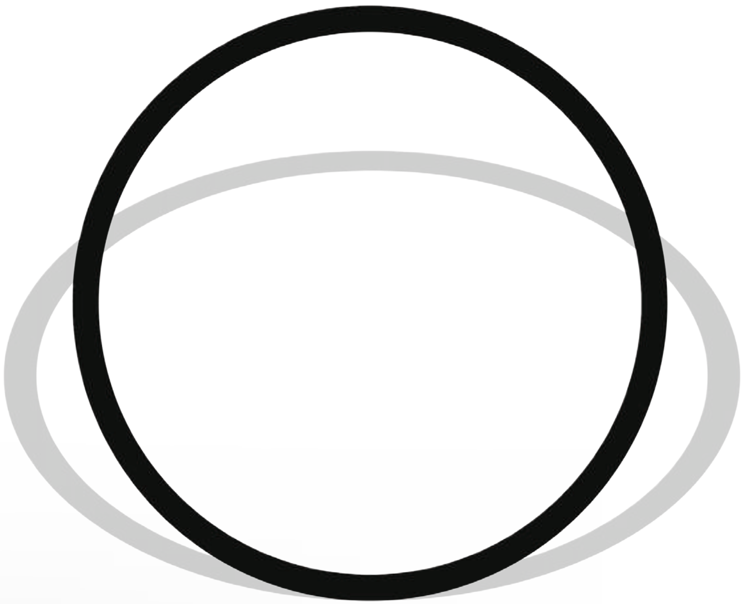
NXD Drain are filtering sand from 1 millimeter. This means that when the water penetrate through the rib, corns from 1 millimeter and below will have access to the drain.
With a new shape the velocity will be 15 % higher than the corrugated drain. With a combination of 15% increased velocity, 60% more water and a smooth inner pipe the flow will lead the sediments to the outlet.

STRENGTH

75% STRONGER

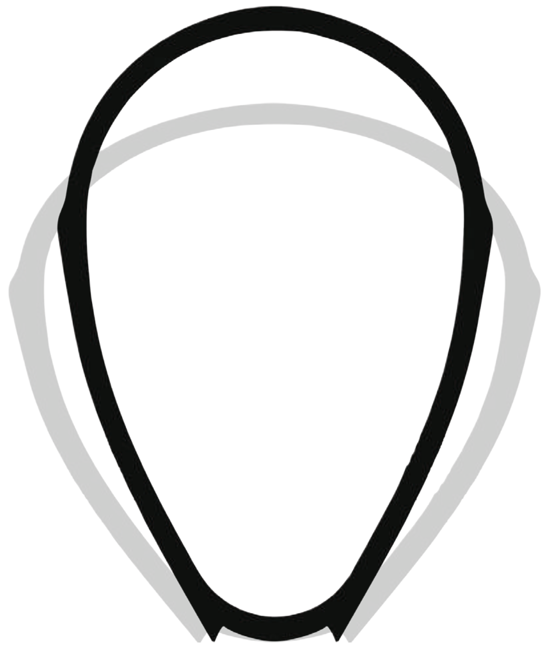
With the new shape and its ribs, NXD Drain can handle a 75% higher pressure than a corrugated drain. This means that you should never be nervous about your drain collapses when operating on the field.
By increasing the strength with 75% means that the risk of deformation of the drain will be low compared to a corrugated drain. If a deformation happen, the new shape retains the water-flow, in contrast to a deformed corrugated drain where the flow will deteriorate.

REGULAR DRAIN
CAN RESIST PRESSURE UP TO
80 KG



LOW FLOW

NXD DRAIN
CAN RESIST PRESSURE UP TO
140 KG

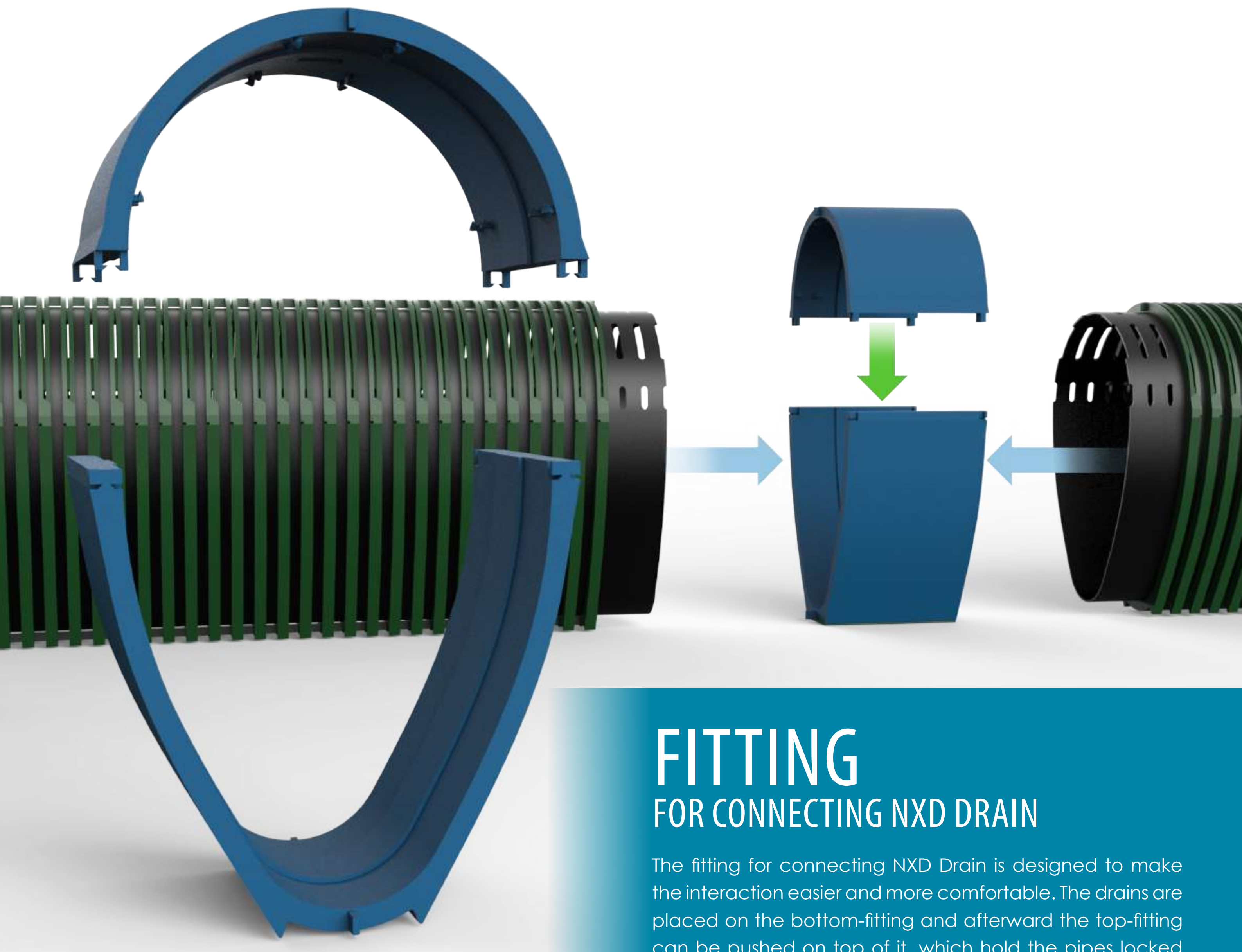


HIGH FLOW

IMPLEMENTATION
WITH DRAINBOX

NXD Drain is the first product on the market which is both flexible and rigid. With its flexible inner pipe and the space between the ribs allows the drain to be rolled which makes it easy to transport, handle and effective to implement. The drain is designed to be rigid when it stands and flexible on the horizontal level. This means with NXD Drain you can be sure the slope does not wave in the soil which often happens with drainbox. The illustrations below shows on the left side a waving slope and on the right side a linear slope.

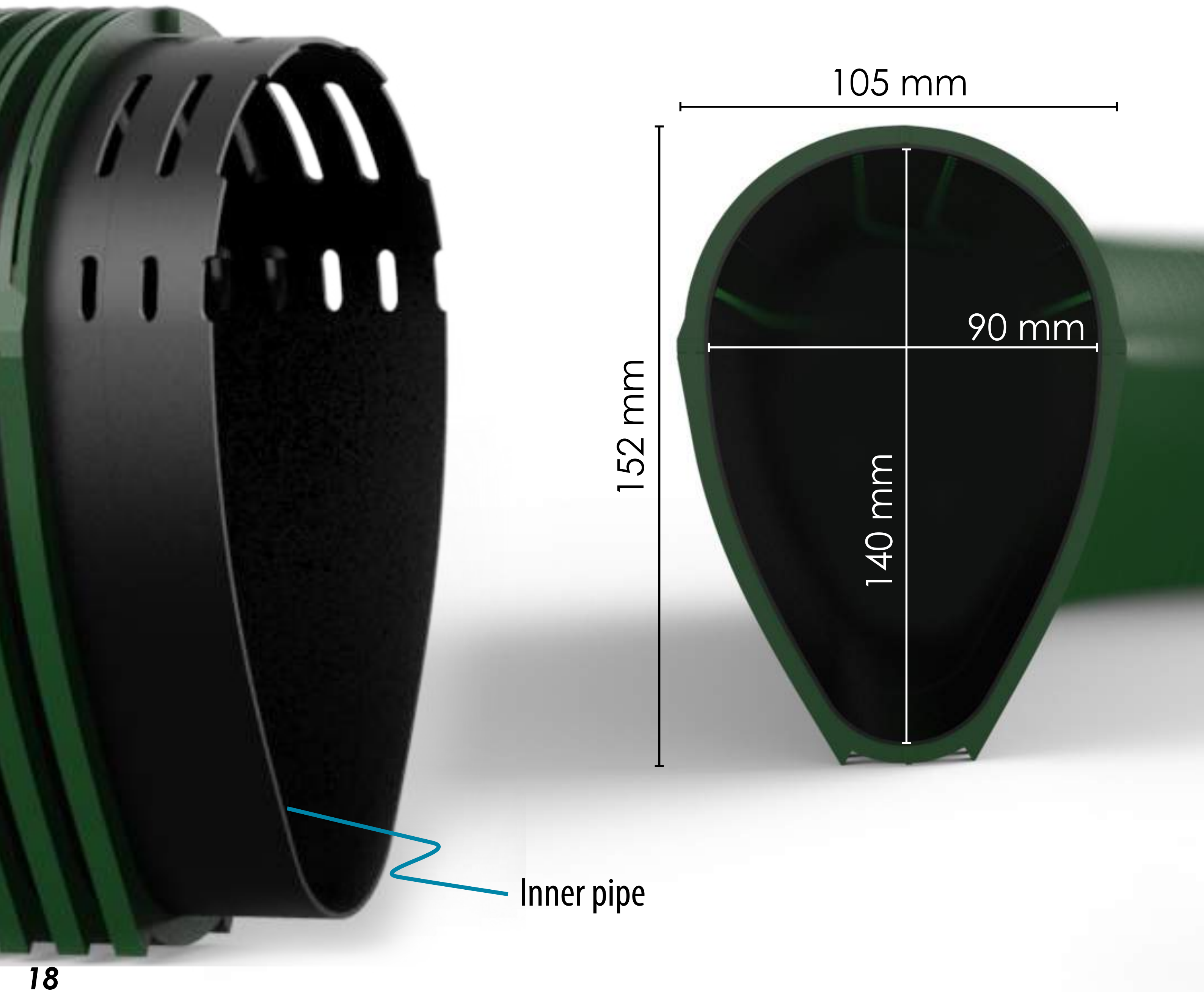
Waving slope   Linear slope



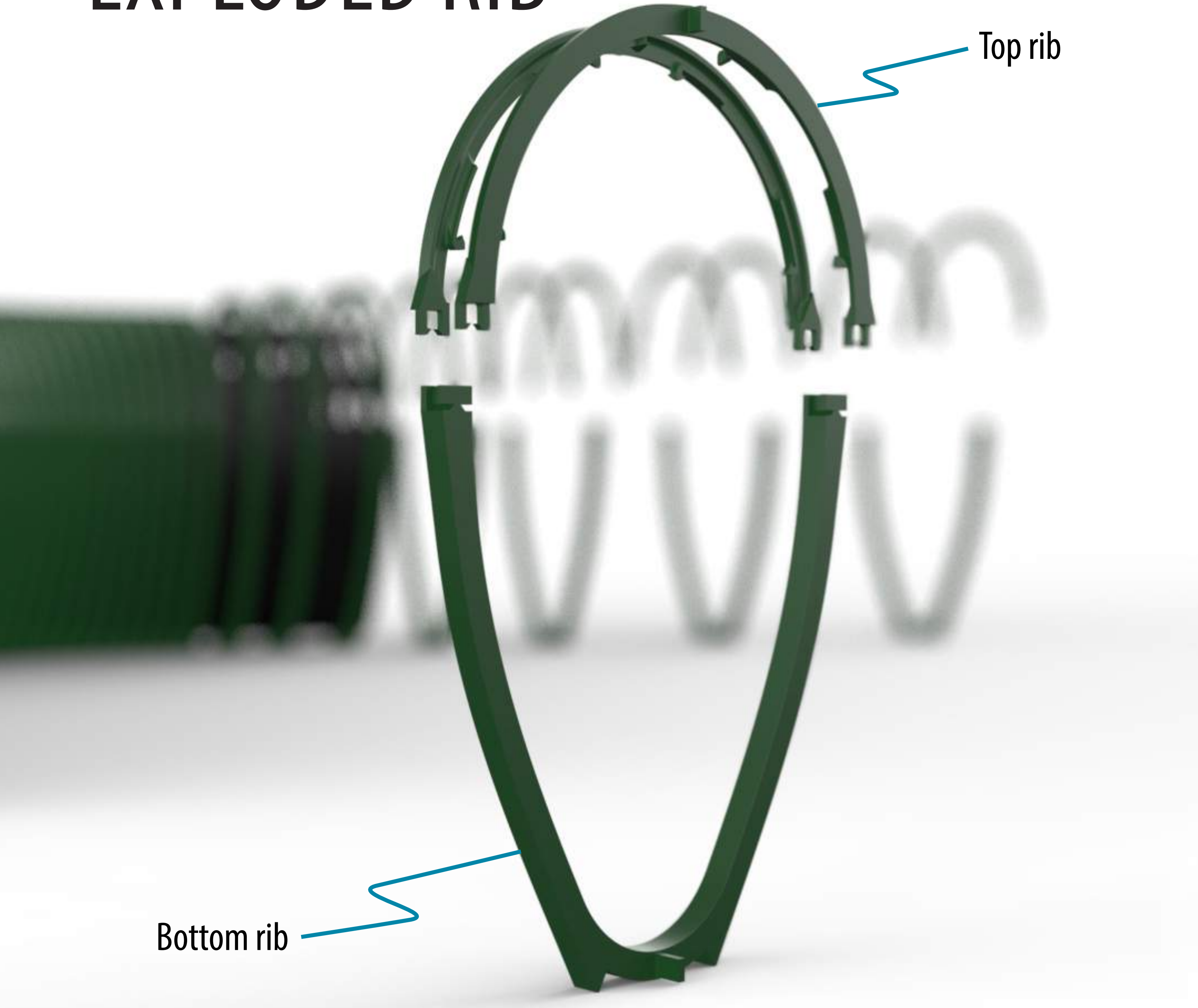
FITTING
FOR CONNECTING NXD DRAIN

The fitting for connecting NXD Drain is designed to make the interaction easier and more comfortable. The drains are placed on the bottom-fitting and afterward the top-fitting can be pushed on top of it, which hold the pipes locked together. The exciting drains should be pressed together with a high force. This is almost impossible without hurting the body, and therefore many are using tape to make sure it would not slip apart. This is not needed anymore.

DIMENSIONS



EXPLODED RIB



INVESTMENT

FOR THE FARMER - PER HECTARE

NXD DRAIN

CORRUGATED DRAIN

INVESTMENT PER HECTARE

	NXD DRAIN		CORRUGATED DRAIN	
	480 METER DRAIN	50.400 DKK	800 METER DRAIN	9.600 DKK
	CONTRACTOR	10.000 DKK	CONTRACTOR	10.000 DKK
TOTAL		**26.000 DKK**		**19.600 DKK**

RUNNING COST & INCOME YEARLY

	NXD DRAIN		CORRUGATED DRAIN	
	31% INCREASED YIELD	1.826 DKK	31% INCREASED YIELD	1.826 DKK
	MAINTAIN / 5 YEAR	-200 DKK	MAINTAIN /1 YEAR	-1.000 DKK
	RETURN OF INVESTMENT	**37 YEARS**	**RETURN OF INVESTMENT**	**24 YEARS**
MORE INCOME YEARLY AFTER ROI		**1.626 DKK**		**826 DKK**
TOTAL INCOME AFTER LIFE TIME 60 YEARS		**41.998 DKK**		**29.736 DKK**

INVESTMENT
NXD DRAIN - 5% MARKET SHARE

NXD DRAIN

INVESTMENT

Development 1 year	408.000 DKK
Consulting	500.000 DKK
Tools	325.000 DKK
Machinery	800.000 DKK
EU Design Registration	5.675 DKK
EU Trademark	10.875 DKK
Total	**2.049.550** DKK

BRAKE-EVEN

	Market share	Turnover	Variable cost	Contribution margin	Balance
Year 1	0%	0	0	0	- 2.049.550 DKK
Year 2	1%	13.608.000	13.154.400	453.600	- 1.595.950 DKK
Year 3	2.5%	34.020.000	32.886.000	1.134.000	- 461.950 DKK
Year 4	**5%**	68.040.000	65.772.000	2.268.000	**1.806.050 DKK**

ROI (Year 4) **88,12%**

NXD
SOON WE WILL INTRODUCE

YOUR

NEXT SIGHT

BELLOW THE SURFACE

NXD SIGHT

NXD SIGHT


SOIL MOISTURE 20%
WATER FLOW HIGH
NXD
SOIL MOISTURE 5%
WATER FLOW LOW


NXD
NEXT GENERATION OF AGRICULTURE

NXD DRAIN

BY

NXD

NEXT GENERATION OF AGRICULTURE

Process report

Industrial Design Master Thesis

Architecture & Design

Aalborg University

June 2018

NXD Drain

M.Sc.04 ID5

Jens Asmussen Hamann & Martin Juul Jensen

0.1 TITLE PAGE

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Time period:
01.02.2018 - 31.05.2018

Team:
M.Sc. 04 - ID5

Supervisor:
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Number of pages:
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The outcome of the development is a new drain, NXD Drain, which penetrates 60% more water and increases the water velocity by more than 15%. The increased velocity in combination with a filtering system makes the drain self-cleanable and thereby removes the problem of blocked drainage. Besides removing blockage problems, have arable farmers possibility to increase their yield by more than 30%. Further, is a concept; NXD Sight, unfolded which changes drainage from a passive tool to an active tool. NXD Sight provides knowledge of drain condition and soil moisture. The data is useful for predicting problems inside the drain. Furthermore does the knowledge of soil moisture enable arable farmers to see where he can operate with heavy machinery without compressing the soil, damaging his crops or getting stuck in a soft mud-spot.

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0.3 MASTER THESIS

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Consultants SEGES - Stinna Filsø and Eskild
Assistant professor - Ming Shen

0.5 TERMS

Filter grit - Specific sized sand.
Ocher - Is a clay earth pigment.
Arable fields - Production of crops
Re-drain - Drainage on fields which already is drained.
Water flow - The ration of water quantity ti velocity.

0.4 READING GUIDE

The master thesis consists of three parts; Process report, Product report, and a drawing folder. Recorded interviews can be found on the attached USB. References are made using the Harvard method (Anglia). Citation and in-text reference are referred to as (Name, Year).

It is recommended to read the product report first to see the final solution. Second the process report, to get an insight of the process toward the solution. Subsequently, the drawing folder unfolds a knowledge of the product dimensions, design, and details.

The product report visualizes the solution and describes the need, product, and business. The product report targets arable farmers and possible investors where it explains why he should choose the solution in the future.

The process report describes how the team managed and structured the iterative process toward the solution. The process report is displayed linear thus it is an iterative process where the team has jumped back and forward in the project phases. The process report is organized with basis in the Stepping Stone mode.

The drawing folder consists of technical drawings of the final product. These drawings provide knowledge about the product dimensions - both to understand the product but also for the production.

Findings
During the process report is essential findings and knowledge highlighted as shown on illustration 3.1.

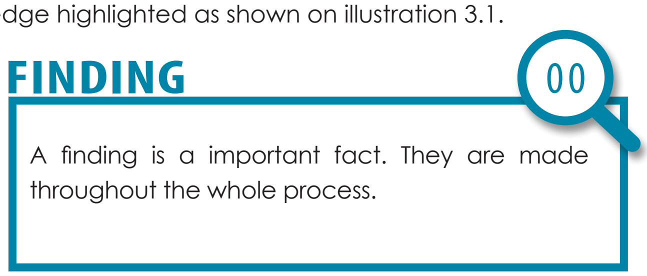


Illustration 3.1 - Finding.

The green boxes which appears in the sections indicates a conclusion or reflection.

0.6 TABLE OF CONTENT

0.7 INTRODUCTION

The following thesis is a result of a process of the development of a new drain for the agricultural sector.
The amount of rainwater has increased in Denmark by 14 %. This amount of water have consequences for farmers as their fields get flooded and their harvest is decreasing due to damaged crops.
The coping strategy from farmers is drainage. Drainage requires a drain pipe which in fact, not have been changed in decades and is not suitable for the new amount of rain. This has consequences of the food production as drainage is an important key to utilize the crops optimum.
Many farmers, contractors, and experts got their own opinion how to approach drainage. Very little research has been done and documented according to drainage. This report collects the different experience-knowledge from the stakeholders and utilizes it for new product development.

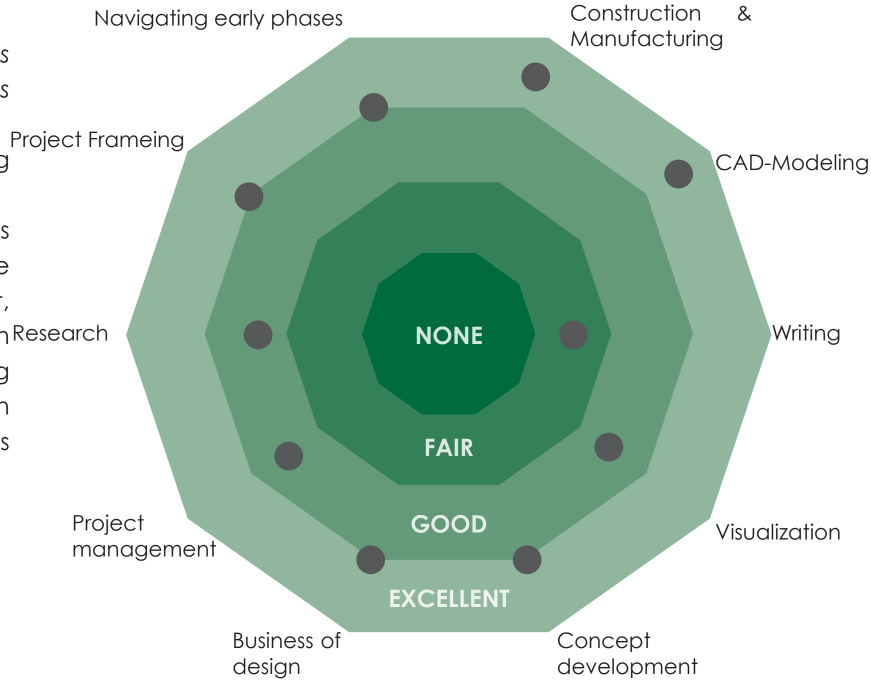
Illustration 5.1 - Flooded arable field.

0.8 TEAM NXD

The following section is shortly describing the intentions with NXD. Further, it unfolds the weakness and strengths of the team.

The intention with NXD is a design and manufacturing company specialized in the agricultural sector.

The team is made with the intention of covering as many of aspect of product design as possible. The team got the strength within concept development, design for manufacturing and networking. The main weakness of the team is documentation and writing of reports. The strength and weakness is reflected in the Gantt chart where a larger amount of resources is linked to writing the reports.



Chapter 1 - Alignment

A reframe of project direction, from the construction section to the agricultural sector, is described.

Chapter 2 - Understand

The chapter unfolds the knowledge which is essential to understand the problems of drainage. The section goes through the functions of the drain, plant conditions, drainage methods, relevant test and competitor analysis.

Chapter 3- Project brief

The chapter shows a brief of the project. The value vision and mission are described through the Product Reasoning Model. Further, is a need- and target specification shown and described.

Chapter 4 - Concept development

The chapter describes the development of ideas to one final concept for further detailing. Further is the evaluation of the concepts detailed.

Chapter 5 - Product

This section shows the detailing from concept to final product.

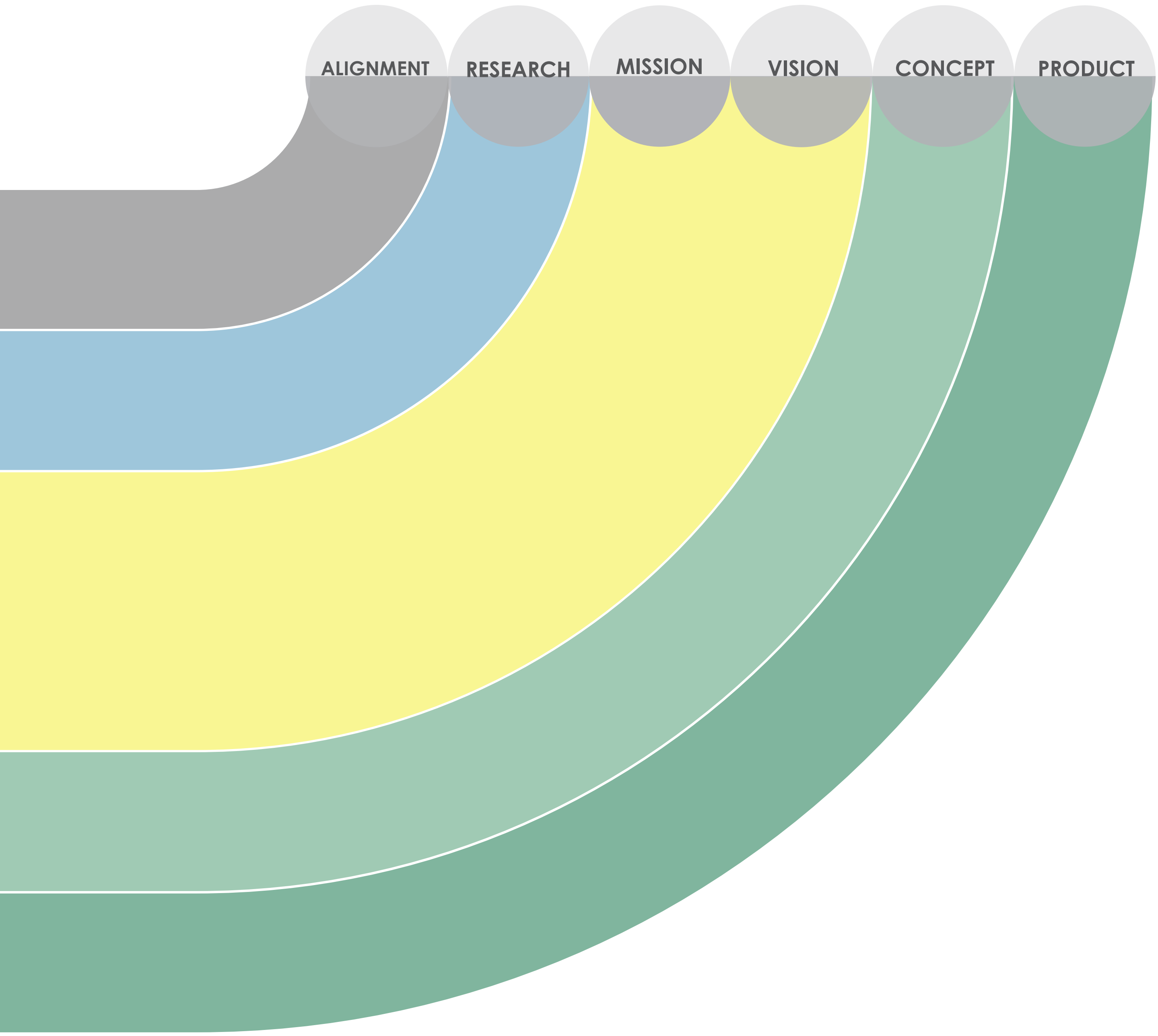
Chapter 6 - Implementation

The chapter displays the business part of the project. It shows detailing of the product cost and return of investment. Further is the business plan made.

0.9 PROCESS STRUCTURE

The following section describes the navigation and the overall phases of the process.

The Stepping Stone model has functioned as the foundation of the process phases (Stokholm, 2011). It has enabled the team to navigate through the different phases throughout the iterative process.
The report is divided into different phases based on the Stepping Stone model. The process is aligned according to the Stepping Stone Model and might be seen linear even though the process has been iterative. An overview of the process is displayed on the Gantt Chart in Appendix 01.



1.0 **ALIGNMENT**

THE FOLLOWING PHASE DISPLAYS THE INITIAL CRITERIA AND HOW THEY ARE USED TO DELIMIT TO A PROJECT THEME. FURTHER IS THE REFRAMING, FROM PROBLEMS ON CONSTRUCTION SITES TO PROBLEMS WITHIN ARABLE FARMING, DISPLAYED. THE MANAGEMENT OF THE PROJECT IS DESCRIBED. THE RESULT OF THE PHASE IS AN ALIGNMENT OF THE PROJECT THEME.

1.1 CRITERIA

Before starting the researching are fundamental criteria listed. These have to ensure high engagement with the project:

- Reachability - the possibility to reach stakeholders, testing facilities, and prototyping.
- Learning objectives - The project has to meet the objectives to a master thesis.
- Reality - The project has real business potential.

The criteria are used for choosing a project direction, described in section 1.3 and 1.4, which the team finds interesting. Hence, the initial criteria are used for navigation within the initial problem statements where the knowledge is limited and problem ill-defined.

1.2 PROJECT MANAGEMENT

This project is managed by using SCRUM (Opelt et al., 2013). The SCRUM tool has provided an overview and alignment of the team through the process. Every morning a SCRUM meeting have been executed where the team planned the day according to the Gantt chart, see illustration 9.2 (full Gantt chart is displayed in Appendix XX). With the basis in the Gantt chart is the backlog of tasks, shown on illustration 9.1, updated. The backlog allowed the team to see the prioritizing of the tasks.

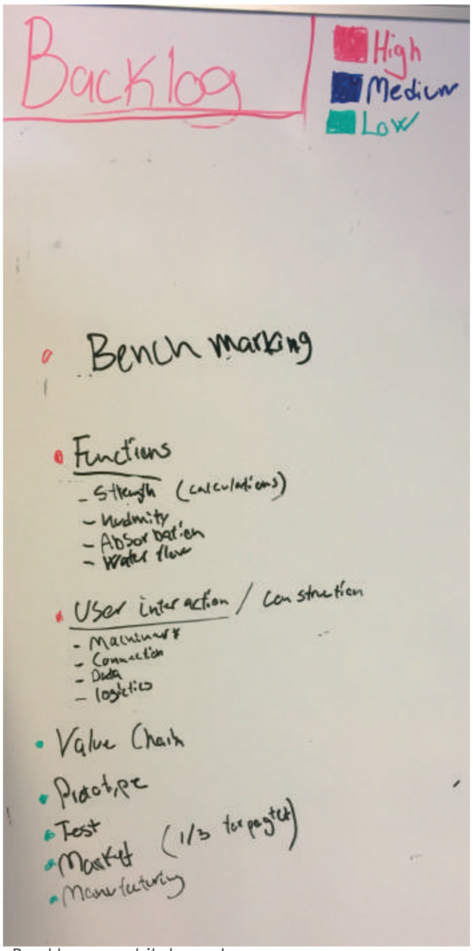


Illustration 9.1 - Backlog on whiteboard.

The Gantt chart is organized according to the Stepping Stone model. All tasks in the chart is labeled with; the associated worksheet, the estimated time needed to complete the task (Resources), the date of execution, the responsible and the percentage of completeness of the task. The Gantt chart was planned in sprints of 14 days by completing a work breakdown structure (Tonnquist, 2009) (Opelt et al., 2013).

To ensure progress of the process, two milestones are planned. The first milestone with focus on the market, need and problem and the second milestone with focus on solution and business. Every 14th day, mini-milestones are conducted with co-students to ensure a meaningful process and to reflect on the process, problem and solution.

Many experts, users, and stakeholders are involved in the process. Hence, is a contact sheet made to manage the relationships and information of the contacts. The contract management sheet provides knowledge about; general contact information, location, communication method and status of response. The contact management sheet can be seen in Appendix 02.

Illustration 9.2 - A part of the Gantt chart.

GANTT CHART

PROJECT TITLE	NXD Drain	PROJECT MODULE	Master Thesis in Industrial Design
PROJECT SUPERVISOR	Finn Schou	DATE	20-01-18
Time budget	525 hours/per person	Rolling planning	14 days ahead

Worksheet No.	TASK TITLE	TASK OWNER	START DATE	DUE DATE	Estimated hours	PCT OF TASK COMPLETE	
1	Pre-phase		22/1	14/2	30		
2	Desktop research - statistics and problem	MJJ	1/1/2018	2/14/2018	5	100%	
	Risks (Project)		2/13/2018	Agile	7		
3	Field research - problem verification and agreement	JAH	1/22/2018	1/22/2018	Divided in research	100%	
-	Team cooperation contract	JAH, MJJ	1/25/2018	1/25/2018	2	100%	
11	initial stakeholder analysis	JAH, MJJ	5/2/2018	5/2/2018	4	100%	
11	Key challange	JAH, MJJ	5/2/2018	5/2/2018	4	100%	
	Set-up project mangement	JAH, MJJ	1/2/2018		10	100%	
	Time used				32	hours	-2 Reminding hours
	Research		1/2	1/3	220		
3	Visit 1 - NCC	JAH, MJJ	5/2/2018	5/2/2018	15	100%	
3	Visit 2 - KJ entrepenør	JAH, MJJ	6/2/2018	6/2/2018	15	100%	
3	Visit 3 - A. Engaard	JAH, MJJ	14/2/2018	14/2/2018	15	100%	
17	Visit 4 - Skjoldager dræn-&entreprenørforretning	JAH, MJJ	20/2/2018	20/2/2019			

January																									
WEEK 1					WEEK 2					WEEK 3					WEEK 4					WEEK 5					
M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M	T	W	R	F	M
1	2	3	4	5	8	9	10	11	12	15	16	17	18	19	22	23	24	25	26	29	30	31	1	2	5

1.3 REFRAME OF PROBLEM AREA

This section is describing the early start of the project where the focus was on construction sites. This section describes the ill-defined problems occurred at the construction sites. Further, why the team decided to look in other project directions. This section is based on: Visits and interviews at NCC, A. Engaard and KJ Entrepræņøren, empirical knowledge.

Communication with operator.

From June 2016 to July 2017 is eight fatal accidents happened around the British construction sites due to earth moving machinery (Theconstructionindex, 2017).

The following accidents happened :

- Hitting a pedestrian
- Driving over pedestrian

The accidents are a result of miscommunication between the machine operator and pedestrian and an unawareness of the position of the pedestrians.

Underneath are different working situations and coping strategies shown in images, see illustration 10.1, 10.2 and10.3.

Illustration 10.1 - Open front window to talk with co-workers.

Illustration 10.2 - Fencing around walking path.

Illustration 10.3 - Communicating by hand signals to machine operator.

Product solution space

When opening up the solution space, the proposals often ended in a headset with a hands-free microphone which allowed the workers to communicate with each other easily. Researching on existing solutions showed many products already solving the problem. The reason for not using the communication solutions depends on further software development and lowering of the unit price. The problem and the solution space did not meet our criteria, learning objectives described in section 1.1, as existing products can solve the problem and only needs to be implemented and developed software wise.

FINDING 01

Many existing solutions can already solve the communication problem and only have to be implemented.

Control of concrete elements

Though a visit at A. Engaard a problem occurred in the process of placing concrete elements. A concrete element got a weight of 9-15 tonne and is moved and lifted by a crane.
The handling of a concrete element is a four-step process:
1. Attachment to crane in floor level
2. Movement of the concrete element
3. Placement of concrete element
4. Attachment of element by shoring jacks
The placement of the element takes around 15 minutes.
The problem is detected from step 2 to step 3. Between these steps, the element is not controllable. Meaning if the wind starts rotating the element is there no way of stopping the concrete element again. In a strong wind, the workers are using a rope to control the element. The controlling is done from the floor level an by hand. The controlling is a hard job because the element is lifted at extreme heights.

Illustration 11.1 - Lifting the concrete element.

Illustration 11.2 - Moving the element.

Illustration 11.3 - Placing the element.

Product solution space

The solution of this problem has to control the rotation and placement of the concrete element. This can, in general, be done in two ways:
- Developing a new machine/crane
- Developing a module which can be attached between the crane and the concrete element.
The solution space did not meet the criteria of personal engagement and the degree of reality. Developing a new machine require a large number of delimitations and does not meet the criteria of reality.

FINDING 02

Constructors are rotating 9-15 tonne concrete element by hand and rope. A new solution requires a large number of delimitations.

Conclusion

The initial research and development were with focus on the construction sector. The problems and their associated solution space did not meet the criterion from the team. The solution spaces and working principles were highly relying on software development and implementation or the development of new machinery. Where software- and implementation development became too weak a project was the development of new machinery a too complicated task for the team. The development of new machinery was not realistic in the project time-line and would require a large amount delimitations. Therefore, the team decided to look in a direction with a more wicked problem statement and with higher personal engagement.
Essential learning to the team is to execute a better strategy for navigating the early phase. The team made a clear plan of execution; 1. Find an exciting problem area, 2. Open up the product/service solution space, 3. Kill the ideas.

1.4 CHOSEN PROBLEM AREA

This section describes the reframe of the project scope. The team unfolds new topics and a negative brainstorm with a stakeholder group. This section is based on: Desktop research and a mini-workshop with farmers.

The team investigated trade magazines of agriculture to find a new problem area. The search resulted in the highlighted topic - drainage.
The climate has been changing in the last decades. One of the changes is rainstorms. Rainstorms have become more intensive and with heavier rain. DMI has noticed an increase of rain in Aalborg, Denmark, by 14,1 % since 1870 (Cappelen, 2018). Climate change is a result of more intense rainstorms and longer periods of drought (Olesen, 2015). Climate change is a problem to our food production as the crop is depending on the weather. This amount of rain is creating flooded areas on the fields which are damaging crops and harvest. Furthermore, is the rain creating soft and muddy areas on the fields which makes the farmer unable to treat the crop properly, this is shown on illustration 12.1. More excessive rain requires existing drainage systems to be in perfect condition to avoid food waste.

The initial research into drainage and the consequences of climate change to arable farmers resulted in following problems:
1. Blockage in drains
2. Nutrient leaching due to increased rain
3. Dry days - no water / Rainy days - Too much water

With a basis in the initial research, the team started to look into the product solution space to investigate the potential of the problem statements. The result was a vision "*making drainage control- and predictable*".
The team was in need of getting further knowledge about different perspectives of drainage. Further, to get the initial vision and solution space proved by stakeholders. Therefore, the team arranged a mini-workshop with the purpose of killing the vision and initial ideas. The initial ideas can be seen on page 47.

FINDING 03

The rain have been increased by 14.1% in Aalborg since 1870, represented as heaver rainstorms. Simultaneously is the period of drought longer.

Illustration 12.1 - Soft and muddy spot on field.

Potential project scope

As the team already have done the initial research within the construction sector was the importance of aiming a problem, with high potential, essential. Therefore, the team arranged a mini-workshop with farmers to discuss the topic. The team did not have great knowledge about drainage, but it was decided to have the mini-workshop to discuss issues regarding drainage topic. The team gathered four stakeholders; a large-scale farmer, an arable farmer, an agricultural contractor and a former farmer, to discuss the drainage topic and the vision. The team introduced the topic and the intentions and visions. The introduction started a discussion and sharing of experience among the farmers. It became clear the for the team that farmers are draining with different approaches and are learning the drainage techniques from each other. The interest confirmed the relevance of the drainage topic. Their main comments and concerns were:

- With a solution which can predict a drain blockage, would be very useful to them. They saw great potential in the vision of the product.
- The complexity of the product sounds high. Mechanical products result in more maintenance.
- A solution to the vision sounds expensive to them.

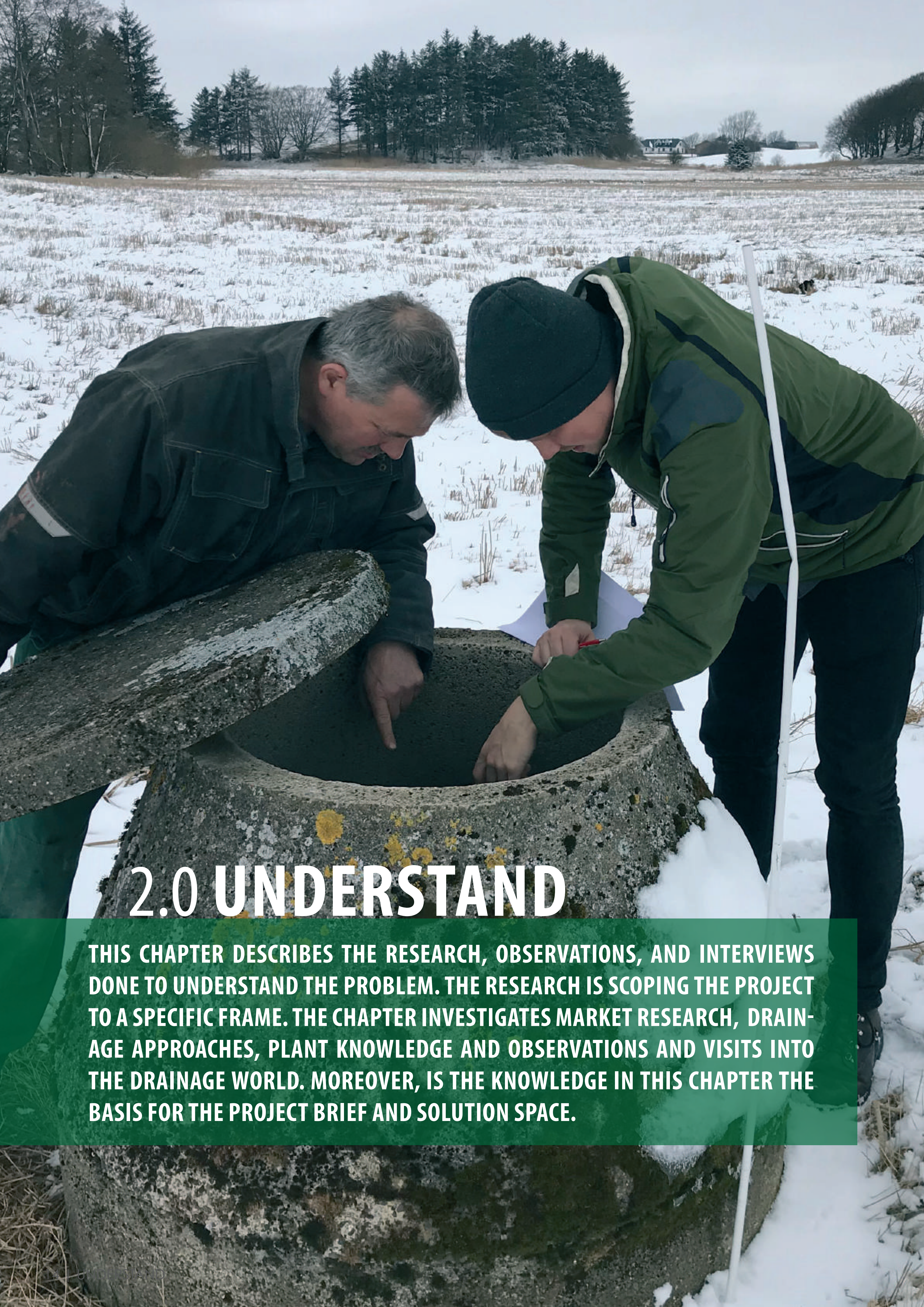
The workshop and newly gained knowledge are compared to the criterion and based on this the team have decided to work further within drainage topic. Next step for the team is to further investigate and research about drainage and the associated problems.

FINDING 04

Drainage is a discussed topic among farmers. Their drainage knowledge is based on experience. The only way of knowing something is wrong with the drain is when the field is flooded.

A mini-workshop and new knowledge have convinced the team to investigate the problems within drainage. The topic and the solution space fulfills the personal criterion to the team members.

Current frame:
Develop a product which can control and predict the need of maintaining in drainpipe systems.



2.0 UNDERSTAND

THIS CHAPTER DESCRIBES THE RESEARCH, OBSERVATIONS, AND INTERVIEWS DONE TO UNDERSTAND THE PROBLEM. THE RESEARCH IS SCOPING THE PROJECT TO A SPECIFIC FRAME. THE CHAPTER INVESTIGATES MARKET RESEARCH, DRAINAGE APPROACHES, PLANT KNOWLEDGE AND OBSERVATIONS AND VISITS INTO THE DRAINAGE WORLD. MOREOVER, IS THE KNOWLEDGE IN THIS CHAPTER THE BASIS FOR THE PROJECT BRIEF AND SOLUTION SPACE.

2.1 DRAINAGE AND THE PURPOSE

To narrow down the project scope and to get a general knowledge about drainage, the team investigated farming trends, the drainages main functions, market potential and the drainage history. The section will specify the context of the project frame. This section is based on: Desktop research.

Today's farming is highly characterized by the digital revolution reflected in the phenomenon "Precision Farming". It covers an array of different methods to predict and fine-tune different needs and risks in the agricultural sector. Precision farming is also represented in arable farming where new products communicate with the farmer about conditions and needs of his crops. All this data is collected above ground level. However, drainage, which is highly essential for growth to a crop, has been forgotten for a period and is highly in focus again. The interest of drainage has been increased with heavier rain storms destroying the yield of crops.

A drain is a pipe full of holes, see illustration 15.1. The drain got two primary functions; lowering groundwater and leading the rainwater away (Nielsen, 2015). Back in days was the primary purpose of drainage to make the farming more cost-effective. Denmark was a very wet country with many lakes which caused many struggles, before the establishment of drains.

Market potential
About half of the fields in Denmark are drained. This is equal to 1.4 million drained hectares of the 2.6 million hectares used for farming in Denmark (Andersen & Sørensen, 2015). Much drainage happened from 1970 - 1980, see table 15.2. Drains have been lasting for many decades. Looking on the lifetime of the drains is a yearly need of drainage estimated to 27.000 hectares in Denmark (Nielsen 2015). 27.000 hectares is equal to 1.01% of the 2.662.030 hectares arable fields. A plot of the drainage need is shown on illustration 15.2.

As 27.000 hectares every year got a need of new drainage has the team decided to focus on the drainage market. The reason is partly because of the market potential, the digital aspect and a high personal interest from the team.

From this research and decision, the next move for the team was to gain more knowledge of the working principle of drainage.

FINDING 05

The yearly need of drainage in Denmark is estimated to 27.000 hectares.

FINDING 06

54 % of all arable fields in Denmark are already drained.

Illustration 15.1 - Traditionally corrugated drain

Drained areal in Denmark			
Year	*Areal (Hectares)*	*Year*	*Areal (Hectares)*
1975	*6.900*	*1982*	*8.900*
1976	*5.900*	*1983*	*10.900*
1977	*4.600*	*1984*	*7.600*
1978	*6.900*	*1985*	*7.400*
1979	*6.100*	*1986*	*6.900*
1980	*5.400*	*1987*	*500*
1981	*8.000*	*1988*	*1.900*

Table 15.1 - Drainage done in Denmark (Nielsen, 2015)

Illustration 15.2 - Map of need of drainage (Olesen, 2009)

2.2 WORKING PRINCIPLE

The following section describes the working principle of drainage. The research is made to gain further insight into the reason and understanding of drainage. The knowledge is the basis for stakeholder visits and interviews. This section is based on; Stakeholder interview with consultant Stinna Filsø, consultant Eskild Bennetzen, drain contractor Jens Skjoldager and desk research.

Illustration 16.3, shows the placement of a typical drain in the context of arable farming. The depth of draining is a very discussed topic where many contractors, experts, and farmers got an opinion. However, through research was different contractors, experts and farmers asked for the drainage depth. The result was a recommended drainage depth of around 0.9 - 1.2 meter depending on the type of soil. Additionally, the distance between the drain is 12 - 25 meter. (Filsø, 2018), (Bennetzen, 2018), (Nielsen, 2015).
When raining and the water-table raises, the drainage system leads the water towards a stream, lake or into a well as illustrated on 16.1 and 16.2.
Illustration 16.3 shows how the water is acting in the soil when the field is flooded due to a drain blockage. When a blockage occurs is the soil saturated with water all the way from the drain to the ground surface.

Illustration 16.1 - Drain outlet into well.

Illustration 16.2 - Drain outlet into stream

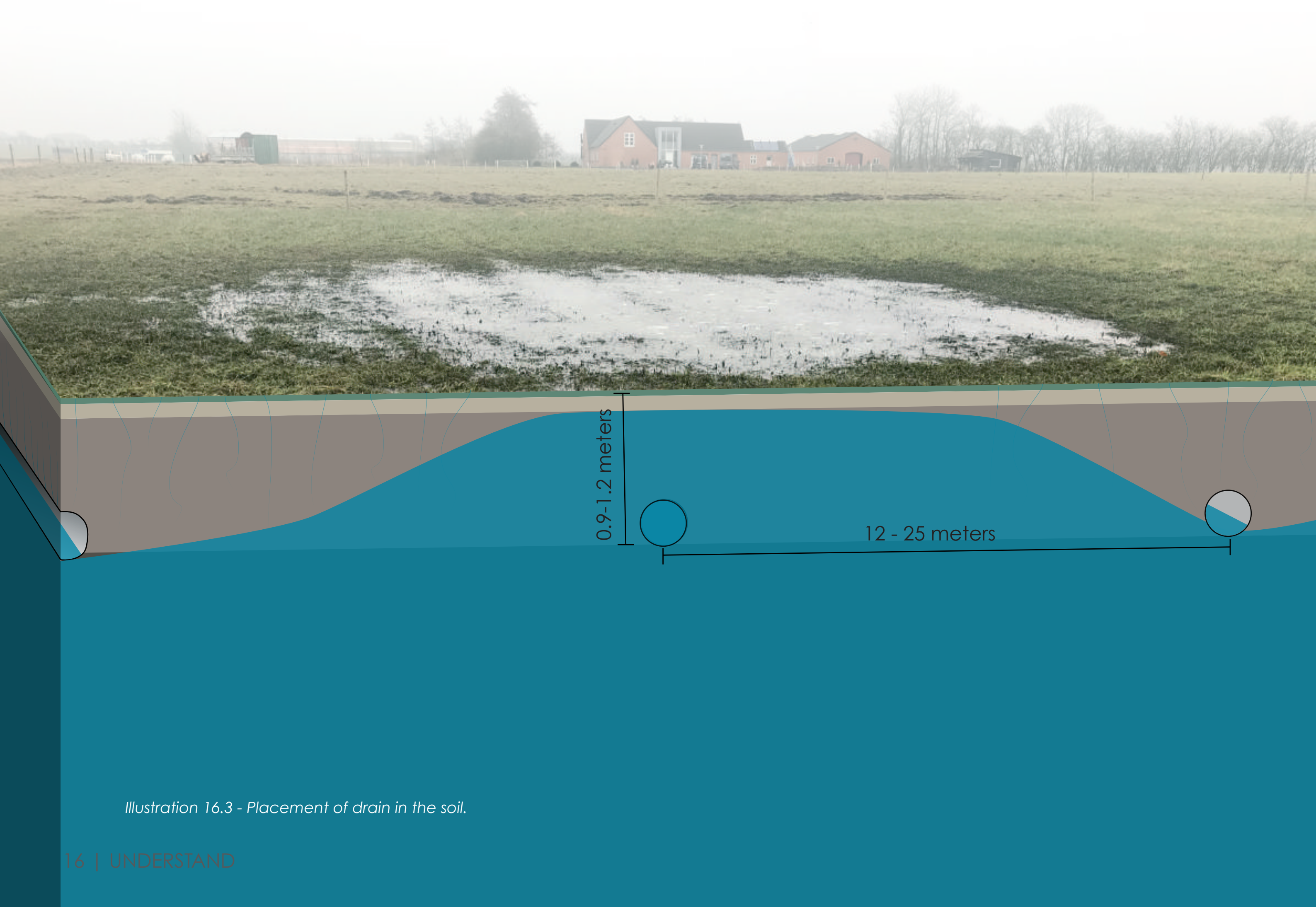


Illustration 16.3 - Placement of drain in the soil.

2.3 PERFECT CONDITION FOR A PLANT

When designing a new drainage solution, it is essential to look into what conditions the plants require to develop the highest yield. Better conditions for the plants will result in a higher yield to the farmer. This section is based on: Interview with Christian Christensen from LandboNord.

The essential needs for a plant to grow

Plants are photoautotrophic organisms. Meaning they can produce all the essential chemical compounds that they will use in metabolism based on light from the sun and 17 different elements to complete a life cycle. The 17 different elements are divided into two groups of macro- and micro-nutrients. Macro-nutrients are the elements the plant has largest consumption of (shown in table 17.1) where micro-nutrients are elements that the plant has a lower consumption of. (Thomsen, Husted & Neergaard, 2013)

Carbon (C), oxygen (O) and hydrogen (H) are transformed to the plant through CO2 in the photosynthesis and H2O from the transpiration. The remaining 14 elements are absorbed as inorganic ions from the roots and divided to the rest of the plant. (Thomsen, Husted & Neergaard, 2013).

FINDING 07

Proper drainage can increase the yield with 19 - 31% as it allows the roots to grow big.

The benefits of drainage

As roots also need oxygen, the root system of the plant cannot live in soil fully saturated with water. Therefore is the size of the root system dependent on the hight of the water-table (Christensen, 2018). Drainage allows the roots to grow deeper into the soil as the water-table is lowered. The result is an extensive root system. Larger roots are increasing the capability to absorb even more nutrients and thereby increase the yield as shown on illustration 17.1(Nielsen, 2015). Former studies have estimated a possible increase of yield by 19-31% with proper drainage (Poulsen, Jensen & Filsø, 2017).

Macro-nutrients		
Element	*Available form*	*Concentration in dry plants (%)*
Hydrogen	H_2O	6
Carbon	CO_2	45
Oxygen	O_2, H_2O	45
Nitrogen	No_3-, NH_4+	1,5
Potassium	K+	1,0
Calcium	Ca++	0,5
Magnesium	Mg_2++	0,2
Phosphorus	H_2PO_4-, HPO_4--	0,2
Sulfur	SO_4--	0,1

Table 17.1 - The need of macro-nutrients for a plant.

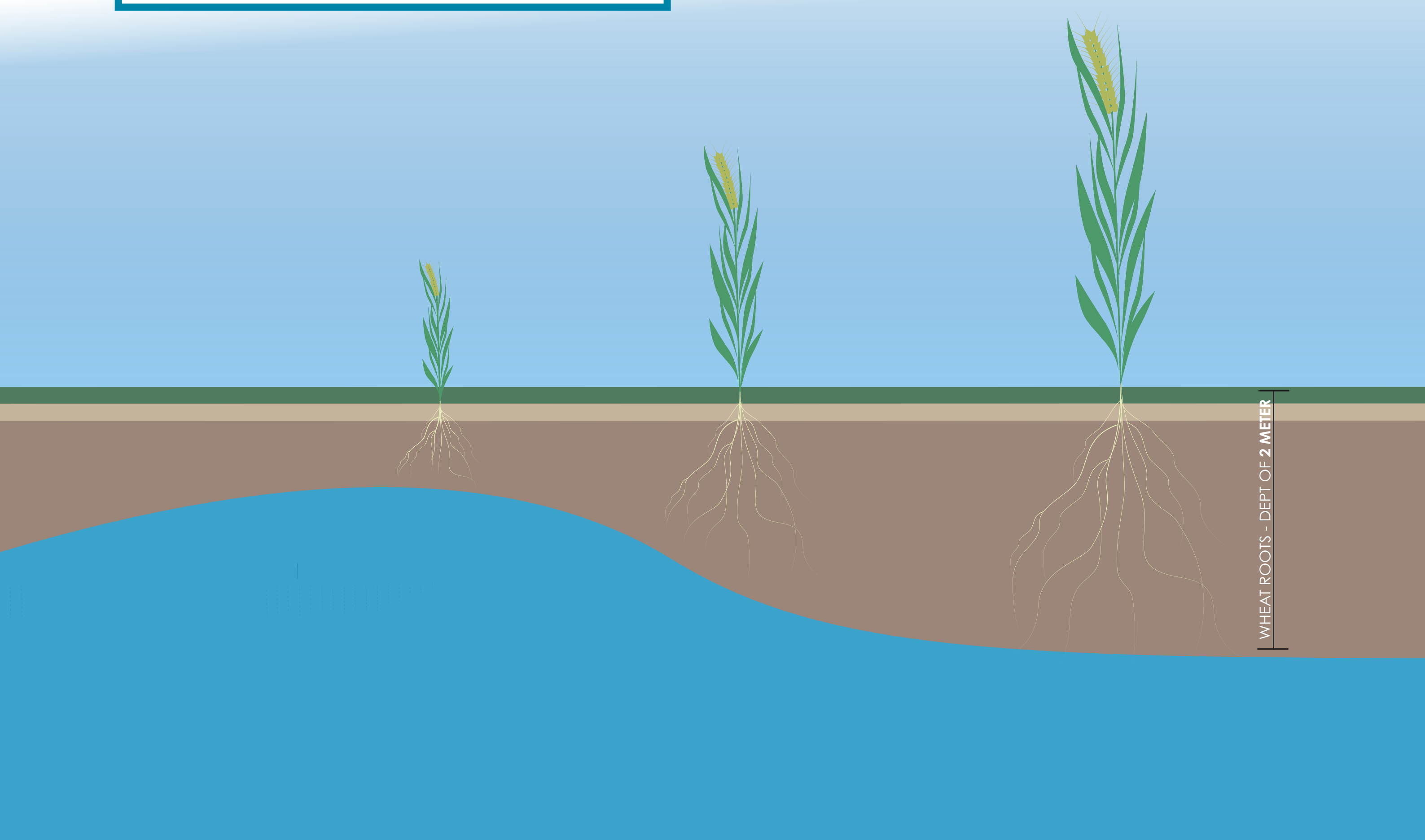


Illustration 17.1 - Effect of the water-table level according to the growth of the root system.

2.4 DRAINAGE HISTORY

The following section describes the development of drainage. The lifetime of a drain is high. Therefore, the team needed knowledge about the history of drainage approaches. This section is based on: Desk research.

Year 1100 - 1200: Monks started draining by trench.

Year 1750: Drainage by trench of larger areas.

Year 1800: First drain pipes was introduced. "Shoe horse tiles" did not have much success.

Illustration 18.1 - Shoe horse tiles.

Year 1842: First cylindrical drain tile was developed and manufactured in Great Britain.

Illustration 18.2 - Drain tile.

Year 1848: First Danish farmer, Adolph Valentiner, to merge and pipe-drain all his fields. He got a significant increase of yield from his crop.

Year 1900: The government owned company "Hedeselskabet" starts economically support of drainage.

Year 1960: Introduction of first mechanical plow for PVC pipe drainage.

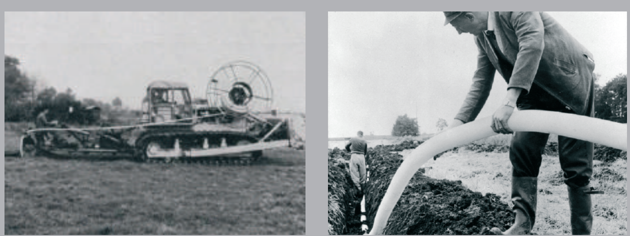


Illustration 18.3 - Plowing and PVC pipe introduction.

Year 2000: The first Dutch fiber drain for filtering fine sand was introduced.

Illustration 18.4 - Dutch fiber drain.

The development of drainage has the last years been low. Only one new kind of drainage is presented in newer time, and this is the Dutch fiber drain. The strategy of the new drain pipes is to filter fine sand to avoid sand blockage inside the drain.
Many farmers have troubles with the Dutch fiber drain as they clog, therefore the most common drain used, is the same used in 1960. Only few cost optimizations have been done.

FINDING 08

The strategy of newer drain pipes is to filter fine sand to avoid sand blockage.

2.5 FUTURE NEED OF DRAINAGE

With the knowledge from the research about drainage history, the following section further discovering the trends and life-cycle doing the time of drainage. This section is based on: Desk research and Interview with drainage expert Stinna Filsø.

By looking back on the number of fields drained in Denmark since 1850, it is possible to see multipliable peaks in hectares drained, see illustration 19.1.
First great peak in the history of drainage happened around 1875 where approx. 30.000 hectares was drained yearly form 1870 - 1880 (Olesen, 2009). The peak occurs at the same time as drain tiles were introduced. The placement of tile drains were unsystematic which caused troubles with managing the water several years later.
The second peak happened 75 years later in 1950. Many struggled with the old drain tiles due to the unstructured system. Hedeselskabet started to provide economic support and supervision to the farmers to create a structured system of their drainage. This happens at the same time as plastic pipes get introduced. Around 25.000 hectares a year was drained from 1930 - 1960 (Olesen, 2009). The drain tiles was replaced by plastic pipes, and both can today be seen operative in the ground all over the world. So saying, some of the drain tiles are still in use as well the plastic pipes from 1930-1950.
Since 1988 the record of drainage data has been decreased as the support from Hedeselskabet stopped, and farmers were in charge of the drainage of his fields. Even through the farmer has to pay himself, is 75% outsourcing the task of drainage (Skjoldager, 2018).
Experts estimate a massive new need of drainage (Nielsen, 2015)(Olesen, 2009). This is both new areas but also re-drainage of the old drainage system. This is partly because of the increased amount of rain and partly because of worn drains (Filsø, 2018). Further, as the lifetime of the drainage systems is around 60 years, is the yearly amount of re-drainage estimated to 27.000 hectares every year (Nielsen, 2015).
The need occurs approx. 75 years from the last significant need of drainage. This gets along with the lifetime of the drain pipes which average are 60 years (Filsø, 2018). Illustration19.1 shows the need of drainage in Denmark from 1850 to 1988 and the possible new need.
By historical- and expert knowledge is it confirmed that there is a link between the development of new drainage methods and the amount of drainage done in Denmark.

FINDING 09

75% of the drainage to day is outsourced to contractors.

FINDING 10

The history of drainage shows that the farmer is willing to adapt to new drainage methods

Through the research is it concluded that farmers are willing to adapt to new drainage methods. Further, experts estimate a need for drainage, but a development of new drainage method is needed.

Doing the first research into the drainage culture have shown many different theories and approaches. First a couple of years ago experts started testing the difference of drainage. Meaning there is no right or wrong answer to the different drainage approaches. Therefore, the team decided to visit three different stakeholders to get their point of view; A contractor who focus on surface water, a contractor who is doing the most common approach and a farmer who have developed his own approach.

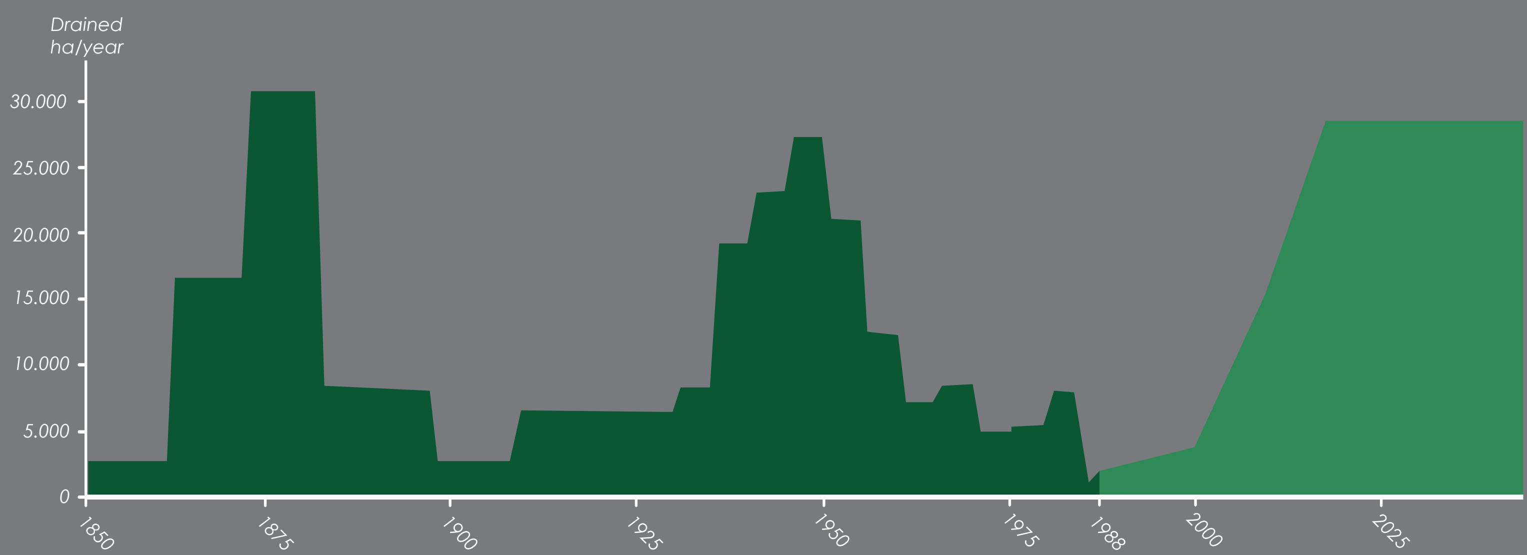


Illustration 19.1 - The need of drainage doing time.

2.6 VISITS AT THREE STAKEHOLDERS

The following section describes empirical data collection conducted through visits at three different stakeholders; Langholt Maskinstation, Skjoldager Dræn & Entreprenør-forretning, and Gunnar Laden. The visits was done as the team had a need for more knowledge of the existing drainage systems and approaches. The section will first explain their company and afterwards their drainage strategies. The section is based on: Situated interview and Acting out (Sperschneider and bagger, 2003).

Langholt Maskinstation

Langholt Maskinstation are specialist in drainage of football fields and golf courses. In these contexts is main struggle to get water at the surface away as fast as possible. Langholt Maskinstation have specialized equipment to put down the drains. Their machinery is a chainsaw which makes the trench. Langholt Maskinstation operates all over Denmark and in the United Kingdom, as not many are doing these kinds of job.

Illustration 20.1 - Chainsaw trencher at Langholt Maskinstation

Used drain facts:

Type:	PVC
Diameter	50 mm
Length:	50 m
Stiffness:	Flexible
Filtering:	Plastic filter
Holes:	All around
Price:	25 DKK/meter


Illustration 20.2 - 50 mm drain

Skjoldager dræn & entreprenørforretning

Is a local drainage company located near Hjørring. The manager is named Jens and he got 5-6 employees.
When a farmer got a need of drainage, they will call Jens. He or one of his employees will then do the drainage job when the soil is dry and operational. They are using the most traditional approaches for drainage; L-Plow and a drain box, shown on illustration 20.3 and 20.4. These methods are the most common approaches used in Denmark and are further explained in section 2.9. Besides installation of new drainage, he also maintains them. This is done with a drain flusher with a pressure of 200 bar.


Illustration 20.3 -Drainbox


Illustration 20.4 - L-plow

Drain facts:

Type:	PE
Diameter	90 mm
Stiffness:	Flexible
Length	50 m
Filtering:	None
Holes:	All around
Price:	12 DKK/meter


Illustration 20.5 -90 mm drain

Gunner Laden

Gunnar is a farmer located near Tårs in northern Denmark. He is the manager of his farm with production of pigs and corresponding 1000 hectare of plant production. Besides these, are Gunnar and his employees excavating his drains by themselves.

The way Gunnar is determining the need for drainage is by looking at the stubble. If the stubble is weak, thin and not firmly planted is it an indication of a plant with a weak root system, see illustration 21.1. The weak root system is equal to a high water table. Where, on the other hand, a thick and robust stubble is an indication of a large root system, meaning the water table is low, see illustration 21.1.

Gunnar own and uses an excavator to excavate the trench for drainage. Gunnar uses top-slotted drain pipes. These pipes are smooth inside which increases the water velocity. The increased velocity has resulted in less maintenance of his drains.

Illustration 21.1 - The spots where crop not are closely guarded is in need of drainage.

Drain facts:

Type:	PE
Diameter	105 mm
Stiffness:	Stiff
Length	4-6 m
Filtering:	None
Holes:	Top-slotted
Price:	21.75 DKK/meter

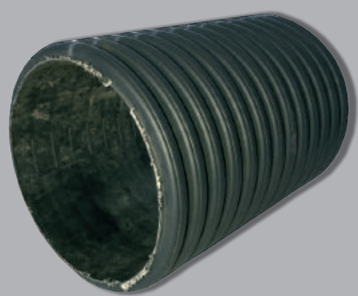


Illustration 21.2 - 105 mm top-slotted drain

FINDING 11

Drainage requires know-how as the decision of new drainage is based on tacit knowledge.

FINDING 12

Gunnar use top slotted drain pipes with a smooth surface to increase the water velocity.

DRAINAGE STRATEGIES

Langholt Maskinstation

The primary purpose of drainage of football fields is to get fast rid of surface water. Therefore, the depth of the drains is around 40 - 50 cm. The drain is surrounded with screened grit which is filled in the trench all the way to the soil surface. The layer of filter grit is leading the water from the ground surface into the drain. Langholt Maskinstation uses 50 mm drain pipes to increase the water velocity. A smaller diameter of drain pipe will increase the water flow. Thereby also the water velocity and ability to be self-clean. See illustration 22.1.

Skjoldager dræn & entreprenørforretning

Skjoldager uses drain pipes with a diameter of 90-100 mm. These are placed at a depth of approx. 1 meter depending on the type of soil. Filter grit surrounding the drain is an option but often used for better penetration of water. Skjoldager uses flexible drains as the implementation time of rigid pipes is too high. Skjoldager uses GPS which allows them a high precision of leveling the drain. A slope of 3 ‰ is defined as self-purifying. This slope is used if the terrain allows it. In many cases, especially in central Jutland, do the terrain only allow a slope on 1‰.

Gunner Laden

Ten years ago Gunnar got an idea of trying to place the drains deeper than generally as the standard drainage systems did not work optimal on his fields. The corrugated drain did provide a high enough water velocity to make the drain self-clean. This resulted in much maintenance and flooded- and unused arable fields. Gunnar developed a unique drainage approach where the drains are placed 2 - 2.5 meters underneath the surface. This approach lowers the water table which allows the crop to grow a deep root system.

The approach used by Gunnar:

1. Gunnar is excavating a three-meter wide triangular trench. The triangle creates larger break through the soil layers. Meaning the water penetration to the drain is higher as the triangle directs towards the drain.
2. In the tip of the triangle is the drain pipe placed. The pipe Gunnar uses is a top-slotted pipe. Meaning the penetration of water only happens from the top. Further, the surface inside the pipes is smooth. According to Gunnar is this one of the keys to success as it makes the drains self-purifying due to increased water velocity. On top of the pipe is filter grit placed.
3. Another important thing to Gunnar is to refill the trench when the soil is dry. Refilling the soil when it is wet results in a compression of the soil meaning the penetration of water is low.
4. Gunnar is not operating on the excavated area before the soil is compressed naturally. This often takes a season before the area is ready to be cultured again.

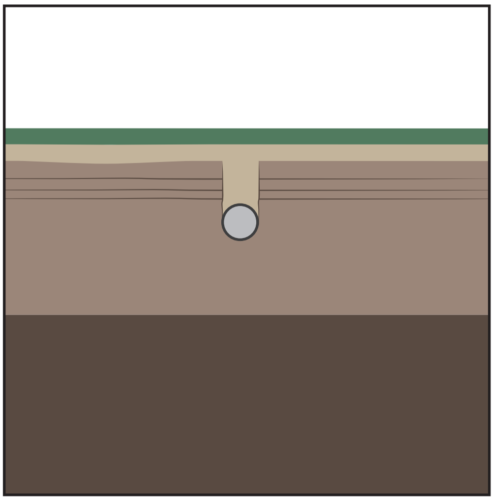


Illustration 22.1 -Surface water drainage.

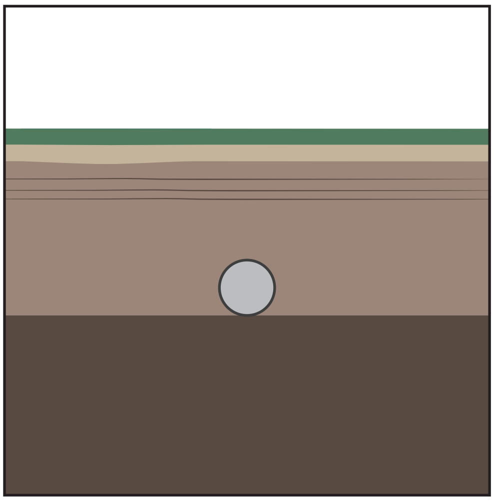


Illustration 22.2 -Traditional way of drainage.

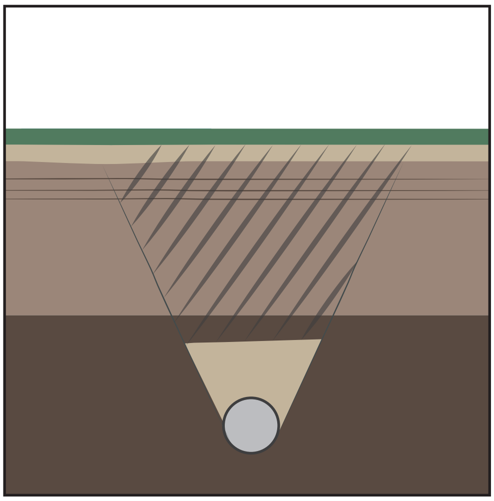


Illustration 22.3 -Lowering the water table drainage

FINDING 13

Skjoldager uses flexible drains instead of rigid to keep down the implementation time. Hence, the drainage cost for the farmer.

FINDING 14

Gunnar avoids using excavated areas until the soil have achieved a naturally compression.

2.7 PROBLEM OF DRAINS

The following section is summary of the different problems of the existing drainage system. The problems are detected during data collection.

Problem 1 - Sand blockage
The problem is represented when the slope of the drain is low. Meaning the water velocity is to low which allows sand to drop to the bottom of the drain. Over time is sand accumulating which will create a blockage in the drain.

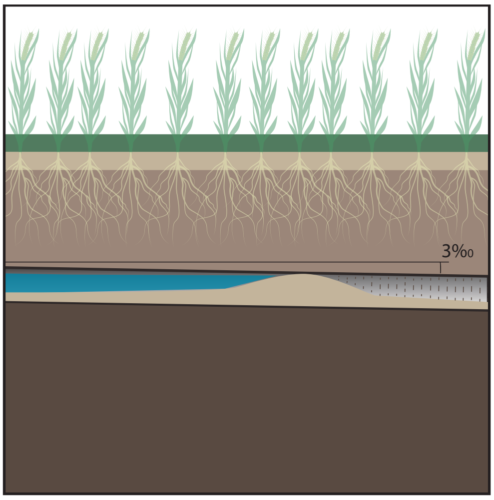


Illustration 23.1 - Sand blockage.

Problem 2 - Roots and sand
The root system of the crops can grow to a depth of 2 meters. Meaning there is a risk of roots growing into the drain pipes. With roots inside the drain makes it easier for the sand to accumulate and thereby create a blockage.

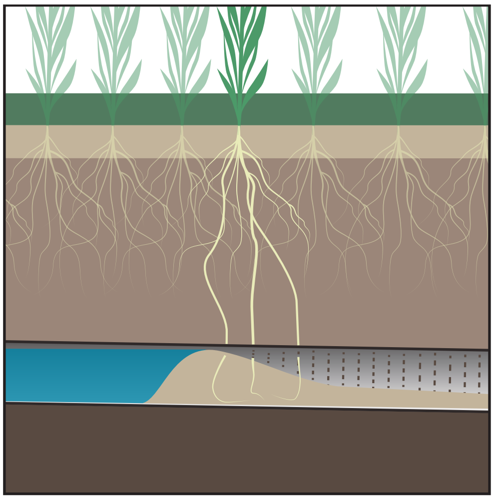


Illustration 23.2 - Roots in drain.

Problem 3 - Heavy machinery
The machinery in the agriculture sector is growing larger and heavier. Due to time constraints from plants, the farmer can not always wait to operate on the field before the soil is dry and strong. The consequence of driving in the wet soil is a higher pressure to the drain which makes the drain collapse.

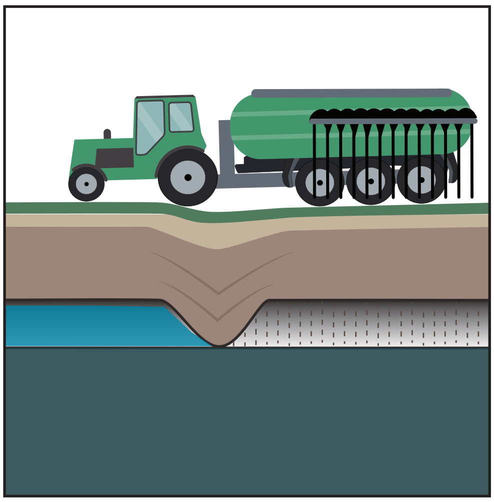


Illustration 23.3 - Collapsed drain.

Problem 4 - Compressed soil
As described in problem 3, is the result of driving in wet soil a higher pressure from the machinery to the soil. This further results in a compressed soil which means all the pores in the soil disappears. This creates a film that the water not can penetrate through. The result is a flood.

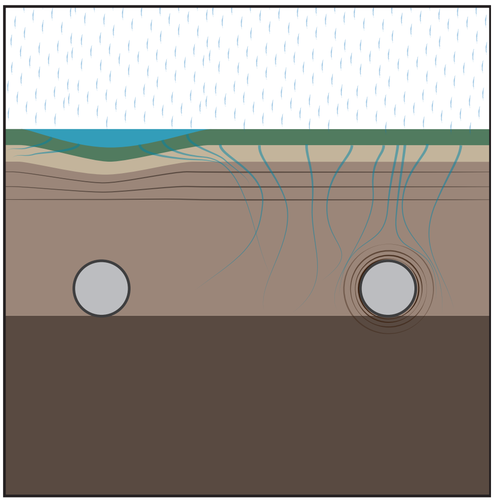


Illustration 23.4 - Compressed soil.

2.8 PROJECT ENGINEERING

This section is describing the whole process of drainage. This section provides knowledge about the engineering, analysis and chooses of drainage method. The section is based on: Interview with Skjoldager Dræn og Entreprænørforretning and Desktop research.

ENGINEERING

There are several factors to consider when the farmer has to establish new drains on his fields. He needs to get knowledge about the conditions on the fields. The main parameters are contour lines and soil type, described in the following sub-sections. These parameters are analyzed by consultants associated with the contractor who, in most cases, is in charge of the drainage work. A digital map will be used as the base for all the collected information about the fields, see illustration 24.1.

Illustration 24.1 - Map field which need drainage.

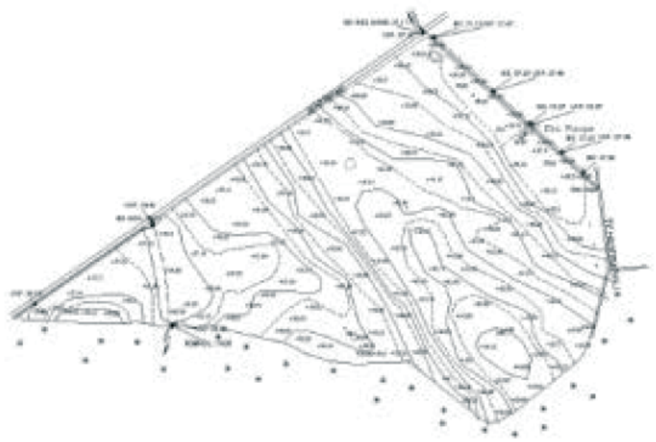


Illustration 24.2 - Contour lines on the field.

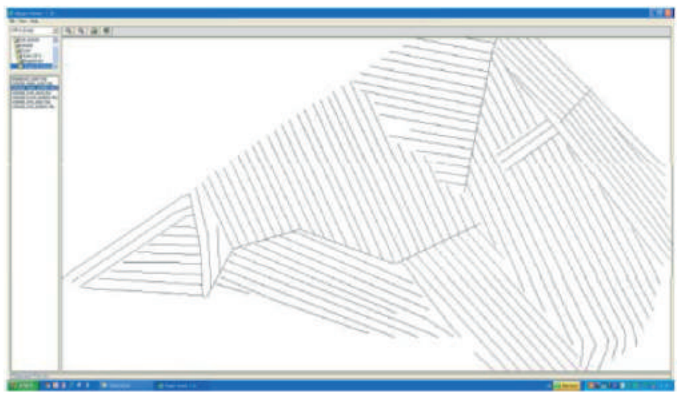


Illustration 24.3 - Contour lines on the field.

Contour lines

The first thing is to register the contour lines and the datum heights on the fields. This data is plotted on a map, with subsequent ditches, roads as seen on illustration 24.2.

The map, also called base-map, will function as a digital management tool where the contractor can plan the drainage structure and system, as shown on illustration 24.3. The structure of the drains is planned in the base-map. The base-map can then be uploaded into the GPS-system on the drainage machinery. The machinery can place the drain with a tolerance of 2 cm with help from the GPS system. (Nielsen, 2015)

Soil type

The soil type is a very important part when planing the establishment of the drain. The soil type is determined from a soil analysis. The analysis is compared with standard characteristics of soil and thereby divided into different standard types (see table 25.1).

The type of soil defines which type of drain that will be most effective for the field. If there is a high clay content in the soil, there is probably a need for surrounding the drain with filter grit. The reason is, as table .1 displays, that clay is very fine corned sand which makes the penetration of water through the clay terrible. The different soil types in Denmark are shown on illustration 25.1.
When the project is planned, the contractor can start excavating the drain.

Type of soil (JB-number)	texture designation	% clay (under 0,002 mm)	%Silt (0,002-0,02 mm)	% Fine-sand (0,02-0,2 mm)	% Sand (0,2-2 mm)	% Humus
1	coarse sandy soil	0 - 5	0 - 20	0 - 50	75 - 100	under 10
2	Fine sandy soil	0 - 5	0 - 20	40 - 95	75 - 100	under 10
3	Coarse clay-mixed sandy soil	5 - 10	0 - 25	0 - 40	65 - 95	under 10
3	Fine clay-mixed sandy soil	5 - 10	0 - 25	40 - 95	65 - 95	under 10
4	Coarse sandy-mixed clay soil	10 - 15	0 - 30	0 - 40	55 - 90	under 10
4	Fine sandy-mixed clay soil	10 - 15	0 - 30	40 - 90	55 - 90	under 10
5	clay soil	15 - 25	0 - 35		40 - 85	under 10
6	Heavy clay soil	25 - 45	0 - 45		10 - 75	under 10
6	Very Heavy clay soil	45 - 100	0 - 50		0 - 55	under 10
6	Silt soil	0 - 50	20 - 100		0 - 80	under 10
7	Humus					over 10
8	Special soil types					

Table 25.1 - Soil types and their characteristics.

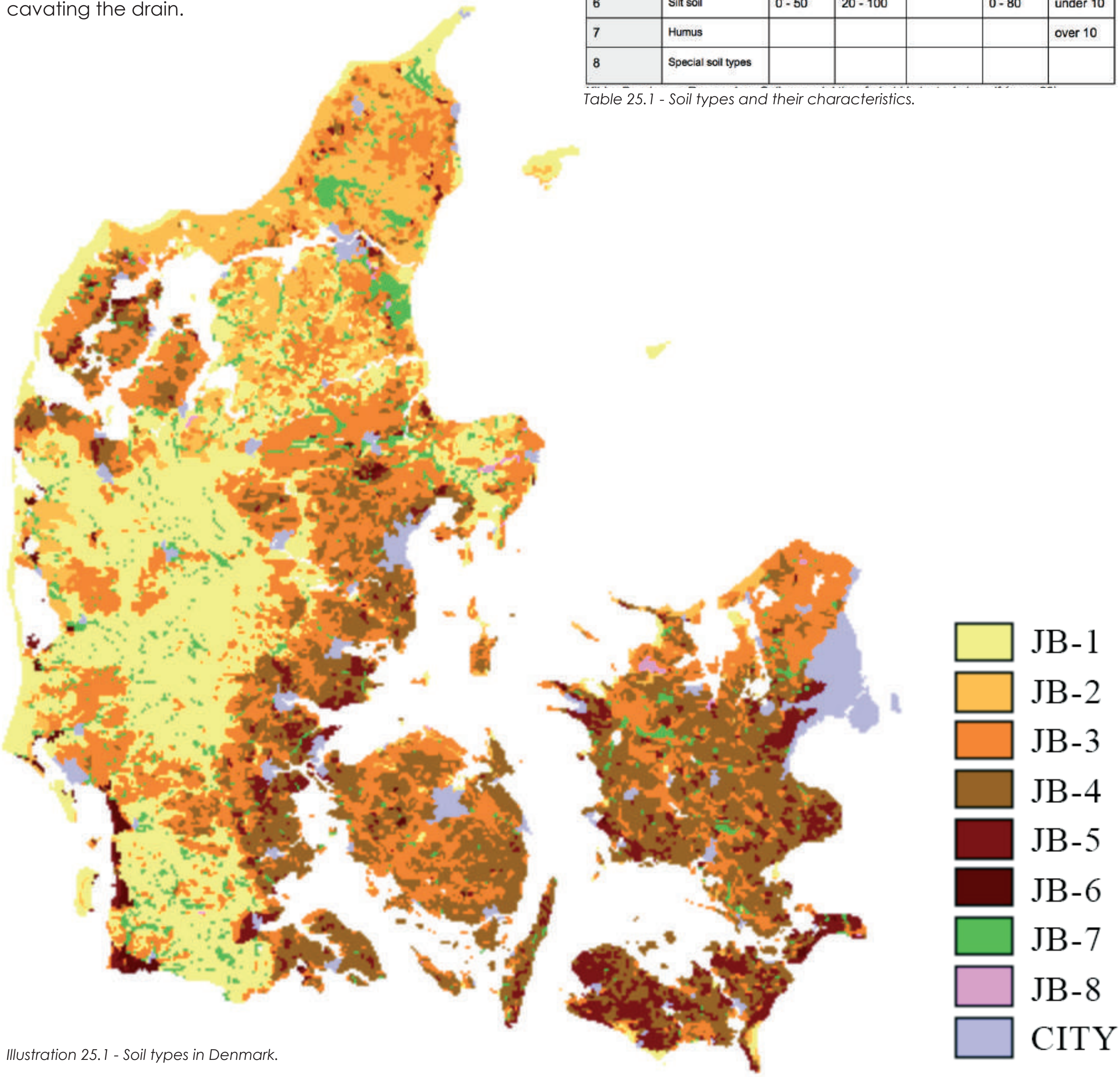
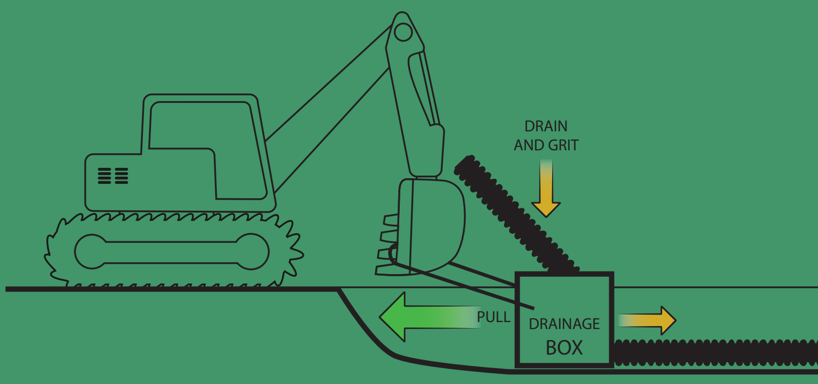


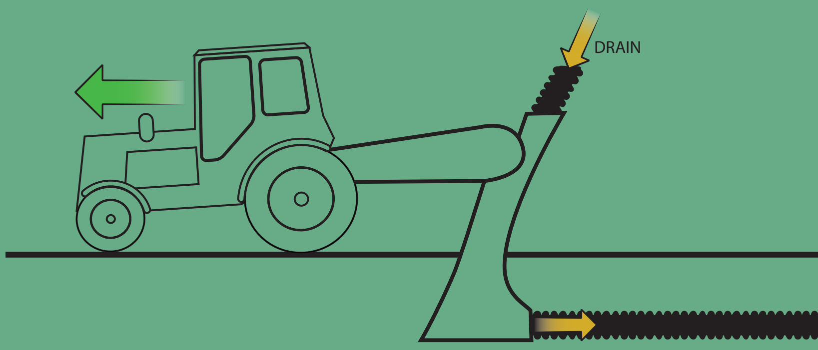
Illustration 25.1 - Soil types in Denmark.

DRAINAGE METHODS
To accomplish drainage, there are various ways of implementing the drains into the soil. The methods are described and illustrated underneath.

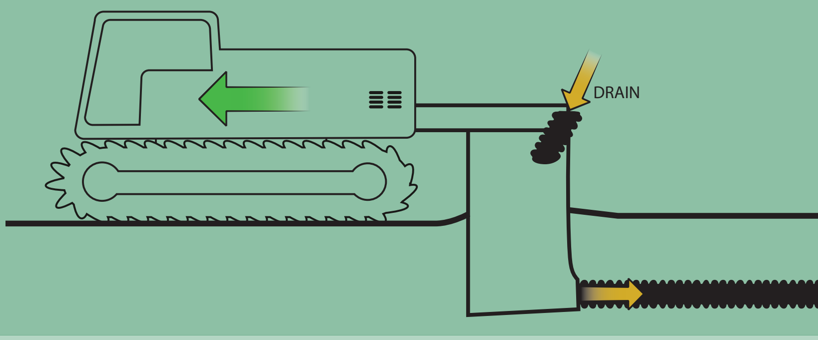
Drainage box and hand power
In both cases is the trench is excavated with an excavator. A time-consuming but straightforward method is to place the drain by hand. This method is often used when using rigid pipe drains.
On the other hand, is only flexible drains used together with drain box. The drain box places Fibertex, the drain and filter grit in the given order. Where the primary purpose of Fibertex is to avoid silt penetrating into the drain when the water-table raises. The excavator pulls the drain box as the trench is excavated, hence the materials are placed.



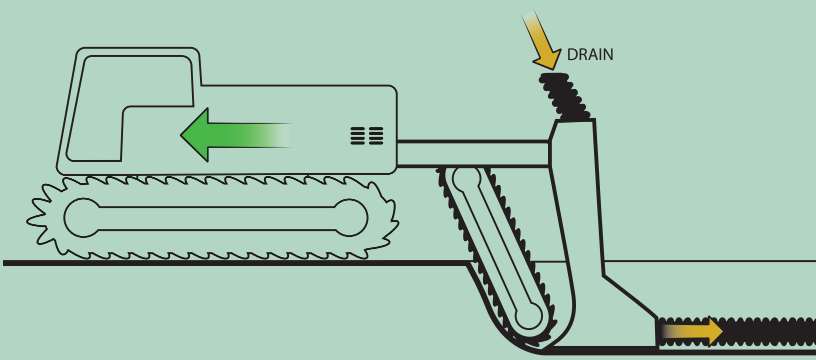
L-plow
The L-plow functions as a regular plow and are pulled through the soil by a tractor. The L-plow places the drain as it plows through the soil. This method only allows the use of flexible drains. Further, is the L-plow only used for drainage of new areas and not when doing re-drainage. The reason is that the existing drainage system cannot be connected to the new system.
If the customer wants filter grit is a box mounted to the plow which allows filter grit to placed on top of the drain.



V-plow
The V-plow is excavated into the ground and pulled through the soil by a tractor. The V-plow lifts the soil as it pulls and thereby placing the drain. This method does not allow filter grit. V-plow is not a conventional method used in Denmark.



Chain trencher
The chain trencher function as an overgrown chainsaw that saws a trench in the soil. The drain is placed into the soil by a box located in the back of the saw. The trench can then be filled with filter grit or the soil the saw has dug up. The chain trencher is not a conventional method used in Denmark.



Implementation cost:
25.000 per hectare


Illustration 27.1 - Excavated trench and laid by hand

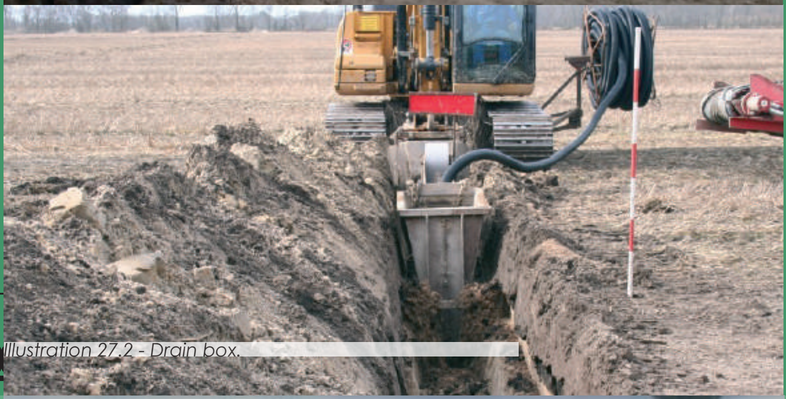


Illustration 27.2 - Drain box.

Implementation cost:
15.000 per hectare


Illustration 27.3 - L-plow.

Implementation cost:
15.000 per hectare

Illustration 27.4 - V-plow.

Implementation cost:
Unknown


Illustration 27.5 - Chain trencher.

2.9 DRAINAGE CASE

The following section shows a typical scenario of drainage. The data of the scenario is a case where the team follows a contractor in their drainage work. This section is based on; Situated interview and acting out (Sperschneider and bagger, 2003).

STEP 1 - PLANNING

Illustration 28.1 - Field marked for drainage.

The first step in the drainage process is to analyze the soil. The soil analysis determines the drainage depth and the distance between the drain pipes. Illustration 28.1 shows how the contractor marks the drainage trench on the field.

STEP 2 - DRAIN BOX PLACEMENT

Illustration 28.2 - Placement of drain box.

Step two is to excavate into the right depth and place the drain box as seen on illustration 28.2. Illustration 28.3 displays the typical material needed when doing drainage. Into the soil are; Fibertex, drain and filter grit placed in the mentioned order.

Fact:
Fibertex is a fiber blanket placed in the bottom of the drain. The function is to avoid silt and fine sand to penetrate into the drain when the water-table raises.

STEP 3 - LEVELING


Illustration 29.1 - Fine tuning the leveling.

To drain with the right slope is the drain box leveled. The leveling is done by placing a laser aiming in between the two lines on the leveling guide plate placed on the drain box. This is shown on illustration 29.1 and 29.2.


Illustration 29.2 - Leveling plate.

STEP 4 - DRAINAGE


Illustration 29.3 - Drainage with excavator.

The following step is the drainage. An excavator is excavating a trench. As the trench is excavating is the excavator pulling the drain box. This places the Fibertex, drain and filter grit. As shown on illustration 29.3.

STEP 5 - CONNECTIONS AND DRAIN EXCHANGE


Illustration 29.4 - Tapped connection.


Illustration 29.5 - Roll exchange.

Fittings connect the drain pipes. However, is tape used to ensure that the fittings is fastened good enough, this is shown on illustration 29.4. The tape is used as the fittings from the manufactures is disconnecting as the drain box is moving.

A roll of a drain is placed on the side of the excavator. Illustration 29.5 shows the exchange of roll. Due to the weight of the drain is the excavator lifting the drain unto the mount. The contractor locks the drain when it is placed right.

This research gave insight and understanding into the drainage process. It can be concluded that the engineering of the project often is done by a consultant associated with the contractor. The contractor is doing the drainage work. The contractor functions as a consultant to the farmer. He recommends different approaches and materials based on the soil analysis.

As the section describes how the drainage is done, was the team still in need of further knowledge of how farmers are dealing with the problems of the current drainage system. It was therefore decided to investigate their coping strategies to the problems further.

2.10 MAINTAINING DRAINS

Section 2.7 unfolds the different problems with existing approach to drainage. Where the following section is unfolding the coping strategies to two of the problems; Low velocity and roots inside the pipes. The purpose of this research is to gather knowledge and understanding of the coping strategies to the problem. The section is based on visit at Skjoldager Dræn & Entrepræenørforretning.

As described is two of the major problems with drain is sediments inside the drain see illustration 30.1 and 30.2. The way farmers detect a problem in his drain is when the field is flooded. If he detects a flooded or wet area is the farmer contacting, in many cases, a contractor who can flush and maintain the drain.
From the flushing machinery is a flushing head entering the drain. The only way of entering the drain is from a lake, well or stream as shown on illustration 30.3. The flushing head use water-jets to flush forward and backward. This is done simultaneously with a rotation of the flushing head as shown on illustration 30.4. The contractor is able to track the length of the hose inside the drain, and in that way locate the problem. The contractor can flush 300-500 meters with a pressure of 200 bar. Using a higher pressure than 200 bar will damage the drain pipes.

Illustration 30.5 - Sand blockage in drain.

If the blockage of sand is too massive or a collapse is represented is the contractor compelled to repair the drain. Illustration 30.5 displays a drain with a sand blockage which requires a re-drainage. In this case, is the contractor able to detect where the blockage occurred by tracking the flushing hose. An excavator is excavating to the drain where the reparation can happen, see illustration 30.6. Reparation is a replacement of the drain.

FINDING 15

The drain pipes is flushed with a pressure of 200 bar.

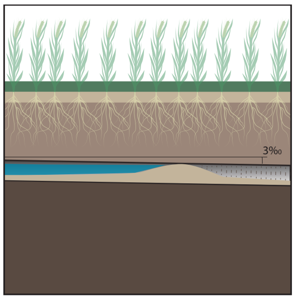


Illustration 30.1 - Low slope.

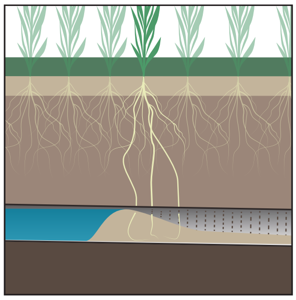


Illustration 30.2 - Roots.

Illustration 30.3 - Drain flusher.

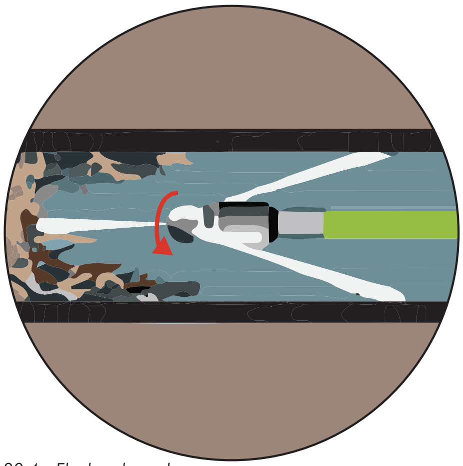


Illustration 30.4 - Flusher head.

Illustration 30.6 - Excavated trench for drain repartition.

FINDING 16

The flushing head got a diameter of 40 mm.

2.11 SOIL STRUCTURE

This section describes the structure of the soil and which impact it has on the plant condition. This research is done as the team was in need of more knowledge about how the water behaves in the soil. This section is based on: Desktop research.

Dexter define the soil structure as "the spatial heterogeneity of the different components or properties of soil" (Dexter, 1988). This means that the soil structure defines the arrangement of the solid grains within the soil and the pore spaces between them (Dexter, 1988). The terms for the different dimensions of pores and solid particles are shown on table 31.1.

PRIMARY PARTICLES	Clay	Silt	Sand	Gravel	Rocks →	
COMPOUND PARTICLES	Domains	Clusters	Micro-aggregates	Aggregates	Clods →	
PORES	Micro-pores	messo-pores	Macro-pores →			
BIOTA	Bacteria	Fungal hyphase	Root hairs	Roots	Worms	Moles, gophers, etc. →
Dimension (m)	10^{-7} · 10^{-6} · 10^{-5} · 10^{-4} · 10^{-3} · 10^{-2} · 10^{-1} · 10^{0}					

Table 31.1 - Corn size (Dexter, 1988).

The soil got different layers as shown on illustration 31.1. The first layer, topsoil, is the layer which consists mostly of pores compared to the other layers. The soil consists of minerals and are composed of hummus (a mix of clay, silt, and sand) (Dexter, 1988). The topsoil is rich in nutrients, therefore, the best area for roots to absorb nutrients. This is the layer farmer typically is cultivating and operating in. The subsoil consists of clay, silt, and sand, in which an accumulation of clay and silt has occurred. The subsoil is less rich in nutrients. Further is subsoil more compressed and consist of fewer pores than the topsoil layer. (Petersen, 1991).

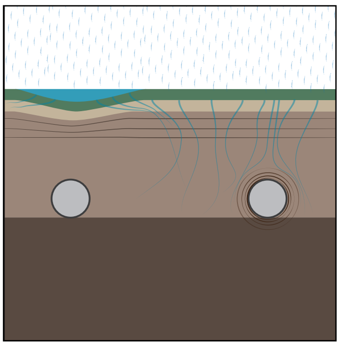


Illustration 31.2 - Compressed soil.

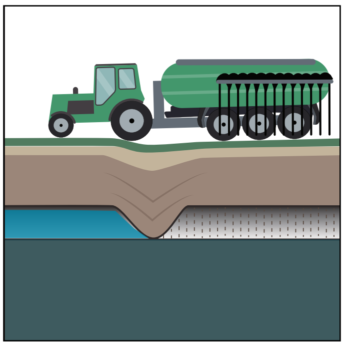


Illustration 31.3 - Collapsed drain.

Damage to the soil structure

The most optimal time for the arable farmer to operate on fields, with heavy machinery, is when the field is dry. When the soil and their pores are dry is the structure strong, and the forces from the machinery are spread evenly into the soil. If the soil is wet, and the pores full of water is the risk of individual grains to coinciding and thereby compress the soil as shown on illustration 31.3. When the soil is com-

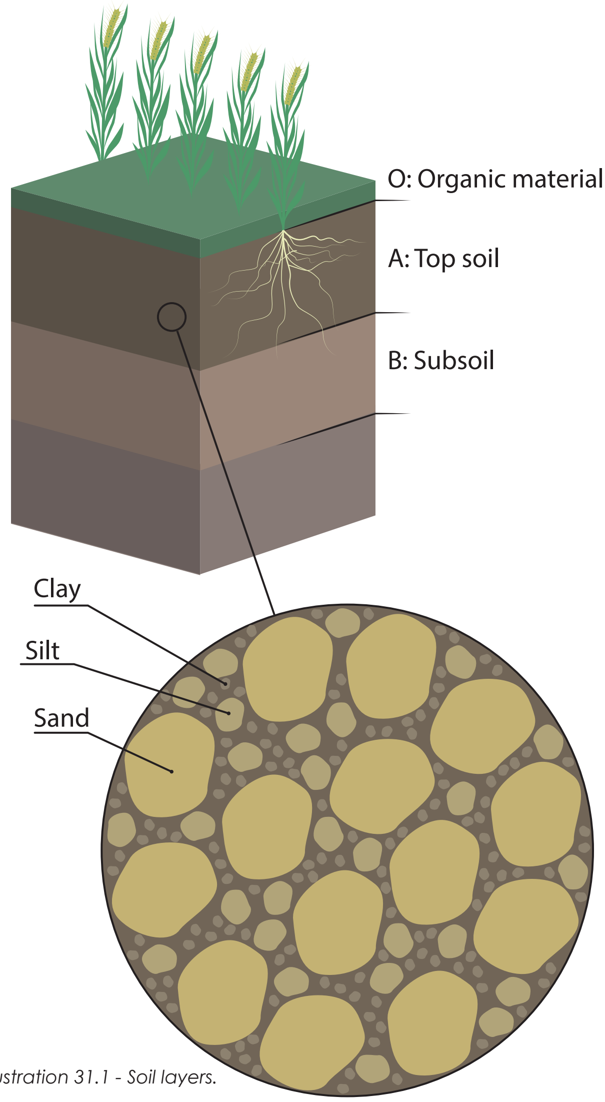


Illustration 31.1 - Soil layers.

pressed is the pores getting smaller or entirely disappear. This allows the top layer to create and act as a film which the water not are able to penetrate through. Illustration 31.2 shows compressed soil and the associated consequences. The same principle happens around the drain when drainage by L-plow or a V-plow as they compress the soil to create space for the drain.

To prevent compressed soil, arable farmers plow and harrow fields. This uncompresses the soil and recreates the soil structure and pores. The farmer plows in a depth of 15-20 cm.

The nature by itself sustains the structure with help from insects and worms as they create corridors in the soil. In the winter when the soil gets frozen it also has the effect of lifting the soil and creates pores.

FINDING 17

Operating in wet soil compresses the soil. Further, is the effect of forces from the machinery higher to the drain compared with dry soil.

FINDING 18

Arable farmers is plowing in a depth of 15-20 cm.

2.12 CONSEQUENCES OF DRAINING

This section will investigate the consequences of drainage. As drainage is changing the ecosystem of nature, have the team decided to investigate the consequences further. This section is based on: Interview with nature consultant Asger Kristensen and Christian Christensen.

Pollution of nutrients

Rainwater penetrates through the soil together with the nutrients. When the water penetrates through the soil it passes the root system where the roots is absorbing some of the water and nutrients. The nutrients and water which not are absorbed penetrates to the groundwater and thereby lead into stream or lakes.

The farmer emits nutrients on the fields with the intention of giving the crop all nutrients needed. If the water-table is high, more nitrogen emitted into the streams as the water not are filtered by the soil and root system, as shown on illustration 32.1 zone 1. With a low water-table the soil is able to filter the nitrogen, and less is emitted into the stream and lakes, this is displayed on illustration 32.1 zone 2.

Nutrients in the streams are not bad for the ecosystem as the algae absorbs them. But with an excessive amount of nutrients is the algae growing strongly and faster than the animal plankton can manage to eat them (DANVA, 2016). The result is a high amount of algae that die naturally and sinks to the bottom of the stream or lake. The bacterias are starting to eat dead algae and thereby expanding the growth of bacterias see illustration 32.1 zone 3.

The large amount of bacteria, in the bottom of the stream, absorbs all oxygen in the water as shown on illustration 32.1 zone 3. The result is organisms and fish are dying due to oxygen deficiency.

A consequence of drainage is the emission of ocher. The streams can handle an even emission of ocher. However, when the ocher emission is excessive and comes in impulses is it a problem. Hence, ocher results in toxic iron. (Kristensen, 2018).

Drainage reduces emission

Discussing the nitrogen emission topic with Christian Christensen from LanboNord gave the team another perspective to nitrogen emission according to drainage. With efficient drainage, the emission would be less. As the drainage of the soil lowers the groundwater, it allows roots to grow large. With a large root system, a higher amount of nutrients will be absorbed in the plant. This results in reduced emission of nitrogen and a crop with a higher yield.

FINDING 19

A better and deeper root system results in a higher degree of absorption of nitrogen.

FINDING 20

Ocher in impulses is destroying the life in streams as it is toxit in large amounts.

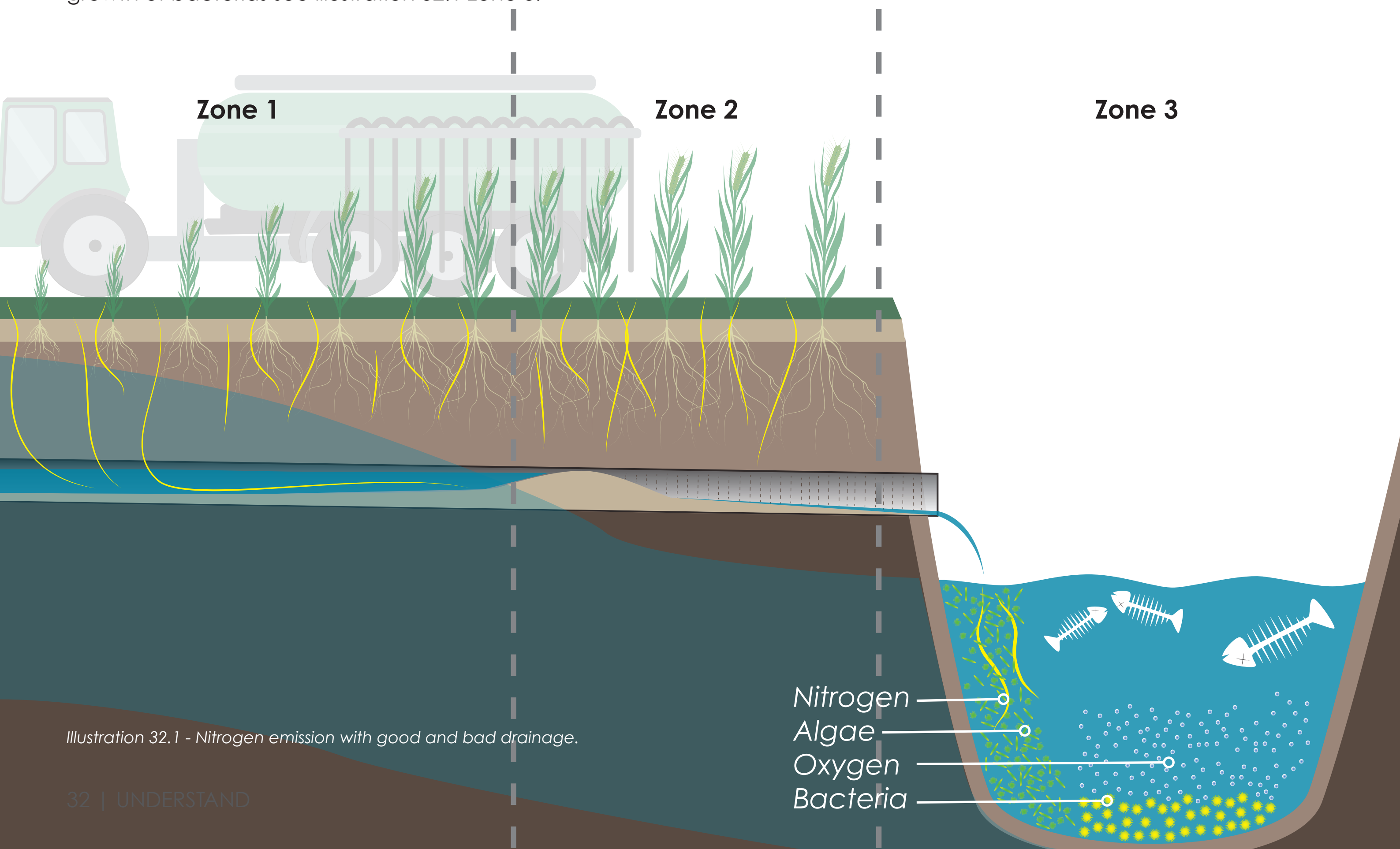
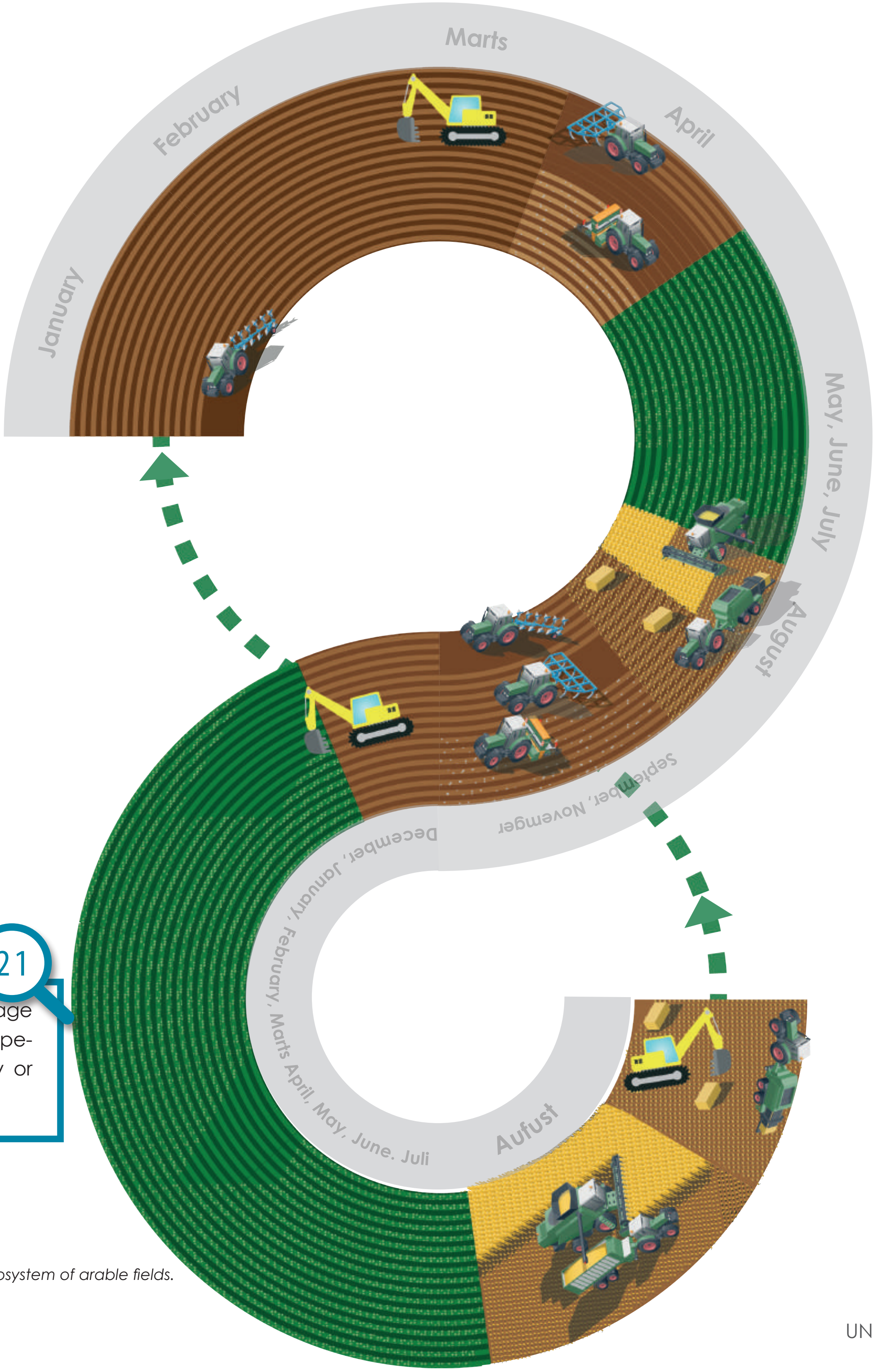


Illustration 32.1 - Nitrogen emission with good and bad drainage.

2.13 ECOSYSTEM OF FIELDS

The following section displays the ecosystem of the arable field. The research is done to gain insight to the different processes doing a season. This section is based on: Desk research and real field strategies from farmer, appendix 04.

A specific ecosystem of an arable field cannot be done, as all the systems of the fields are unique. However, illustration 33.1 shows the typical processes of the field.
This case is based on a field with barley. The plowing takes typically place in January and February where the fields are semi-frozen and allow operating with the machinery. It is also in this period where the drainage happens. In April is the field harrowed and seeded. May, June, and July are the plants growing and the only operation required is nursing by spraying for insects and fungus. The harvest of crop takes place in August. This dry period allows drainage again. To ensure a high yield is farmers changing the crop every season. Meaning period of executing the different processes on the field changed according to the crop. However, the order is basically the same.



FINDING 21

The soil allows drainage in winter and summer periods. If, the soil is dry or frozen.

Illustration 33.1 - Ecosystem of arable fields.

2.14 PERSONAS

The following section describes costumers and their intention with drainage reflected as persona'. These are made to communicate and align within the team what the different needs is to the costumers. The persona is divided into modern farmer, exploratory farmer, contractor and in appendix 03 is a tenant and renter described. This section is based on: Empirical knowledge from visits and interview and Cooper persona

The persona gave the team a tool to align when designing the product. Further, is the persona used for explaining the different point of views when having interviews with consultants, manufactures and possible investors.
The persona is associated with a matrix describing their relative standing to investment according to drainage performance.

MODERN FARMER

The modern farmer has multiple employees and many hectares field. His fields are a mix between rented and owned. He acts as a manager for his employees, unlike the exploratory farmer. He is in charge of logistics, structuring and planning.

When he sees a need for new drainage he calls the contractor and informs him. The contractor inspects the drain condition and decides if the drain can be fixed by flushing or if it needs to be completely re-drained.
The modern farmer believes in the contractor and sees him as the expert as he got knowledge about drainage.

A low drainage cost is an important factor to the modern farmer. However, the price does not exceed what the contractor recommends in the sense that the farmer wants the drain to last and function in the long term. Therefore is the modern farmer placed in the middle on illustration 34.1. He is willing to compromise the investment in order to follow the recommendations from the contractor.

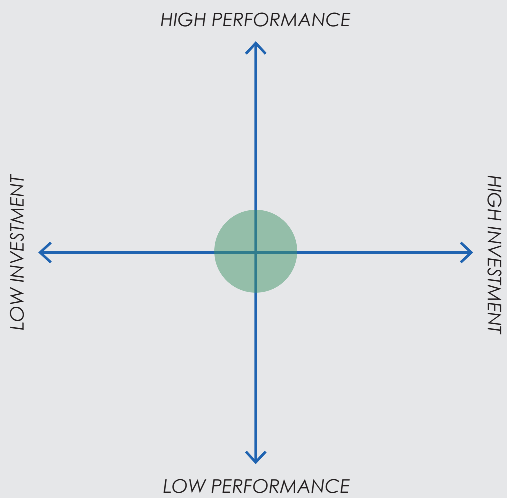


Illustration 34.1 - Modern farmer, performance investment sheet

EXPLORATORY FARMER

The exploratory farmer have multiple employees and many hectares field. Opposite the modern farmer he is on the fields with his employees. He uses time on testing his own theories to become wiser and to get the most out of his crops.

When he spots a need for new drainage it is either because an area is flooded or because he can see the need reflected in the crop.
He got the machinery needed for drainage. The approach to drainage is build on his own experience and theories. He have gained the drainage knowledge by trying different methods based on what makes meaning to him. The Exploratory farmer can see the proof of his approaches by looking at the yield of his crops.
He is willing to use resources to try new drainage methods to make the amount of yield even greater. The accounting for the yield shows that it is worthwhile to drain efficiently in the long run. Therefore, the exploratory farmer is placed in the "high performance - high investment" corner on illustration 34.2.

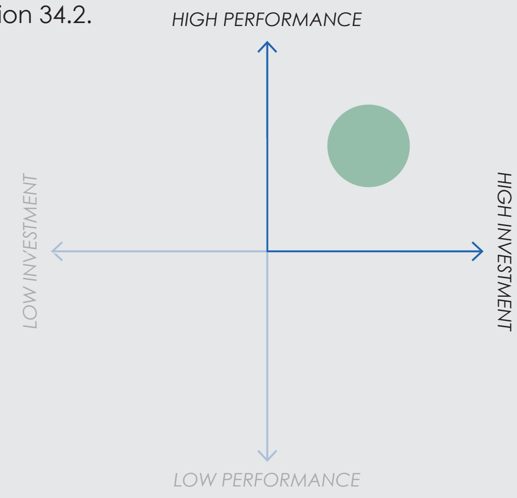
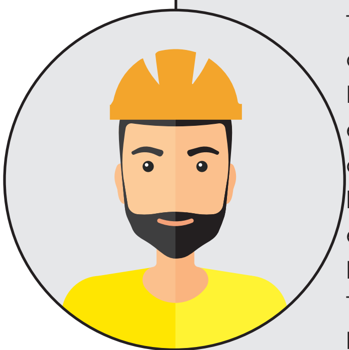


Illustration 34.2 - Exploratory farmer, performance investment sheet

Illustration 35.1 - 1/3 of the fields in Denmark is leased by other farmers.

One third of the arable fields in Denmark is owned by landlords and leased by farmers. These two kind of persona's is described in Appendix 03. As 1/3 of Denmark is leased gave the business aspect of the project a new perspective. As, the tenant is in charge of maintain and repair the drains. Drainage is a long term investment where a typical rental agreement last for five years.



CONTRACTOR

The contractor is doing around 75 % of all drainage work in Denmark.
His drainage knowledge is based on experience. The contractor got a professional pride and wants to make the best solutions as possible to the farmer. He is recommending different materials to the farmer which he thinks is the best in the given case.
The contractor is placed in upper left corner on Illustration 35.2. This is because he want to deliver a low-cost solution with high drainage performance for his customers.

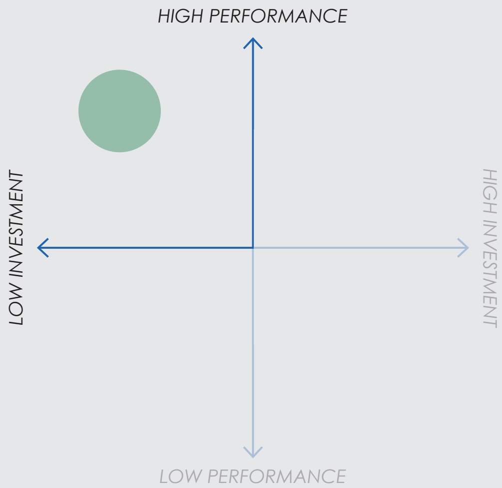


Illustration 35.2 - Contractor, performance investment sheet

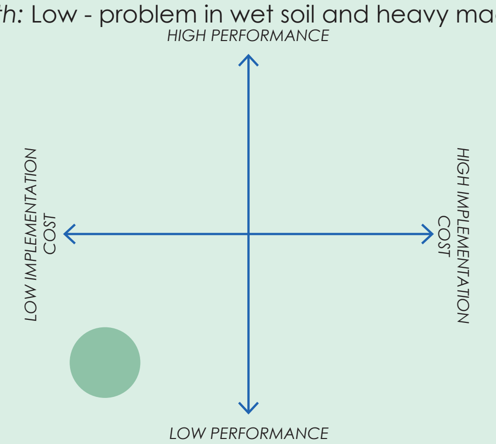
2.15 COMPETITORS

The following section describes the major competitors in the drainage sector, see full analysis in Appendix 05. The relative positive and negative properties of the drains are described. The parameters used for evaluation is: Implementation method, maintenance, water-flow and strength. This section is based on: Tests and empirical knowledge.

Illustration 36.1 - Corrugated drain.

Corrugated drain

The traditional corrugated drain is the most sold drain in Denmark.
Implementation: Drainage box, L-Plow, V-Plow and by hand.
Water-flow: Low - due to the grooves are slowing the flow.
Maintenance: Flushing yearly - the low flow results in sand accumulation.
Strength: Low - problem in wet soil and heavy machinery



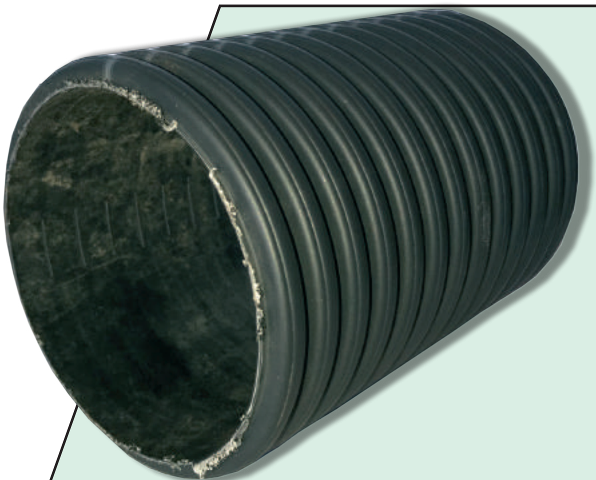
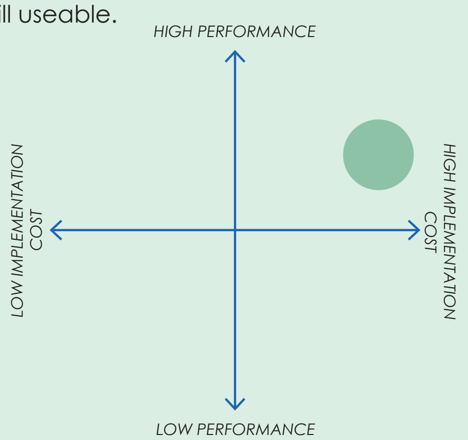


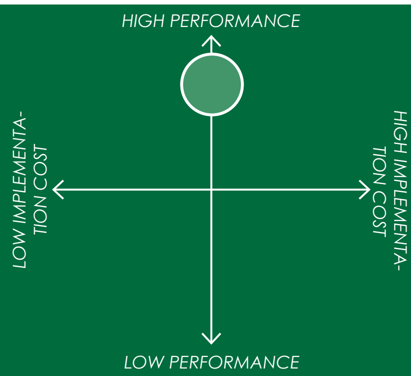
Illustration 36.2 - Top-slitted drain.

Top-slotted drain

The top-slotted drain is rated as the drain with highest performance by the team.
Implementation: By hand.
Water-flow: High - due to the smooth inner surface.
Maintenance: Flushing every 2.5 year .
Strength: Medium - deformation in wet soil and heavy machine but still useable.



This section made the team aware of the two major competitors and their advantage and disadvantages. This made the team enable to position the up coming product in the market according competition on performance. Based on this, the team decided to analysis the corrugated drain to get more data on the drainage performance.



2.16 ANALYSIS OF EXISTING DRAIN

The following section will describe an analysis of the corrugated drain, as it is the most used drain. The drain is analyzed through tests of strength by Finite element analysis (FEA), pressure test and hands-on experience. The drain performance was tested in a simulated context. This section is based on: Finite Element Analysis, deformation analysis and performance test.

Deformation analysis

A twenty-centimeter long corrugated drain was explored. It consists of a wall thickness of one millimeter, shaped with grooves to give the drain strength as shown through a cut in the drain on illustration 37.1.

The mechanical deformation was explored by applying even pressure on top of the pipe to see the deformation as shown on illustration 37.2. The applied pressure simulate the pressure int the soil in the most critical situation. It was observed that the sides of the drain was exposed to the highest stresses. Further, was the penetration holes in the sides deformed and as seen on illustration *37.3*, the holes are expanded to five millimeters. If the same deformations are represented in the soil, do sand below 5 millimeters have access to the drain. This can be very critical as a blockade will grow large and block the drain.

Illustration 37.3 - Deformation of holes inside corrugated drain

FEA

Finite Element Method is used to estimate the allowed pressure applied to the corrugated drain. To make calculations of the drain should the pipe be addressed as a beam. However, addressing the pipe as a beam would not give a realistic picture of the stress, strain, and deformations. Therefore, the team arranged a pressure test at Concrete Lab - Aalborg University to compare the FEA, the pressure test is described on page 68.

Within the FEA the CAD-model was applied with the material similar to the corrugated drain, PE - 80. On top of the CAD-model, a block was placed with an even pressure of 0.8 kN. Illustration 37.4 displays the Von Mises stress. The material, PE - 80, has its yield stress at 22 MPa.

22 MPa is equal to 22000 N/m2 as the Von Mises stress is specified in the FEA. The scale showed on the illustration 0.4, shows the yield stress will occur at the light blue color. It can be concluded that applying the corrugated drain with 80 kg, it will deform and because the stress exceeds 22 MPa, it will continue the deformation until it breaks.

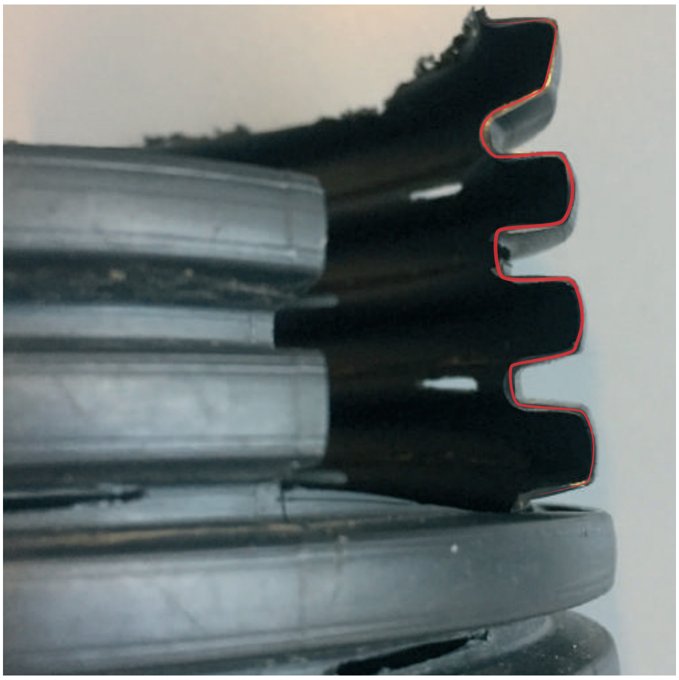


Illustration 37.1 - Cut that show grooves in corrugated drain

Illustration 37.2 - Deformation of corrugated drain

The FEA shows that the stress are highest on the sides as the previous investigation also showed. The FEA match the pressure test described on page 68.

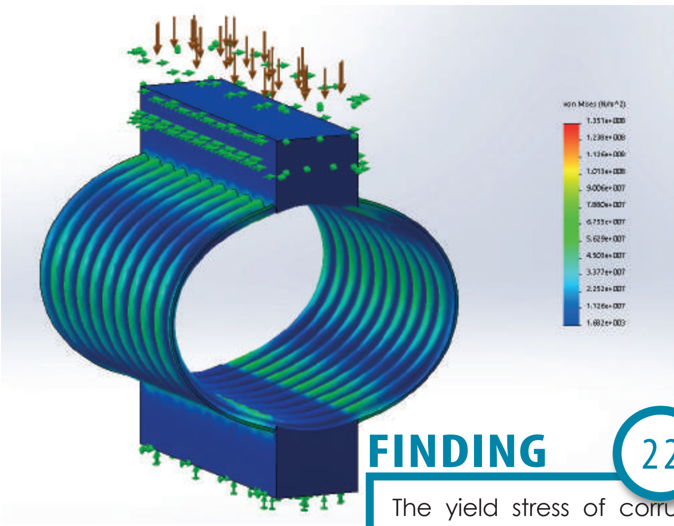


Illustration 37.4 - Von Mises stress plot.

FINDING 22

The yield stress of corrugated drain is 22 MPa which is equal to a pressure of 0.8 kN.

Performance test 1

The corrugated drain' ability to drain was simulated through a test box as shown on illustration 38.1. The drain was surrounded with soil and a rainstorm was simulated to see how the corrugated drain behave. A rainstorm is defined as 15 mm rain within 30 minutes. The water needed related to the box dimensions are calculated:

Box dimensions 50 x 75 x 1,5(rain) = 5625 cm^3
cm^3 into Liters = 5625/1000 = 5,625 L
Liter pr. 5 min. = 5,625/6 = 0,937 L/5min
For the test: 6 Liter within 30 min.

Through the 30 minutes test, every 5 minutes one liter of water was spread all over the test box. The amount of water penetrated through the drain will be measured every 5 minutes. The result of the test:

Water applied	Time (min.)	Water drained
1 liter	0	0 ml
1 liter	5	0 ml
1 liter	10	0 ml
1 liter	15	3 ml
1 liter	20	4 ml
1 liter	25	5ml
0 liter	30	7 ml

The test showed that the soil got stuck in the penetration holes immediately and blocked for the water as shown on illustration *38.2*. Only a minimal amount of water could penetrate through which meant that the drain could not work optimally. It also turned out that along with the small amount of water, fine sand came in. The sand dropped to the grooves immediately, as there was no flow at all in the drain.

The team chose to empty the test box and place filter grit around the drain to see the effect of it.

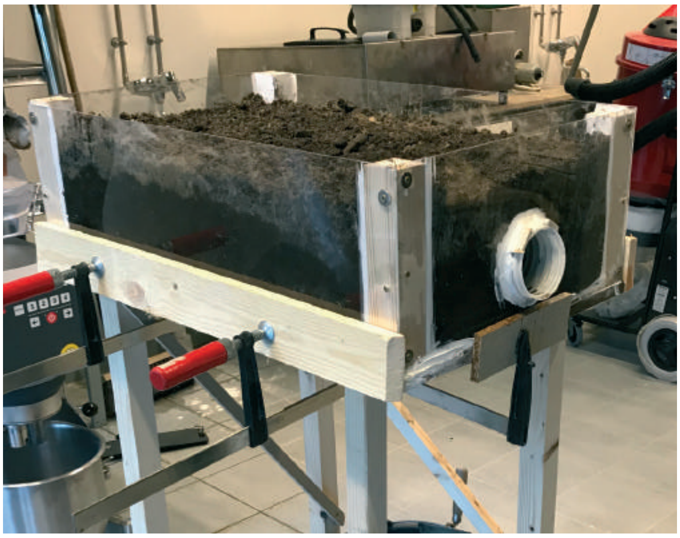


Illustration 38.1 - Box for testing performance

Illustration 38.2 - Blocked penetration holes test 1

Performance test 2

The filter grit was placed around the corrugated drain as seen on illustration *39.1*. The exact same test was made on the new setup and gave the following results:

Water applied	Time (min.)	Water drained
1 liter	0	0 ml
1 liter	5	150 ml
1 liter	10	300 ml
1 liter	15	1000 ml
1 liter	20	1750 ml
1 liter	25	2600 ml
0 liter	30	3500 ml

The test clearly showed the importance of filter gravel. By adding the filter grit, the water could now penetrate through the soil. Due to the filter grit with the grain size, 1 - 4 mm, there was no blockage at the penetration holes. Increased water penetrated into the drain created a water flow inside the drain. With the larger amount of water, it was even more clear how the sand settled in the grooves. The flow was far from high enough to lead the sand out, as shown on illustration 39.2.

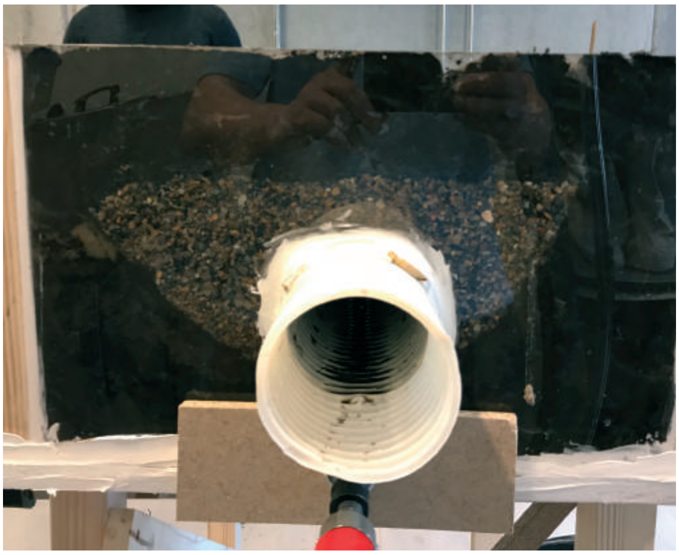
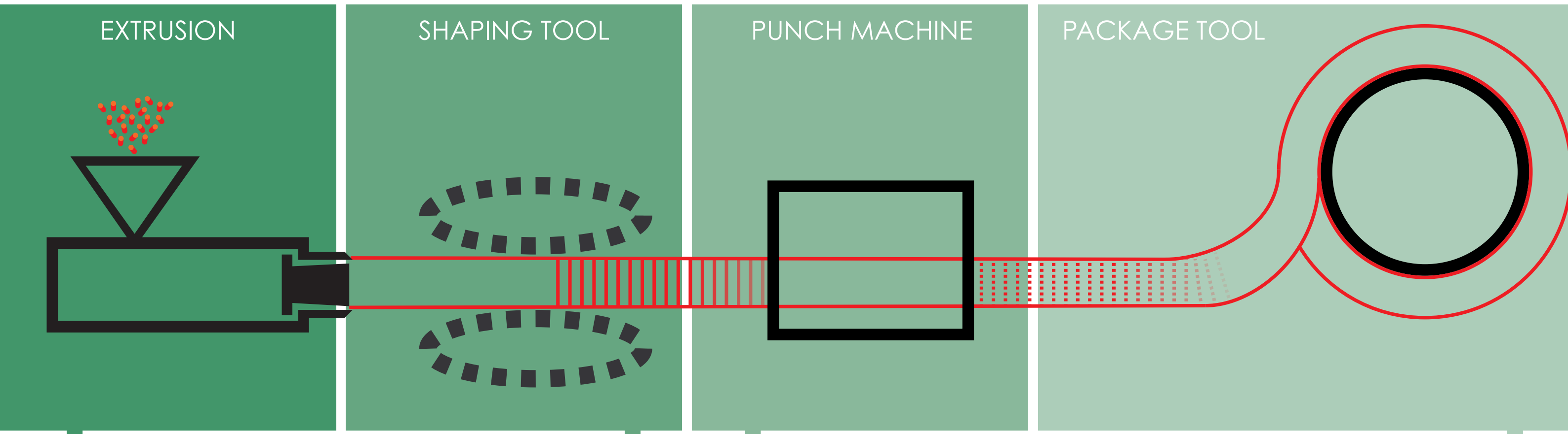


Illustration 39.1 - Corrugated drain with filter grit

Illustration 39.2 - Penetration holes test 2

2.17 VISIT AT WAVIN

The previous section unfolds an analysis of the corrugated drain pipe. This gained an insight in the reasonings behind the corrugated drain but the need of knowledge about the production of the pipe was not satisfied. Therefore, was a visit at Wavin conducted. Wavin in the biggest manufacturer of pipes in Europe. This section is based on: Visit at Wavin, Shadowing and Situated interview (Sperschneider and bagger, 2003).



Extruder heats the plastic and extrudes it in a circular shape into the shaping tool.

Illustration 40.1 - Extruder for drainpipes.

From the shaping tool is the drain lead into a punch machine. This creates the penetration holes all around the pipe.

Illustration 40.5 - Tool for penetration holes.

Illustration 40.4 - Punch station.

The extruder leads the pipe into a shaping tool. The tool creates the grooves by air pressure.

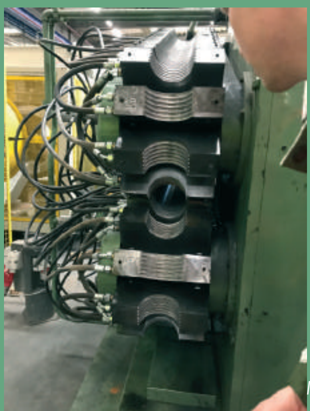


Illustration 40.2 - Tool for grooves.

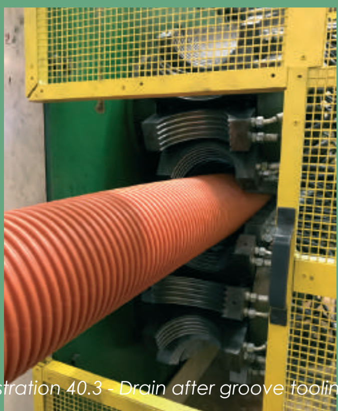


Illustration 40.3 - Drain after groove tooling

The last production step for the drain is to be rolled up and strapped. The machine counts the amount of meter and is automatically cutting the drain at 50 meters.

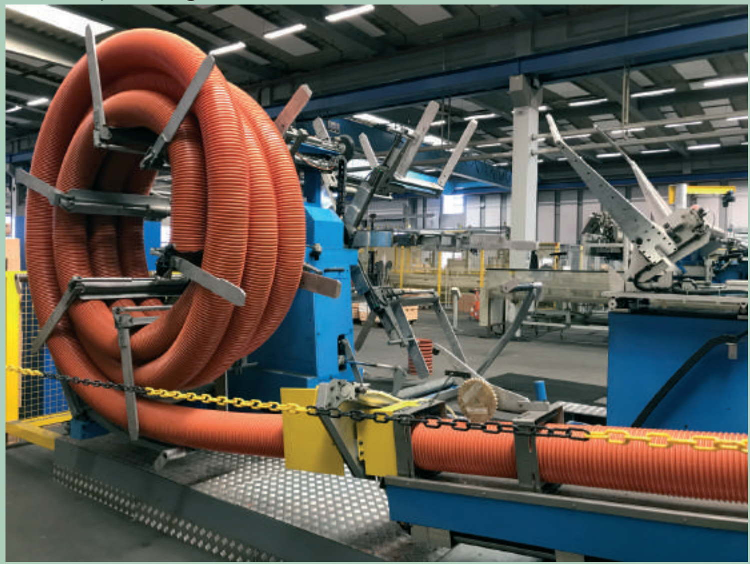


Illustration 40.6 - The drain is being prepared for logistics.

2.18 BUSINESS POTENTIALS

This section is describing the business potentials within draining. Further, it describes what a solution is worth to a farmer.

Determining the value of drainage is a hard thing to do, as without drainage the work on the farm would be harder. Without drainage many small seas and streams would dominate the fields. The streams would spilt up fields in smaller pieces which will effect the mass production of crops. Furthermore is a proper drainage important to the crops as described at section 2.3. Former studies has estimated the possible more income with proper drainage to 19-31% (Poulsen, Jensen & Filsø, 2017). This case is also represented at a visit at farmer Gunnar Laden which got a significant increase of the yield due to proper drainage. Though the research the team noticed two possible market directions which is described as market potential 1 and 2.

Market potential 1 - Existing drains:
Around 53% of Denmark is already systematic drained (Olesen, 2009). This is around 1.5 million hectares of arable fields. These drains got a need of maintenance and reparation.

Market potential 2 - New drainage:
It is estimated that yearly 27.000 hectares in Denmark has to be drained/re-drained (Nielsen, 2015). This is a mix of fields which got a new need of drains but mostly fields which got a need of re-drainage.

2.4 WHAT IS A SOLUTION WORTH?

The following section will describe different cases of what a solution is worth. As the agricultural sector is hardly depended on all incomes to survive on the market. Thus it is important, to the team, to create some limits and knowledge of the money perspective of arable farming. Effective drains can increase the yield and thereby the income by 19-31% which is a remarkable profit to the farmer.

The following example is based on the average yearly harvest of barley per hectare in Denmark:

Average harvest of barley:	58 hkg/ha
Trading price (2016):	101 DKK/hkg
Turnover:	5.888 DKK/ha
Contribution margin:	5633 DKK/ha

Possible yearly more income	
Worst case 19%	1120 DKK/ha
Best case 31%	1826 DKK/ha

The contribution margin covers (Højholdt, 2015):
• Seeding
• Fertilizer
• Plant health projection

Beside these fixed costs do the farmer have different variables cost to pay. Some of these is drainage and man- & machine working hours.

The result of this section is knowledge of the business aspect of arable farming where the upcoming solution is worth:
Worst case - 1120 DKK/ha yearly
Best case - 1826 DKK/ha yearly

3.0 **PROJECT BRIEF**

BASED ON THE RESHEACH IS AN PROJECT BRIEF MADE WHERE THE MISSION, VISION AND NEEDS ARE SHOWN. FURTHER IS THE PROJECT BRIEF SHOWING THE TARGETS THE TEAM ARE AIMING. THE PROJECT BRIEF IS USED AS NAVIGATION TOOL THOUGH THE PROCESS AS THE BRIEF CREATES A FRAME OF THE PROJECT.

3.1 VALUE VISION AND MISSION

The following section displays the mission and value vision of the product. This section is based on: Empirical knowledge gathered from visits, The Product Reasoning Model (Haase and Laursen, 2017).

The team have decided to use The Product Reasoning model to create project frames in the different aspects of the product development. This gave the team a vision and communication tool which aligned the team though the process of the emotional demands.

Main paradox	***A matter of course***		
	Insight Due to increased amount of rainwater the drain systems has to be in perfect conditions to handle the amount of water. However, the existing drains are old, poor and collects too much dirt which results in drain blockage.	**Aspired value** The aspired value is to develop a drain where dirt can not be stock and require less maintenance.	**Working principle** A new drain which increases the water-flow to make the drain self-purifying.
Market	***The new smart drain***		
	Insight Experts estimates 400.000 hectares is in need of being re-drained. Many farmers are ready to try something new as the existing drains are poor and require a lot of maintenance.	**Aspired value** The aspired value is to develop a drain that can compete on other aspects than price.	**Working principle** Design the drain as it has multiple functions. Designing the strength ribs as they can use surface tension to filtering the sand and water.
Interaction	***Looking in the crystal ball***		
	Insight The only way the farmer knows a drain blockage has occurred is when the field is flooded. First when the water is gone the farmer is allowed to repair the drain. And maybe it will work this time.	**Aspired value** The aspired value is to create a system which makes the condition of the drains more predictable. This will avoid lost money on flooded fields and bad crops.	**Working principle** Give the farmer knowledge about the water-flow. This can determine when the drain needs to be maintained and thereby the farmer can act before it is too late.
Expression	***The big tractor effect / From a passive tool to active tool***		
	Insight Many farmers enjoys driving in big tractors even though their need of such a big tractor are limited. They like the feeling of great power. They got this feeling from the day they bought the tractor. An investment in drainage is a expensive long term investment without any feelings associated.	**Aspired value** The aspired value is to develop a drainage which is more than a drain. A drain which helps the farmer in his daily tasks. Where the drain now a days is a passive tool becomes an active tool in the daily work.	**Working principle** Give the farmer information of the soil humidity so he can avoid driving in soft spots on the field. This allows the farmer to schedule the fieldwork in relative to the soil condition.

3.2 PROBLEM STATEMENT

How can we design a system/product for the agricultural segment which

- eliminates the drain to get a sand/root blockage coursed by low water flow?
- eliminates collapse of drain coursed by to heavy machinery?
- ensures the optimal soil structure?

3.3 TARGET PRICE

Based on the increase of yield due to proper drainage, a target price have been made. The target price covers the cost of implementation of drainage. This is because that the worth of the product is only represented when the product is implemented.

The target implementation price is **1120 DKK/ha yearly.** This is equal to the worst case if income with properly drainage.

3.4 NEED SPECIFICATION

The following section summarises the different needs which is derived through the process of understanding the problem. The section is based on: Empirical knowledge from the visits and Need Specification(Ulrich & Eppinger, 2012).

A table of needs is specified though a need specification (Ulrich & Eppinger, 2012). The needs is derived from the different findings which is represented though the process report. The need specification is written in the language of the users. This is done as the team brought the list to the different stakeholders to evaluate the importance of the needs. The importance is rated from 1 - 5 where the value had the following meaning:
1 - Unimportant
2 - Unimportant but nice to have
3 - Nice to have
4 - Need to have
5 - Must have

The importance was rated from one to five to make an appropriate variation. The need specification have been specified in a continuous process as the team have gathered knowledge. The voting of the needs have been done by users and the team members, see Appendix 06. The user and stakeholder involvement have been done to make the specification more objective and to get their opinion expressed in a quantitative way.
The need specification is made to specify the importance of the needs according to the user and stakeholders. Together with the vision, the need specification helped the team to align and navigate doing the research- and ideation phase. The need specification is going to be used for evaluating the idea and concepts through the process but also as foundation to the target specification.

NEEDS					
No.	To who		Criteria	Importance	Finding
1	The farmer	The concept	can inform when a blockage in his drains occurs	3.6	04
2	The farmer		allows controlling the level of water-table	3	03
3	The farmer		can be maintained by flushing machinery	4.6	15,16
4	The farmer		can easily be replaced when damaged	4.6	13
5	The farmer		allows knowledge of the drain condition	3.6	04
6	The farmer		allows knowledge of the soil condition	3.6	14,17
7	The contractor		fits the current architecture of drainage machinery	2.3	09
8	The contractor/farmer		can handle a higher amount of water	2.3	03
9	The ecosystem		reduces the amount of nitrogen emission	2	19
10	The farmer		is self purifying	4.3	12
11	The ecosystem		makes sure ocher not are emitted in impulses	3	20
12	The farmer		can resist the pressure from soil and machinery	5	22
13	The farmer		must be a economical solution	5	13

Table 45.1 - Derived and interpreted needs

3.5 TARGET SPECIFICATION

The following section displays the target specification which is made as an guideline for the concept development. This section is based on: Need specification, Benchmarking and The needs-metrics matrix (Ulrich & Eppinger, 2012).

As the need specification is written in the language of the users, the target specification works as a tool for guidance with quantitative parameters for the concept development. The target specification is expressed though metrics and an related value. The need specification was the foundation to the target specification. To ensure all the needs are represented in the target specification, the team created a needs-metrics matrix (Ulrich & Eppinger, 2012), see appendix 06. All the needs and metrics are listed in the matrix which shows the relation between need and metric. This made the team aware of representation of the need in the target specification.
In order to specify the marginal- and ideal value, the team created a competitive benchmarking chart (Ulrich & Eppinger, 2012), shown in appendix 06. The chart is based on the two competitors; top-slotted drain and corrugated drain. The specification is therefore an guarantee of innovation of performance according to the competitors.
The following target specification is the final before the product detailing.

DEMANDS - TARGET SPECIFICATION					
No.	Need No.	Metric	Units	Marginal Value	Ideal Value
NXD DRAIN					
1	8,9	Size of penetration holes	mm^2	90	>90
2	13	Implementation cost	DKK/ha	22.095	<22.095
3	13	Lifetime of drain	years	15	60
4	10,11	Speed of 1 litre water on 1 meter (Water flow)	m/s	1.09	>1.09
5	3,8	Inner drain size	mm^2	8660	>8660
6	3	At least one point Drain diameter	mm	40	>40
7	3	Resist flushing at 200 bar	Binary	Yes	Yes
8	12	Resist applied pressure (10cm)	N	800	>800
9	7	Diameter of a roll	mm	600	<800
10	7	Weight of roll	kg	30	<30
11	10	Surface roughness inside drain	mm	1.0015	<1.0015
12	4	Distance of ribs	mm	1	5
13		Plastics can be separated	Binary	Yes	Yes
NXD SIGHT					
14	6	Measured soil humidity	Binary	Yes	Yes
15	1	Deliver data to web platform	Mb		
16	5	Measures water level in drain	Binary	Yes	Yes
17	5	Measures water flow in drain	Binary	Yes	Yes

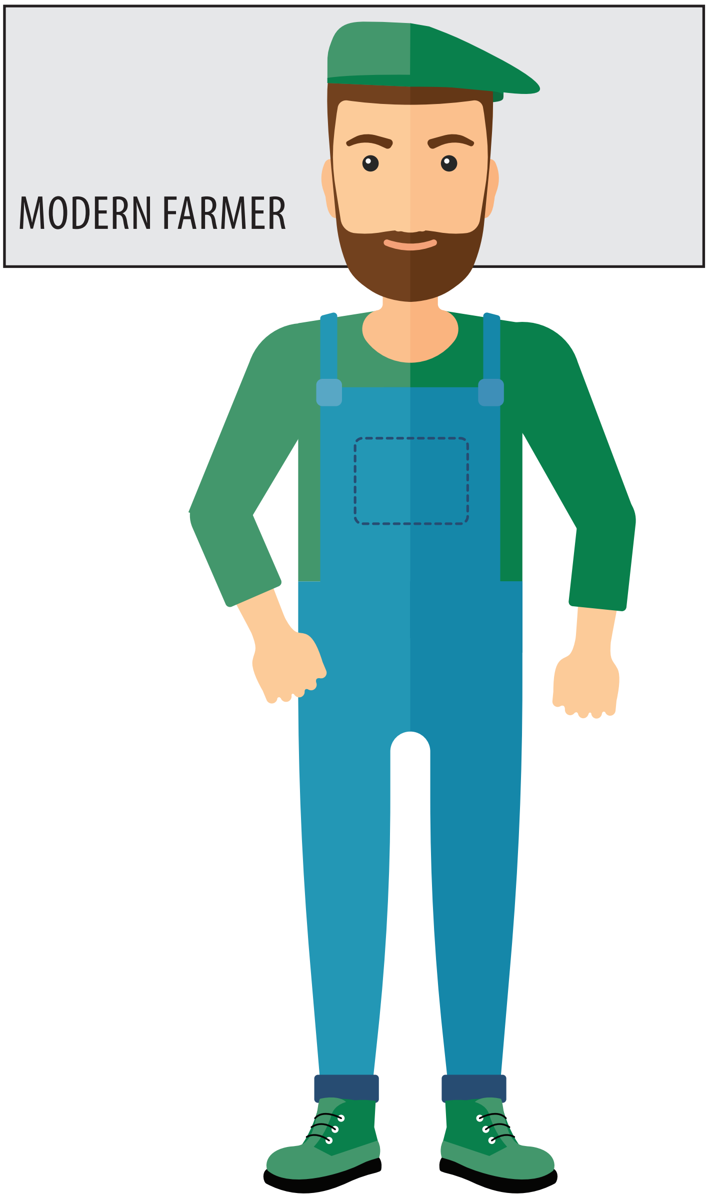
Table 46.1 - Target specification

Reflection:
The target specification is a great guiding tool doing the project. But, when doing innovation where new parameters is crucial is the target specification not sufficient enough. This is partly because of the ability to set a quantitative value and partly because of the aim of new emotional value too the user. The target specification is therefore been used in a combination with the Product Reasoning Model in order to cover all intension of the upcoming product. The target specification ensures the incremental performance innovation and The Product Reasoning Model ensures the aim of radical innovation of meaning (Verganti, 2003).

3.6 TARGET GROUP

This section describes the target group. These are made to align the team within the users point of view.

The team sees an opportunity aiming the modern farmer. The modern farmer is chosen as he got limited knowledge about drainage. The farmer trusts the drainage work done by the contractor. The modern farmer represents 75% of the market where the remaining 25% is the exploratory farmer (Skjoldager, 2018).
The way the product is going to reach the modern farmer through the contractor. The contractor got a professional pride, as one of his values is to deliver the farmer an effective drainage system. The exploratory farmer is coping the strategies from the contractor if the exploratory farmer sees a potential in the up comping product. In this way is the product reaching, overtime, the remaining 25% of the market, but with focus on the modern farmer and contractor.



4.0 CONCEPT DEVELOPMENT

THIS PHASE DISPLAYS THE PROCESS OF CONCEPT DEVELOPMENT. FROM IDEATION TO CONCEPT SELECTION AND EVALUATION. THE CONCEPTS ARE SPECIFIED AND TESTED. THE RESULT IS A COMBINATION OF TWO CONCEPTS FOR FURTHER DETAILING.

4.1 IDEATION

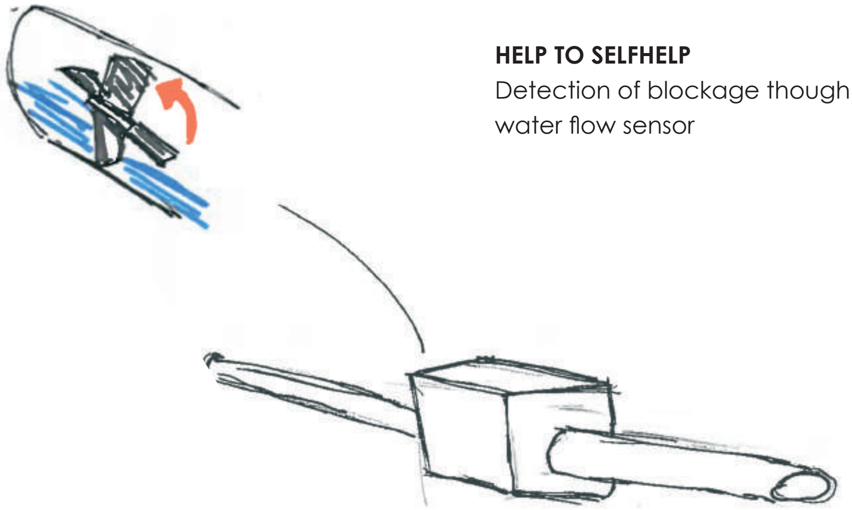
The following section displays the initial ideation based on the initial knowledge conducted through desktop research. The ideation happened under the frame "More effective drains due to increased rainwater". The purpose of the ideation was to get the initial thoughts of the different paradoxes of the topic out of the head. The section is based on: Knowledge conducted through desktop research.

Round 1
The ideation is based on different initial paradoxes occurred though the research:

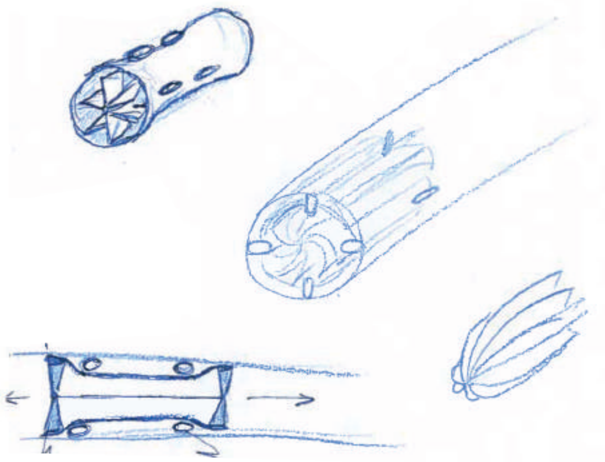
- Increased rainwater - the drains can not handle the water.
- The only way to see a sand blockage is when the field is flood.
- Stream and lakes dies due to nitrogen emission. This is coursed of drainage.

In advance of the ideation an initial need list, see page 43, were made. This had function to navigate and evaluate the ideas. Through the need list all ideas were evaluated with pros and cons according to the needs. This gave the team an indication of which ideas fulfilled the needs and the different paradoxes. The team used the pros and cons to combine the best of the different ideas. The first sketching rounds was made with basis in the paradoxes with a time interval of five minutes. See further ideas in Appendix 07.

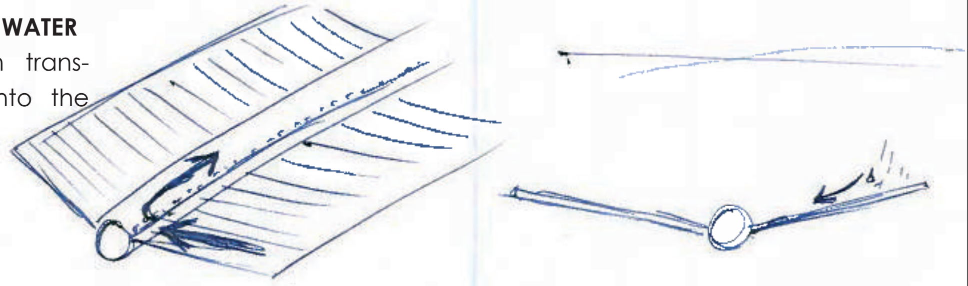
Outcome
Illustration 49.1, 49.2 and 49.3 displays selected ideas from the initial ideation. The ideas was mainly focused on the existing drainage system which limited the variation of ideas.



HELP TO SELFHELP
Detection of blockage though water flow sensor



SELF CLEANER
Using the ribs to move around inside drain to clean them.



ABSORB MORE WATER
Blanket which transports water into the pipe

4.2 TRENDS

This section unfolds the trends within farming. Further is the point of view of stakeholders listed. This resulted in a ideation round two with focus on the future farming. This section is based on: Desktop research.

Trends in the agricultural section

The trends within farming are divided into two things - products & approaches and stands.

Farming and its behavior react on the stands from the end-user. The focus of the recent years has been on organic food and the emission of pesticides. The focus has changed the mindset of farmers which is trying to reduce their emission of the needed chemical within arable farming. The reduction of chemistry is both targeted the crop but also the emission to the lake and streams, as described in section 2.3, which politician blames drainage.

Looking at new products within farming is the term "Precision farming" often represented. This is products which make an uncontrol- and predictable task, as arable farming, more tangible by using advanced technologies. Products for precision farming is products like FieldSense or Xarvio. FieldSense, shown on illustration 50.1, is a weather station measuring the single the field. It provides the farmer with valuable data which is used to determine the execution of the different tasks. FieldSense is showing the precise weather conditions which are essential knowledge when deciding when to spray the crop. Where Xarvio, shown on illustration 50.2, is a web-based platform which can predict the need for the crop by using satellite photos. This data can be plotted into GPS system of the tractor and thereby adjust the emission of nutrient to the single plant.

Illustration 50.1 - FiledSense weather station.

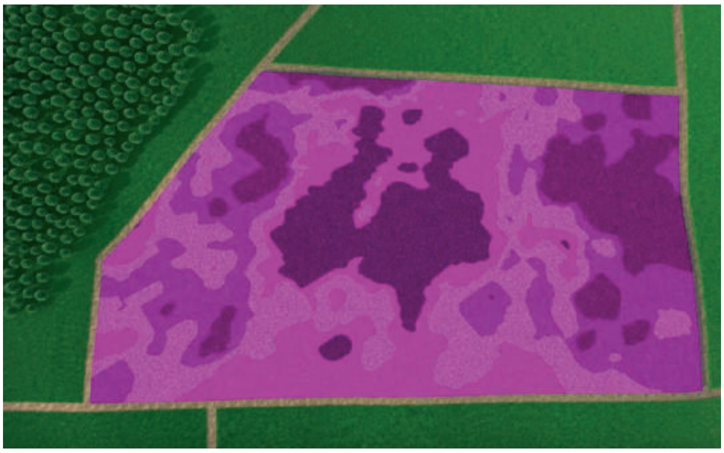


Illustration 50.2 - Plot of field from Xarvio.

Round 2 - Future farming

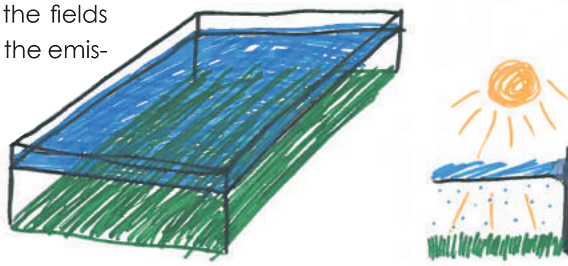
With a foundation in the trends and needs from section 3.1, the team started a second sketching round focusing on the digital aspect of drainage. The sketching happened in several rounds of five minutes.

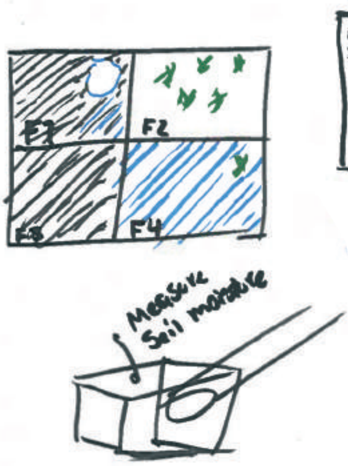
Outcome

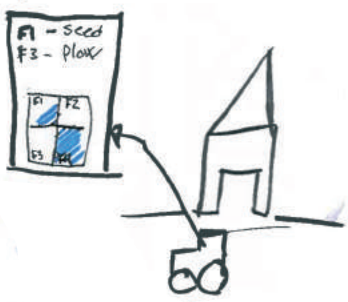
The variation of ideas spent from whole concepts to a principal level. The idea "water control" is far out futuristic where idea "nutrients" and "soil moisture" is more reachable. The team has made some initial criteria where one of them was reachability. Therefore is the ideas which not can be reached in this project sorted out.

WATER CONTROL

A layer on top of the fields which can control the emission of rainwater.

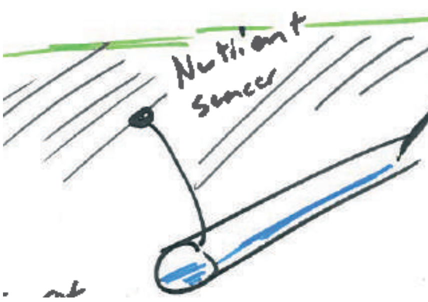






SOIL MOISTURE

Sensors are measuring the soil moisture. A plot of the fields and their drive-ability enables the arable farmer to plan his day on the fields.



NUTRIENTS

Use sensors to control the amount of nitrogen emitted into the streams.

4.3 CONCEPTS

The following section displays the development of concepts. The team had a wide range of ideas. As well, was the knowledge of drainage grown and the four problem statements were defined. Therefore did the team a new ideation round with focus on combining the ideas to concepts according to the needs and problem statements.

The focus of problems was as following:

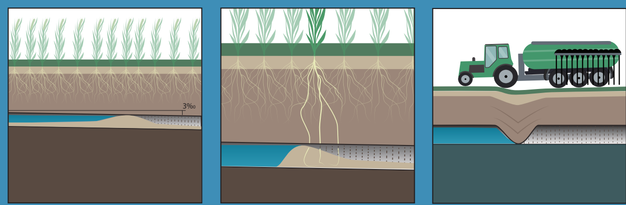
- Sand blockage
- Roots into the drain which creates a blockage
- Compressed soil due to heavy machinery
- Collapsed drain due to heavy machinery

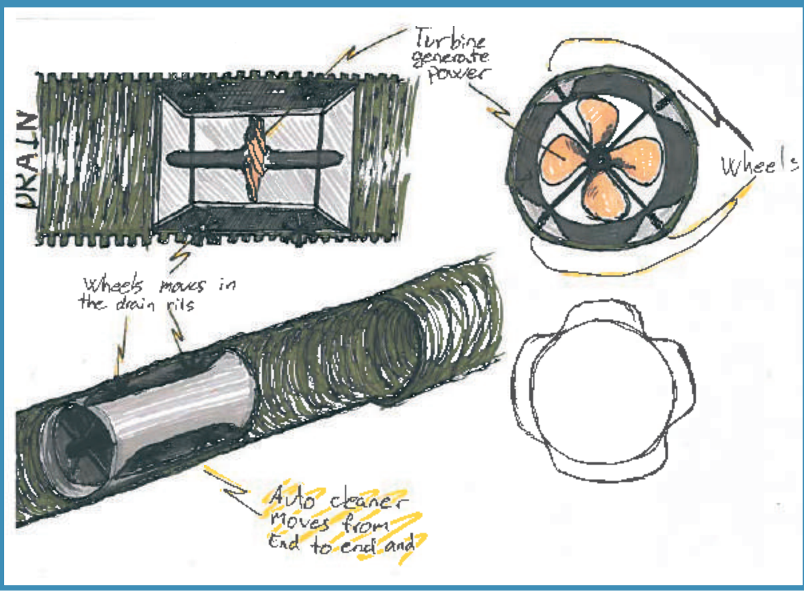
Further was the two possible market directions, existing drainage systems and re-drainage, in focus. The market directions are described in section 2.19. The team made different concepts upon the market focus. All the concepts were tagged with pros and cons. The concepts with the highest potential was further developed. The result was three concepts. Two of the concepts aimed at the existing drainage market: "Pump station" and "Self-cleaner". The concept "New drain" got to focus on the re-drainage market. The strategy from the team was to present the concepts to consultant Christain Christensen from LandboNord and further bring the concepts to a milestone for comments and evaluation.

MOVABLE CLEANER

This concept is dealing with the problems: sand and roots in drain. Further is it combining the digital aspect as it can inform the farmer of where a blockage has occored. The moveable cleaner is targeted the existing drainage market.

PROBLEMS IN FOCUS





The moveable cleaner is a device placed at the end of a drain. The concept functions as a robot lawn mower, where it is moving inside the drain. As the concept moves it flush and cleans the drain.

Modeling

The team made a muck-up of the concept. This gave the team an idea of the proposition of the concept. However, it did not give the team an indication of the complexity of the mechanism. The team was in a concern of this would be a too complicated a product compared to the task. The mock-up is shown on illustration 51.1 and 51.2.

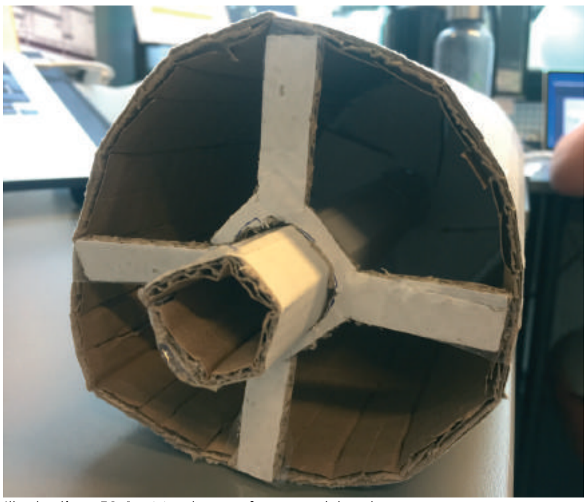


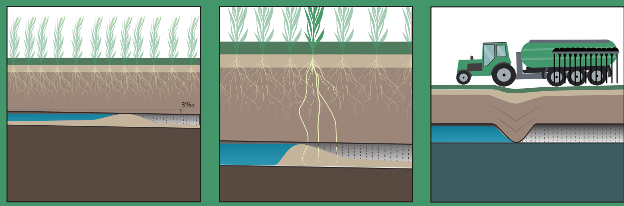
Illustration 51.1 - Muck-up of moveable cleaner.

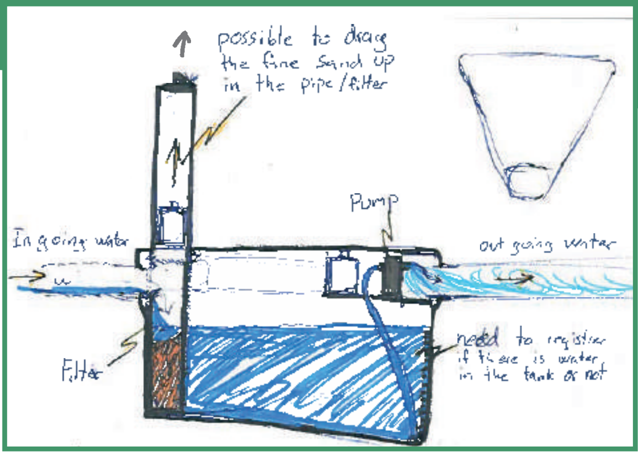
Illustration 51.2 - Muck-up of moveable cleaner.

PUMP STATION

This concept is dealing with the problems: sand and roots in drain. Further is it combining sensors for monitoring the soil moisture and water flow. The pump station is aiming at the existing drainage market.

PROBLEMS IN FOCUS





The pump station is placed instead of fittings at the drain pipe. From the water inlet is a filter positioned to filter sediments. The water is then lead into a small tank. As the water level rises in the tank, a pump starts pump the water into drain outlet. The result is a high water flow which is cleaning the drains. When the filter is full of sediments, the pump station informs the farmer. The top of the filter is placed 30 cm from the surface to make the exchange easy.
Illustration 52.1 displays the mock-up of the concept. The mock-up is used for determining the volume of water in the tank according to the dimensions.

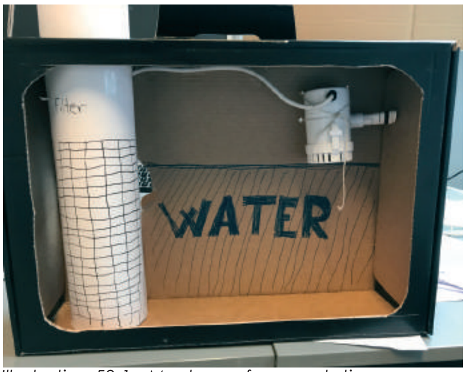
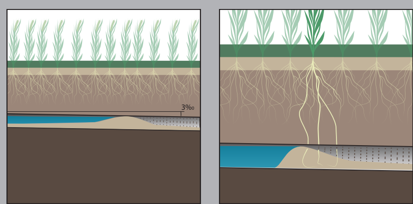


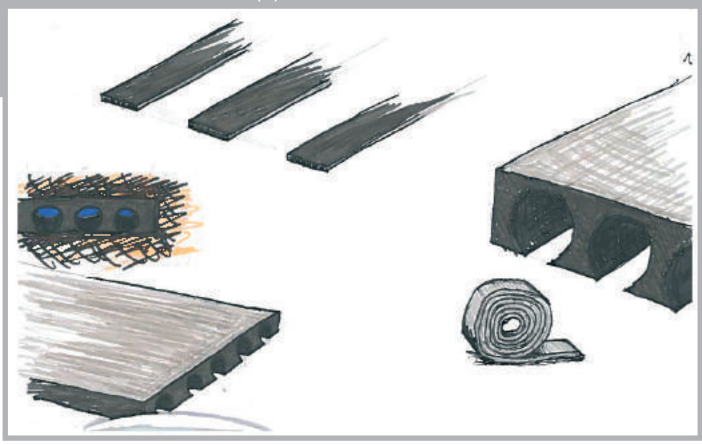
Illustration 52.1 - Muck-up of pump station.

NEW DRAIN

This concept is dealing with the problems: sand and roots in drain. The drain is a radical rethink of the existing drain. Hence, it is targeted the re-drainage market and thereby looks on new drain approaches.

PROBLEMS IN FOCUS





The new drain concept is based on the idea "Absorb more water". Concept New drain has to be placed instead of the old type of drain. The concept uses surface tension to absorb and transport the rainwater. The new drain is filtering the rainwater and is not carrying the sediments.

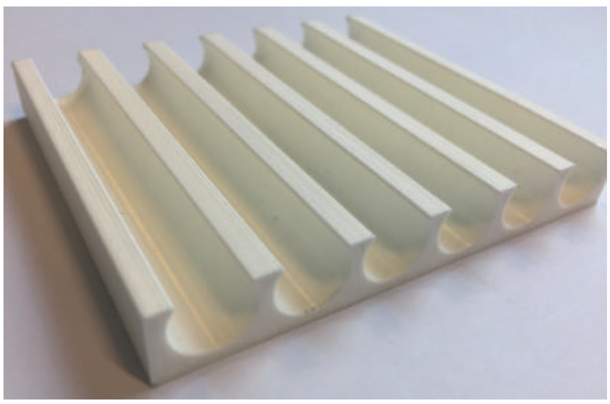


Illustration 52.2 - 3D print of concept new drain.

4.4 MILESTONE

The following section unfolds the evaluation of the three concepts. The goal of the evaluation is to end up with one concept for further development. The team used the milestone to get comments and evaluation of the three concepts.

At the milestone, the team presented general knowledge about drainage and the purpose. The four problem with the existing drainage system was explained. As well, the two market potentials and how the concepts are addressed to the markets.

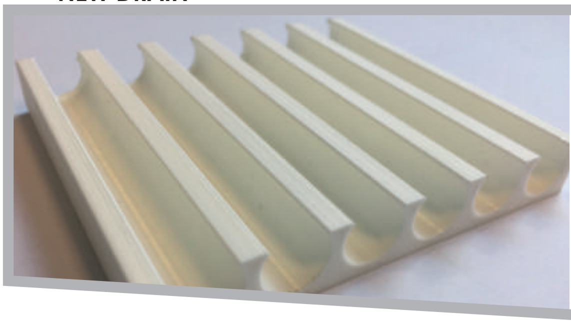
MOVEABLE CLEANER

Comments:
- The vision of the concept is good.
- The complexity of mechanical functions might be complex.
- How is the farmer enable to fix the drain when the moveable cleaner is inside the drain?
- Is it a permanent solution or a tool which replaces flushing approach.
- The concept do not solve the problems.

PUMP STATION

Comments:
- How do farmers find the filter in the soil?
- How is the station supplied by power?
- How often does the filter exchange happen?
- Is silt creating a blockage in the filter, or destroying the pump?

NEW DRAIN



Comments:
- The working principle works in theory but will it work in practice?
- How can this be implemented in the existing drainage system?
- Is the solution complicated enough for an industrial design master thesis?

Based on the comments from the milestone was the goal to converge the three concepts to one.
An essential comment to the moveable cleaner was "The concepts do not solve the problems". The concept is coping with the problems, but not solving them as the concept is just another way of maintaining the drain pipes. Based on this and the complexity of the product did the concept naturally die by itself.

The team was not able to draw any conclusion of the further development of the last two concepts. Though, the team tried to compare it with needs and demands to converge it to one concept. The concept was not concrete enough to draw any conclusion. The team decided to develop the two concepts to make them more concrete.

4.5 UNFOLDING CONCEPTS

An unfolding and development of two concepts, Pump station and new drain, is done for being able to converge it into a final concept. This section is based on: Test, interviews and moddeling.

Pump station
To make the pump station tangible did the team research on the resources needed to make a proof of concept. Further, was different cleaning methods tested.

The focus from the team was on how to power the pump. The ideas with potential were sollar cellar, wiring, and battery. To get an insight into the complexability of the pump system was an early prototype developed, seen on illustration 54.1.
To further improve the ability to clean the drain did the team test the effect of turbulent water seen on illustration 54.2. The test did not show any significant different in the movement of sediments compared to a regular flush. The grooves stopped velocity and turbulent of the water. Thus, an achieved effect was at the start of the drain.
The experiment made the team think in new directions. The result was a system where the drain pipe generates higher water flow by gravity as shown on illustration 54.3. The slope of the drain can be increased to 6 ‰.

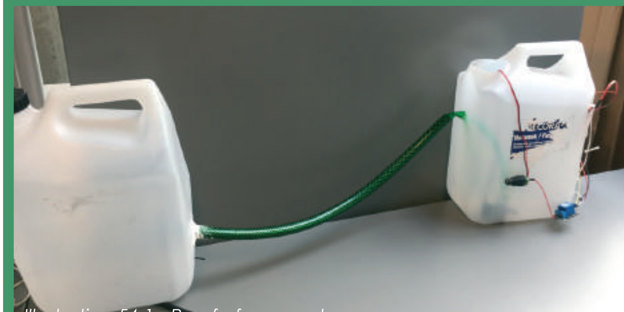


Illustration 54.1 - Proof of concept.


Illustration 54.2 - Water circulation experiment.

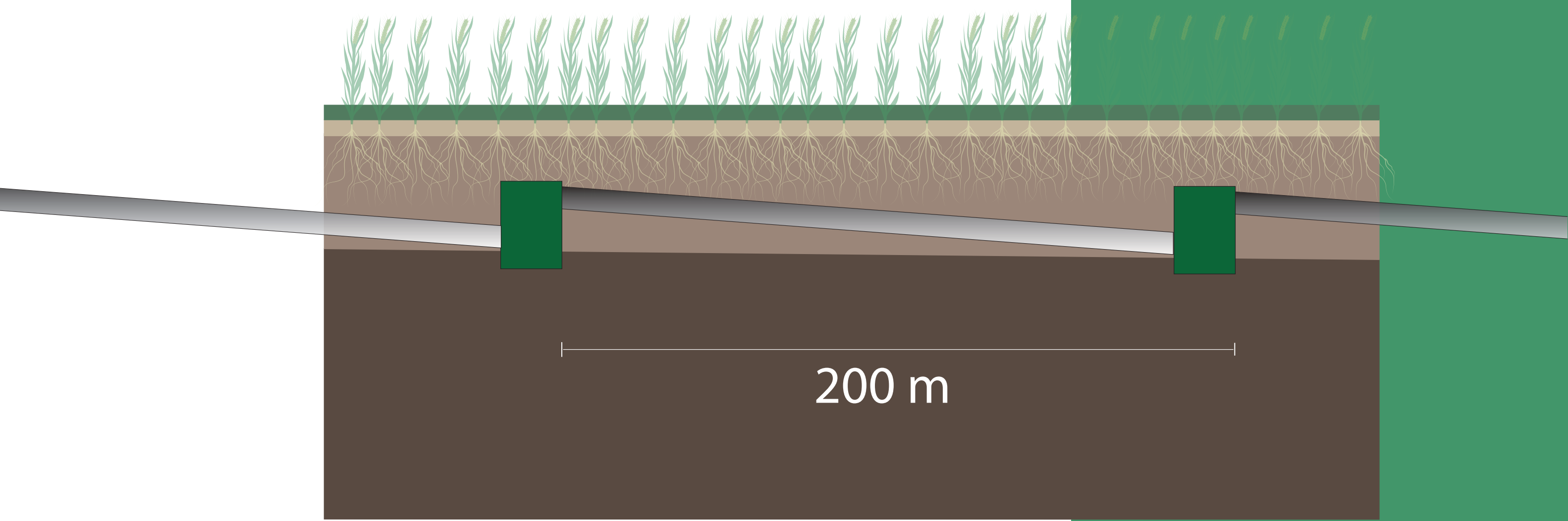


Illustration 54.2 - Increased velocity by using gravity.

Meeting with Ming Chen
The second part of the concept is the digital aspect. The need for knowledge about the drain- and soil condition is essential to arable farmers. But, to receive data require the data to penetrate through the soil. The team started to research for working principles in similar contexts. The result was safety systems for the mining industry and from avalanche beacons, see research in Appendix 08.
With foundation of these working principles did the team contact Ming Shen, an expert in wireless communication.
Ming Shen, recommended the team to look for technologies like SigFox or NBIOT. These are low power transceivers where SigFox can handle small data sets and NBIOT large data sets.
To receive the data is Ming recommending a drone solution. This is because the soil is absorbing the signal. Ming estimates that a signal can be provided approx. 2.5 meter from the surface.

Illustration 55.1 shows an idea of how the data of soil moisture can be presented to the arable farmer. This allows the farmer to plan his day on the field according to the moisture of the field. This prevents the soil from getting compressed. Initial soil moisture data was collected to see if it even was possible to make a relation between flooded areas and the moisture at the drain, see Appendix 09. The team could through the test see a relation between the soil moisture and driveability of the soil.

Illustration 55.1 - Idea of interface for soil moisture.

New drain

The new drain is focusing on the re-drainage market. The concept intends to create a new type of drain.
The team has therefore ideated on a new type o drain according to the four problem statements. Illustration 56.1 and 56.2 shows some of the first shapes which have to create an increased flow. By combining the drain concept with the digital aspect resulted in a solution which could control the outlet of the pipe. By controlling the water outlet is it possible to keep the rainwater for drought periods, the concept can be seen on illustration 56.1.

Illustration 56.3 shows the further development of illustration 56.2. The concept creates a higher velocity due to the shape. As well, is the shape easy production wise.

The concepts is further developed, and the team has decided to evaluate the concepts to converge to one final concept. Section 4.6 displays the selection and evaluation of the concept for further development.

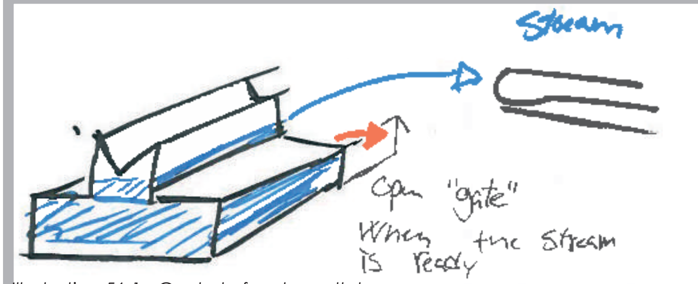


Illustration 56.1 - Control of water outlet.

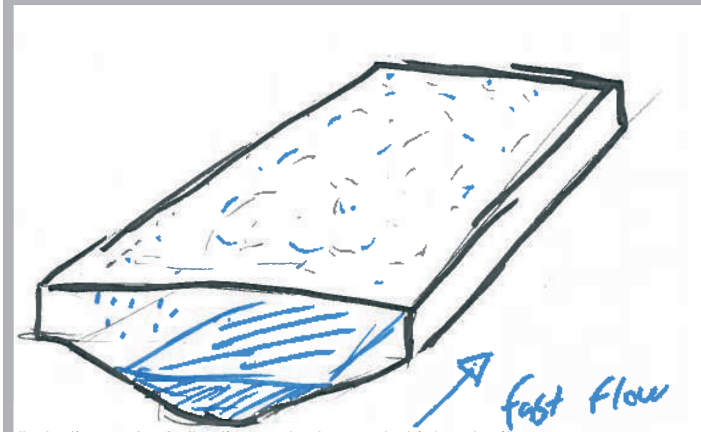


Illustration 56.2 - Collecting water to create high velocity.

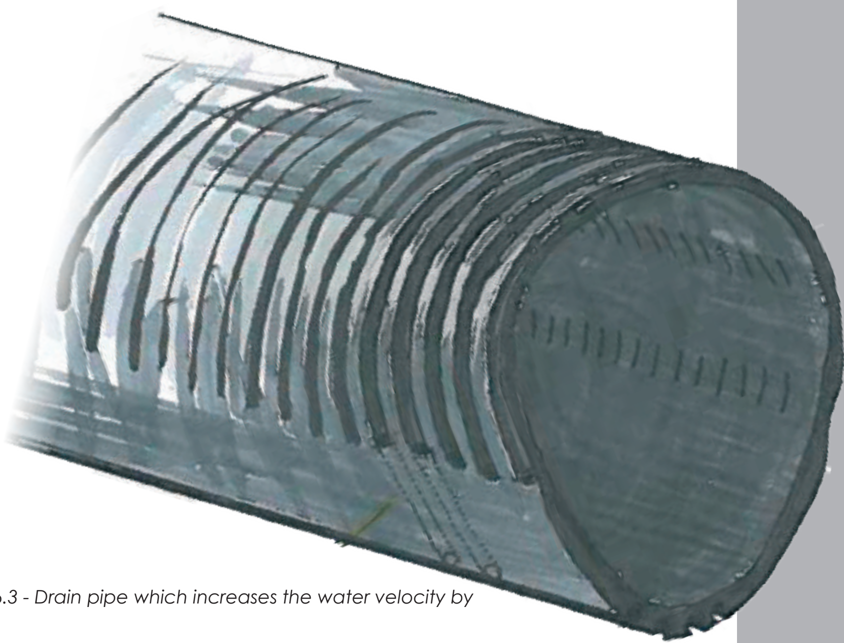


Illustration 56.3 - Drain pipe which increases the water velocity by the shape.

4.6 CONCEPT SELECTION

The following section is describing the selection of a concept for further development. The team brought three concepts to a stakeholder to evaluate the three concepts. This section is based on: concept evaluation matrix (appendix 06) and a visit at Sønderjysk Landbrugs Forening (SLF).

Based on the need specification, described at page 46, the team evaluated the following two concepts; Pump-station and New Drain. The goal was to get an indication of which concept to further develop. It was decided to use the *Concept-scoring Matrix* (Ulrich & Eppinger, 2012), shown in appendix 06. The traditional corrugate drain is used as reference product in the model. This made the scoring of the concept easier for the team as the performance of the concepts could be related. The Concept-scoring matrix indicated concept "New Drain" as the concept with most potential to fulfill the needs.

The Concept-scoring matrix is relaying on the teams subjective perspective which can be narrowed to an favorite concept. Therefor, the team contacted SLF for a evaluation meeting. The reason for choosing SLF was because of their knowledge for their costumers. They are a union which provides knowledge and consultants for niche farms, low- and big scale farmers. The team brought a poster explaining the problem statements and the concepts. Further, was "proof of concepts" brought as conviction of the concepts, see illustration 57.1 & 57.2. The meeting took place in Vojens where Carsten Kock (crop consultant) and Asger Kristensen (nature consultant) represented SLF, see full comments from the meeting in Appendix 10.

Selected comments on concept Pump station:
• Hard to maintain - cleaning filter, reparation etc.
• Concern of product cost.
• Too many stations on a field - preferably to scale the concept for maybe 20 hectares per station.
• Possible product for niche farmers - hard to see the product in large farming.

Selected comments on New Drain:
• Same water flow principal as used in streams
• How do the contractor place the drain, the shape of the drain does not have a planar surface to be placed on.

General comments
• Who has to pay for the solution - 1/3 of all arable fields is leached.
• Like the way we want to get information about the drains. This is useful for analyzing effect of drainage. But also as guarantee of the work done by the engineers and contractor.

Carsten and Asger saw a high potential in concept New Drain. They liked the principal of concept pump station and saw potential in production of niche crops.

The team have decided to further develop concept New Drain in a combination of concept Soil monitoring. This is partly because of the indication from the concept-scoring matrix and partly because of the comments and evaluation with SLF.

Beside choosing to work further on concept New Drain is it decided to use digital aspect from concept Pump station. This is because of the response from users and stakeholder which saw this concept as a strong add on to the new drain.

Illustration 57.1 - Setup of concepts and poster for presenting at SLF.

Illustration 57.2 - SLF located in Vojens.

5.0 PRODUCT

THIS CHAPTER DISPLAY THE FINAL DETAILING OF CONCEPT NXD DRAIN ACCORDING TO THE NEED AND DEMANDS. THE DEVELOPMENT OF FUNCTIONS TO THE DRAIN IS EXPLAINED. THE CHAPTER FURTHER UNFOLDS RELEVANT TESTS.

5.1 DELIMITATION

This section describes the delimitation of the project. Further, it unfolds the plan of development of new product for NXD.

In the previous did the team choose to work further on a new type of drain in combination with the digital aspect from concept "Pump station".
The team have strategically decided to limit the development to the new type of drain. This is because the problems of the existing drains has to be solved before developing the digital aspect of drainage. A new type of drainage can be considered as must have where the digital drain can be considered as a nice to have. When the drain is fully developed is the plan to make the digital aspect as second product in NXD portfolio.

Product name
The two concepts have until now been refereed as concept "New drain" and "Soil monitoring". The team have decided to name the two concepts. The new drain is going to be the next generation of drainage and is therefore named NXD Drain. The soil monitoring concept is named NXD Sight as it provides the farmer with an extra sight of the soil- and drain condition. Further, does the NXD Sight name fit to a web platform or similar as the farmer can get insight in the field.

NXD DRAIN

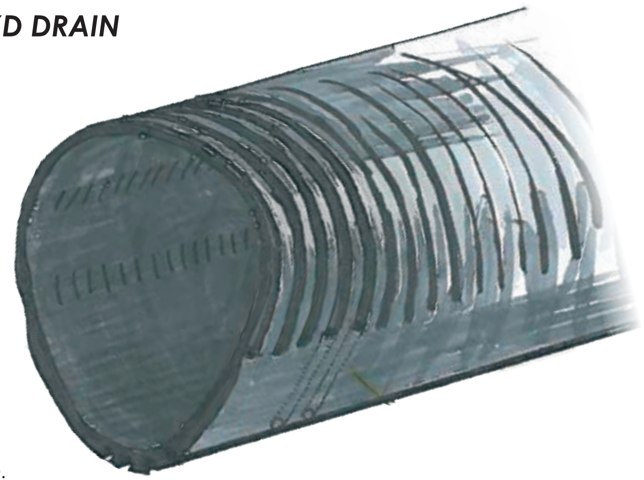
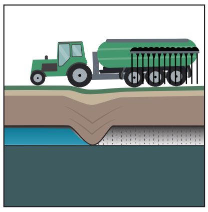


Illustration 59.1 -NXD Drain.

Illustration 59.2 -NXD Sight..

5.2 DEVELOPMENT OF STRENGTH AND WATER VELOCITY

The following section displays the systematic exploration and development of optimal strength and water velocity. The development happened with a basis in the target specification, see section 3.5. Each topic is explored individually and afterward combined to the chosen shape, Appendix 11. The topics is linked with the illustration of the related problem. This section is based on: Test, observations, Eskild Tjalve' shape-concept approach and desk research.

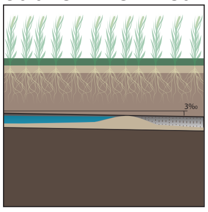


Exploration of strength

The focus of this section is within the problem - drain collapse. The shape of the drain is explored concerning the effect of forces from the soil to the drain.

The forces from the soil will affect the drain highest in the vertical direction as shown on illustration *60.1*-A. (Liang-Chaun, 1978). When the machinery is operating above the drain is forces even higher in the vertical direction.

With a basis in Tjalve' shape-concept approach (Tjalve, 1976) is different basic geometries listed with pros and cons related to the minimize the impact of force on the drain, see Appendix 11. The strongest shape counteracting the forces in the soil was a standing ellipse. The shape will equalize the forces to constant throughout the shape as shown on illustration *60.1*-B.



Exploration of increased velocity

ITo avoid blocks caused by an accumulation of sand, the shape of the drain are explored with a focus to increase the water flow and velocity. The team was in need of knowledge of the level of water flow the drain has to be able to handle. Therefore, a test box was created to perform a test with a perfect condition to find the maximum of water penetration and thereby the water flow, seen on illustration 60.2 and Appendix 12. A corrugated drain was used as test drain. When surrounding the corrugated drain with water was only half of the drain filled. The water could not penetrate fast enough to fill the drain, see illustration *60.3*. The team concluded that the corrugated drain newer is going to be half filled in its real context as the soil is slowing the penetration.

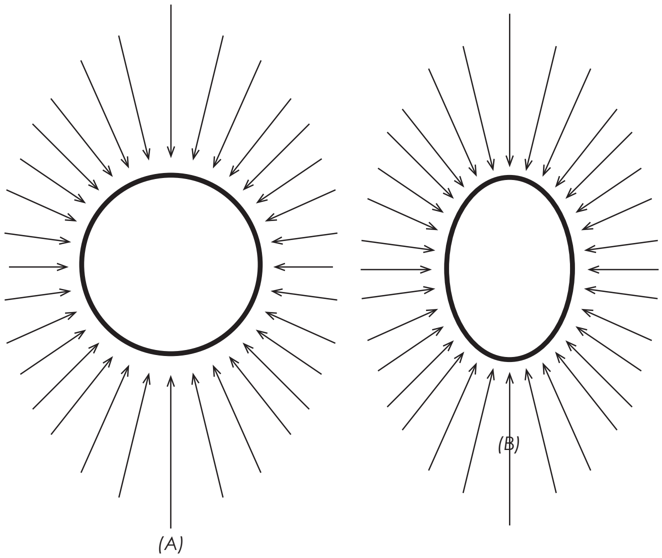


Illustration 60.1 - (A) Forces from the soil on a regular pipe. (B) Forces from the soil on a ellipse shaped pipe

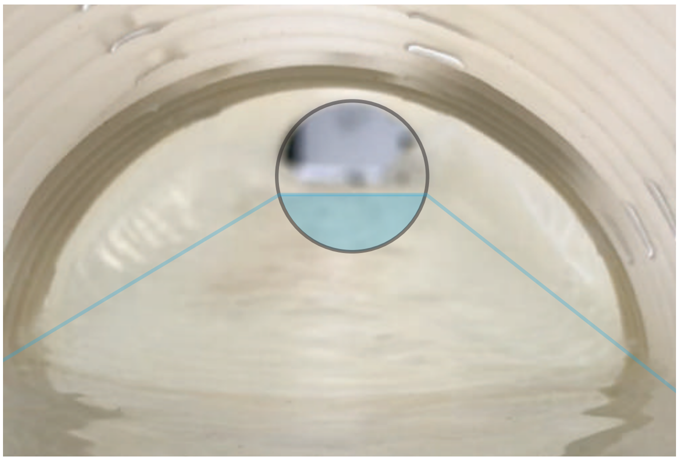


Illustration 60.3 - Below half filled pipe

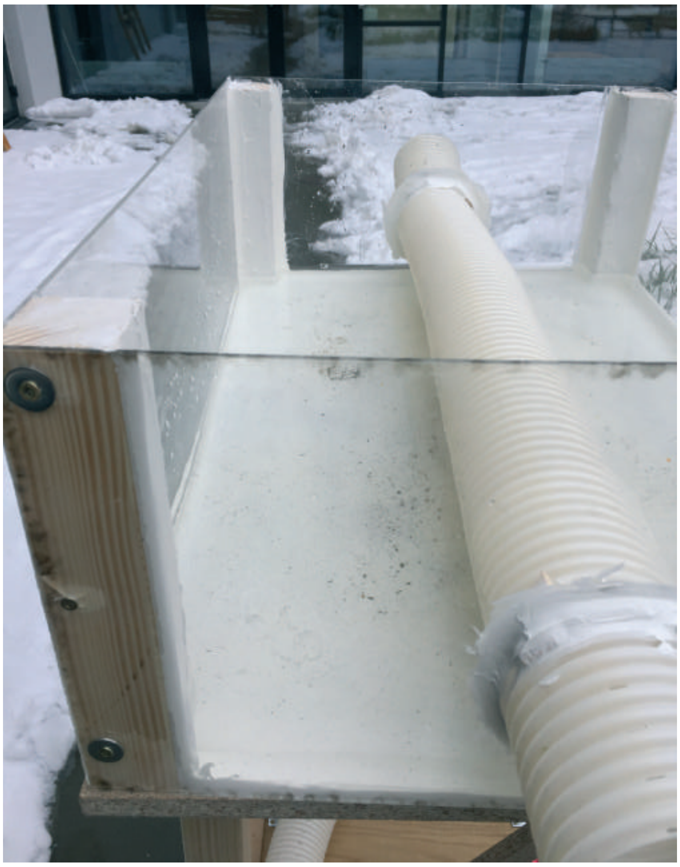


Illustration 60.2 - Water penetration test setup

To get a better idea of the water flow is the test result compared with observations of drainage outlets on different fields illustration *61.1*. The result is an estimation of the typical water level in the drain. The drain is usually filled from 0 to 10% as shown on illustration *61.2*. With the newly gained knowledge and demands from the problem "sand drop" is the shape of the drain further explored.

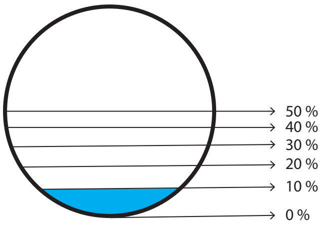


Illustration 61.2 - Flow in a Full vs. not full drain

When the water level in the drain is low compared to the drain diameter, is the water covering a large surface in the bottom of the drain. Meaning a high amount of water is in contact with the inner drain surface, and thereby slowed by the surface resistance. To increase the ability to move solids and fine sand in a low water flow situation, the shape of the drain is explored in a relation to increase the water velocity.

As it can be seen on illustration *61.3* a triangle is able to collect and concentrate the water, no matter the amount of water. Choosing the triangle will give greater water velocity in a low water flow situation and a large surface on the top of the drain meaning a large area for penetration of water. This compared with the knowledge of how the forces will affect the drain in the soil, the triangle will be weak. The forces are affecting the plane sides of the drain meaning the sides will buckle as shown on illustration *61.4*.

Combining the ellipse shape with the triangle gives an egg shape as shown on illustration *61.5*. The top of the egg shape is wide with a large surface allowing the water to penetrate into the drain with help from the gravity. The bottom parabola concentrates the water independent of the amount of water. The shape has a strong construction because the shape has a curvature all through the shape. To test the water flow and velocity of the shape was a 3D printed model placed together with two competitors, a corrugated drain, and top-slotted drain, see illustration 61.6. The test is further described in section 5.3.

Illustration 61.5 - Egg shape, combination of ellipse and triangle

Illustration 61.1 - Observations of existing drainage outlet

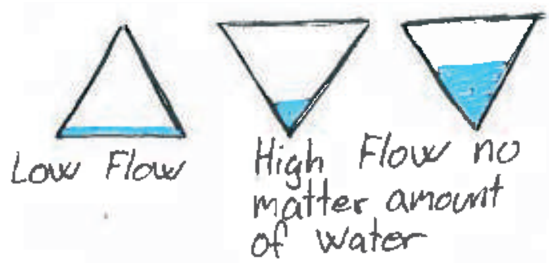


Illustration 61.3 - Flow in a triangle

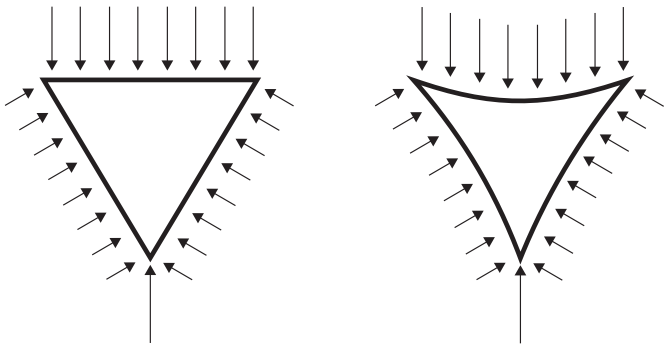


Illustration 61.4 - Buckling of triangle

Illustration 61.6 - Test of flow

5.3 FLOW TEST

The following section displays a test conducted by the team. The test was made to gain knowledge about the water flow and velocity of the egg-shaped drain pipe.

The three pipes were each three meters long and placed on a plain piece of wood. The pipes were leveled with a slope of 6 ‰ to make sure the slope was precisely similar. To make the corrugated drain pipe competitive was it covered by soil as the drain has penetration holes all way around. The soil was compressed to simulate the real context. The inlet of water was measured, and a bucket was located at the outlet to collect the outgoing water.
This enabled the team to compare the outlet of water. By taking time on the water getting from the inlet to outlet, it was possible to examine the velocity. The top-slotted drain and NXD Drain are both closed at the bottom, and therefore the same amount of water came through. The corrugated drain did not deliver water at all. All the water penetrated through the holes and into the soil and the water only reached one meter into the drain. After several attempts to get water through the corrugated drain, the team concluded that the drain was unable to lead the water unless it is under constant water. This will happen in context if the water-table exceeds the drain. It also means if the water-table is lower, farther down than the drain, the water will be lead into the soil instead of in the stream or well.
As NXD Drain and the top-sliced drain was the drains leading the water to the outlet, was it only possible to get results from them.
Due to sources of errors such as precision timing, drain length, amount of water and material surface roughness the test failed. The team could not draw any definite conclusion to the water velocity from the test, besides it is impossible to test the corrugated drain. The team decided to test the top-slotted further- and NXD drains in a controlled environment.

Illustration 62.1 - Test of flow. Left: NXD Drain Middle: Corrugated drain Right: Top-slotted drain

Illustration 62.2 - Test of flow

A second test was executed. Besides testing the velocity is the test made see the ability to transport solids that penetrated into the drain. Thereby, getting an idea of which corn size the increased velocity can transport, see Appendix 13. JB2 soil and grit from 1 - 4 mm were placed within both drains see illustration 63.1. The solids were flushed through the drains with a constant water flow of 0,35 liter per minute. The water and sediments were collected and weighted at the outlet to see the amount of sediment lead with the flow, see illustration 63.2. Though several numbers of test attempts with 70 g. 1-4 mm grit placed in both drains, was the top-slotted drain average 5 gram better than NXD Drain. The same test was done with JB2 soil. To get an idea of the outlet weight was the sediments filtered by a piece of fabric and weighted. The precision of the weight was low to get any comparison. The water in the fabric could not be controlled. However, it became clear how the solid in the water reacted in the water flow as shown on illustration 63.3. The team concluded that the roughness of the inner surface is very important according transport to sediments. Further, was the team able to see that the drain could carry sediments smaller than 1 mm.

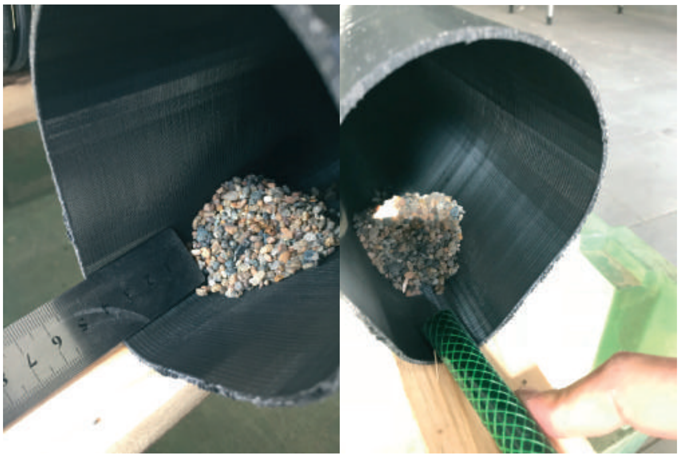


Illustration 63.2 - Test of flow, 1 - 4 mm solids

Illustration 63.3 - Solids reaction to flow and drain surface

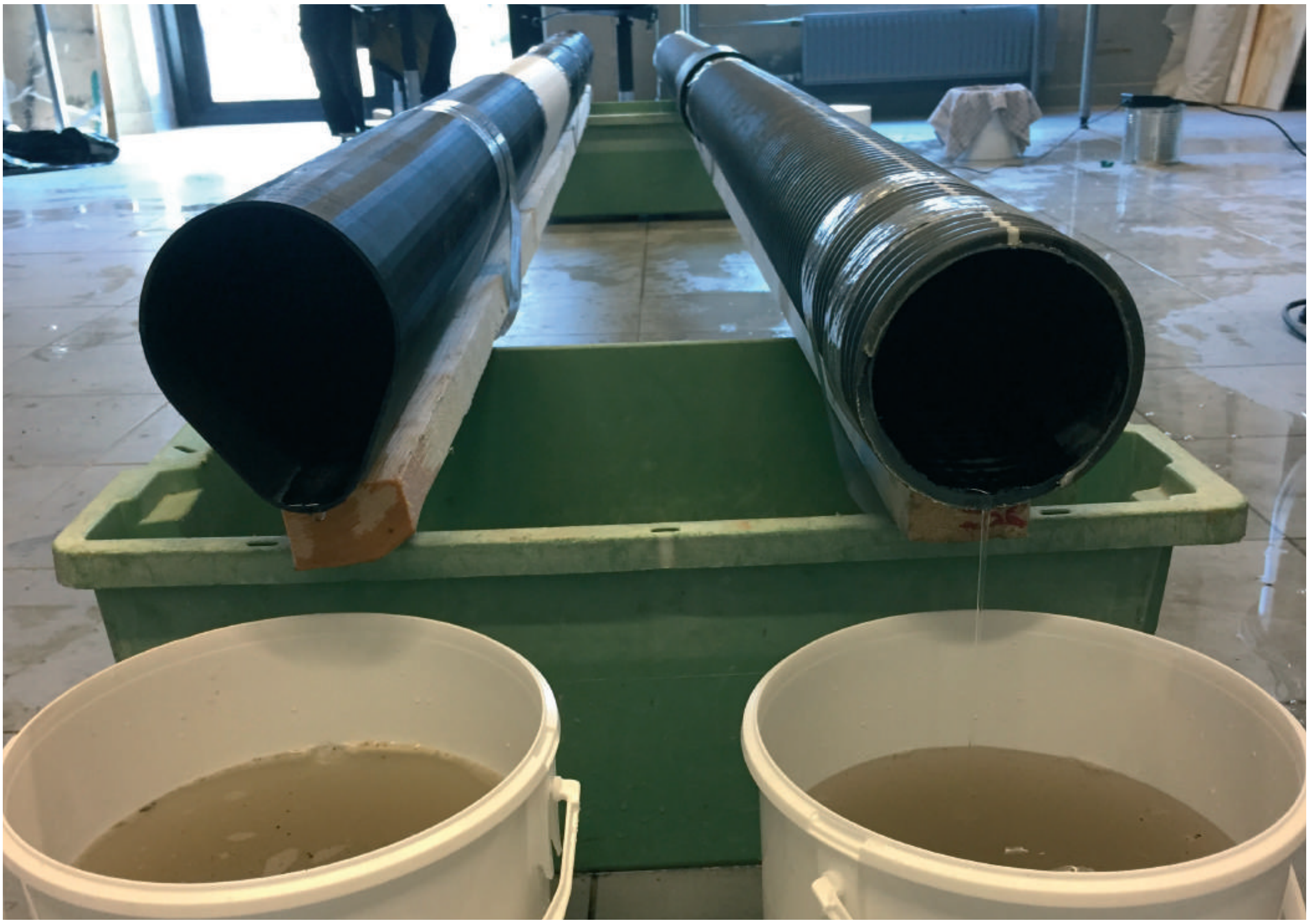


Illustration 63.1 - Test of flow, moving solids

5.4 DETAILING SHAPE

The following section describes the theory of water velocity in pipes. The team has twice failed to try to conclude according to water velocity on a quantitative approach. As a self-cleanable drain is an important need and one of the value-visions did the team decide to research on the theory of pipe velocity.

The following is Manning's Equation which describes the average velocity at uniform flow (Regueiro-Picallo et. al, 2016):

$$U_{av} = R_h^{2/3}\sqrt{S}/n$$

U_{av} is the average velocity (m/s). R_h is the hydraulic radius (m) is determined by the cross sectional flow area divided by the wetted perimeter (Regueiro-Picallo et al., 2016). S is the slope (m/m) and n describes Manning's roughness coefficient ($s/m^{1/3}$). Due to Manning's equation a higher hydraulic radius is equal to a higher average velocity. The perfect circle got the highest full-bore discharge as this geometric got the highest hydraulic radius (Regueiro-Picallo et al., 2016). The increased velocity will remove and clean the sediment out of the drain system. This advantage can be conducted to the egg-shaped geometric as it consists of different sized circles.

With a basis in theory for the velocity of water is the radius of the circle in the bottom defined. The radius is related to the level of water in the existing drainage system which is 10% filled, see section 5.2. The corrugated drain is only 10 % filled. The new shape will increase the velocity at a low flow situation as it got a higher hydraulic radius. If a heavy rainstorm occurs and the water volume is increased to 50%, do the circular drain provide a higher velocity as,

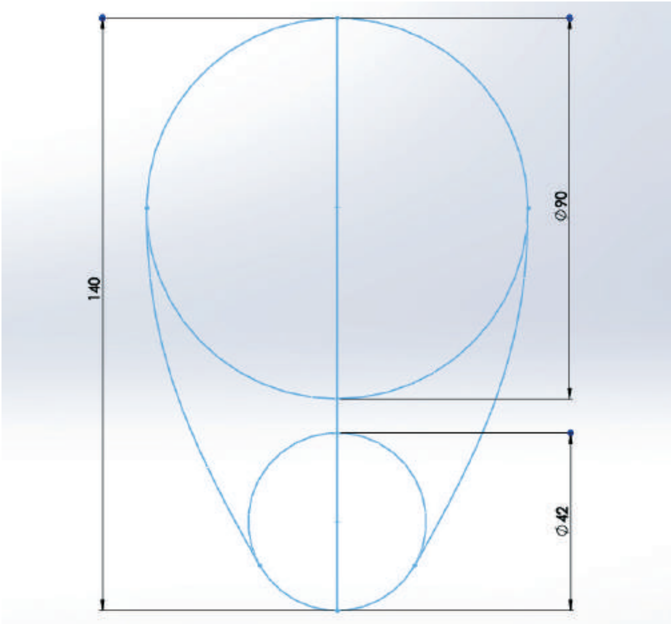


Illustration 64.1 - Dimensions of NXD Drain

in this case, the circle has a higher hydraulic radius. However, nothing is lost, as in this situation is the velocity is high enough to transport the sediment. To compare the velocity, the team made a simulation using ANSYS. Illustration 64.2 and 64.3 displays the result. The simulation is done with filled pipes with low velocity. From the simulation was it possible to conclude that the NXD drain got a higher average velocity, where the corrugated drain got the highest velocity. Further, shows the streamlines on illustration 64.3 that the NXD drain got high velocity in the bottom where the sediments are located. The conclusion is that the NXD drain is 15% higher average velocity compared to the top-sliced drain pipe.

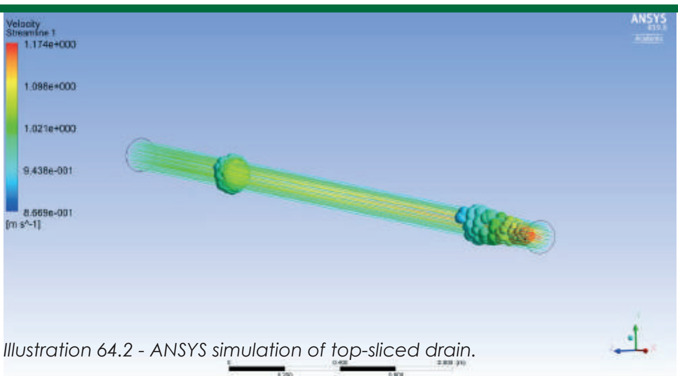
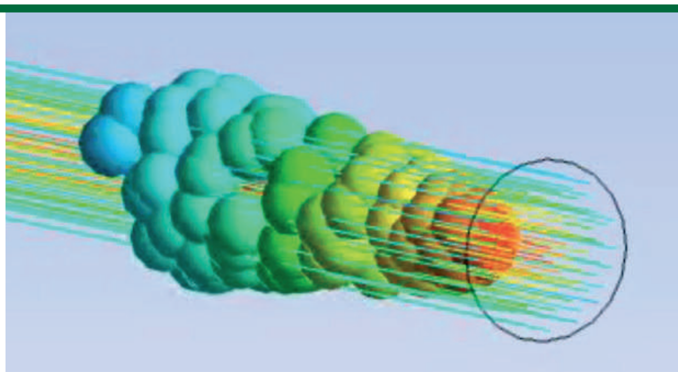


Illustration 64.2 - ANSYS simulation of top-sliced drain.



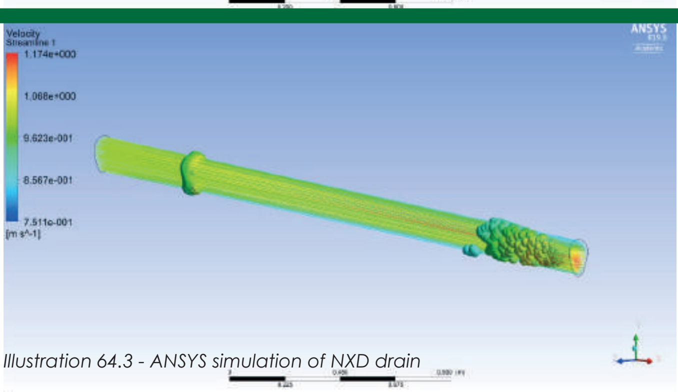
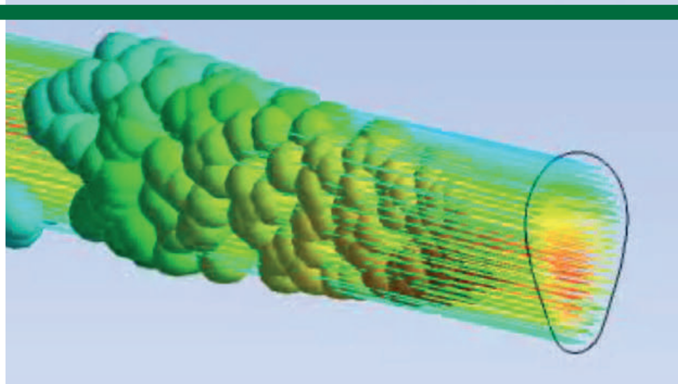


Illustration 64.3 - ANSYS simulation of NXD drain



5.5 RIBS

This section unfolds the development of the ribs of the drain. The needs and demands related to the ribs are, it has to be flexible for keeping the cost relatively low. Also, the ribs should give strength to the drain for avoiding collapse. The section is based on systematic ideation, desk research and 3D-printed function-models.

The corrugated drain is using what we call traditional ribs to provide strength for the drain. It is a cheap and effective solution with low use of the material. The same principle is investigated for NXD Drain. Different shapes are compared to how the forces will affect them as seen on illustration 65.1. To expand the ideation and possibilities for strengthening the drain, placement of a grid inside the drain was explored. Illustration 65.2 shows a grid placed inside the drain to strengthen it. The grid will strengthen the construction in both pressure and tensile forces. The disadvantage of putting the grid inside the pipe is less space for the flushing head when maintaining, and at the same time, it will make the structure rigid meaning the pipe not can become flexible

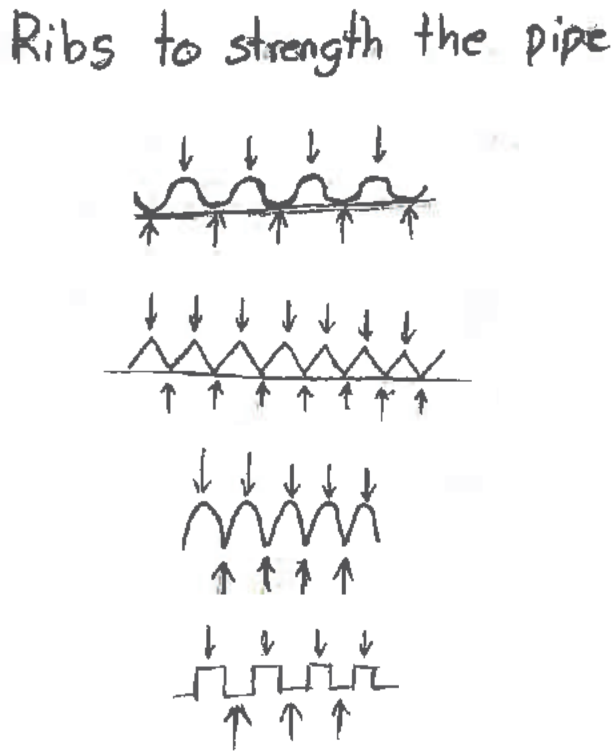


Illustration 65.1 - Traditional ribs shape investigation

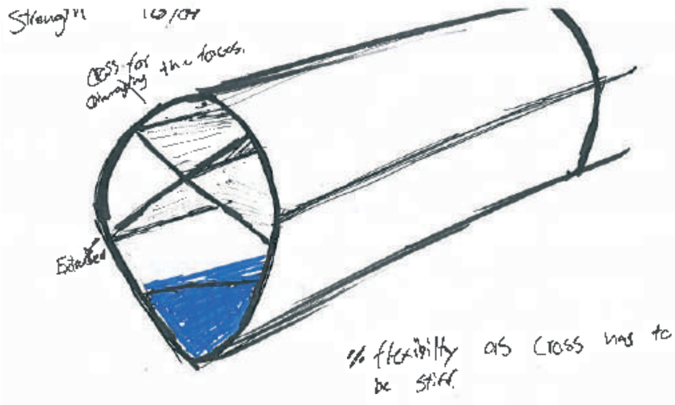


Illustration 65.2 - Strengthen construction from inside

With the disadvantage of placing the grid inside the drain, it was concluded that the ribs should be placed on the outside of the drain.

By moving the strength to the outside of the drain as ribs, it was investigated whether the ribs could have multiple functions than strength in the form of filtering sand or lead the water with capillary forces.

To use the natural forces as capillary power like the concept "New drain" is using from section 4.3 and see illustration 65.3. The biological forces within water should be investigated further to become more aware of the parameters that have a role in how the water reacts.

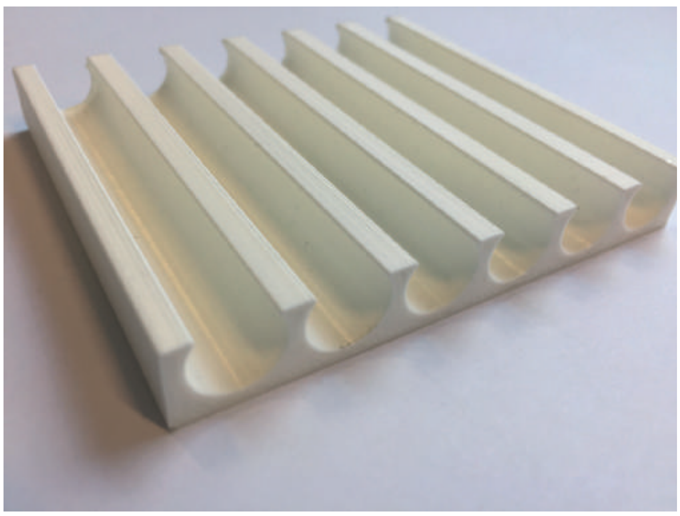


Illustration 65.3 - 3D-printed model of concept New drain

Natural forces for water

This section will look into how the water can be lead or transported with biological principle. The working principles of capillary power, surface tension and basic rules of H2O is investigated. It is done to get knowledge about how water reacts, and probably be implemented and used for the Concepts.

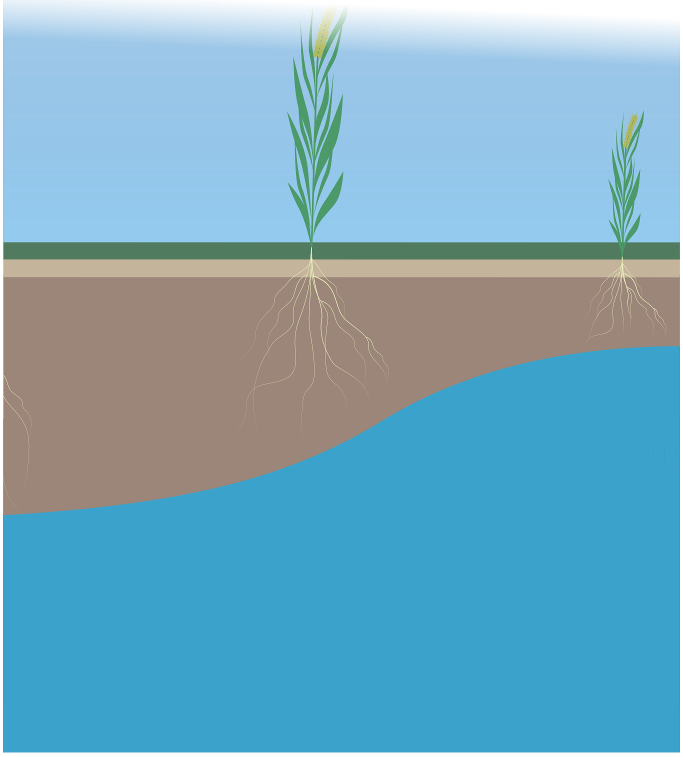


Illustration 66.1 - roots and the water-table

The Capillary action

One place where Biological forces transport water is inside plants and trees which is known as the capillary action. Inside roots and stalk of a plant, it consists of small tubes which function as the highway for the water to be transported. The small tubes allow the water to climb up through the roots and the stalk, called the capillary action, for delivering the water to the leaves and the rest of the plant.

The capillary action is also seen in the soil, where the structure of the soil creates small crevices. The crevices work as small tubes where the water can climb through, as seen on illustration 66.2 and thereby raise the water-table in the ground.
(Robinson, -)

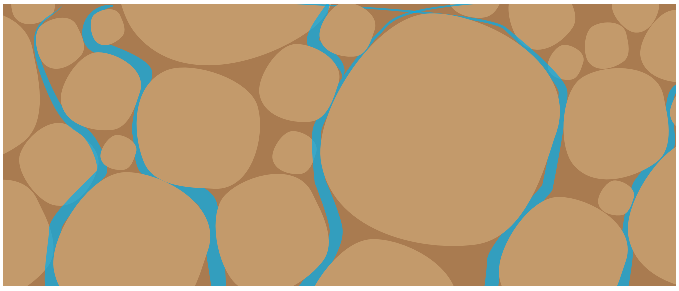


Illustration 66.2 - Capillary action within soil

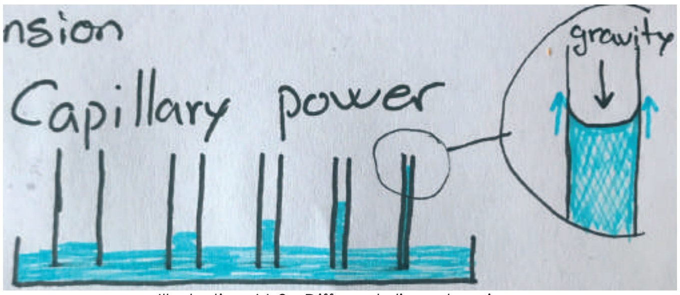


Illustration 66.3 - Different diameter pipes

Limitations within the capillary action

The water can climb to a certain height which is determined by the diameter of the pipe and the air temperature. A test with different tubes of different diameters is placed in a tank with water as seen on illustration 66.3. The test will show, the tube with the smallest diameter will lift the water highest. This phenomenon can be described with Jurin's law that defines the height (h) of a liquid:

$$h = \frac{2\gamma \cos\theta}{\rho g r},$$

γ is the liquid-air surface tension, θ is the contact angle, ρ is the density of liquid, g is the local acceleration due to gravity, and r is the radius of tube.
For a water-filled glass in standard laboratory conditions, γ = 0.0728 N/m at 20 °C, ρ = 1000 kg/m3, and g = 9.81 m/s2.
(Batchelor, 1967)

$$h \approx \frac{1.48 \times 10^{-5}}{r} \text{ m.}$$

For the following values, the height of the water column is:

Glass tube with a **2 m radius** the water will raise **0,007 mm**
Glass tube with a **2 cm radius** the water will raise **0,7 mm**
Glass tube with a **0,2 mm radius** the water will raise **70 mm**
(Batchelor, 1967)

Reaction to different surfaces

The water can react different in relation to the structure of the surface.

Hydrophilic means that the surface attract the water. This happens when the surface and the material has a flat structure and thereby create a flat drop as seen on Ill. XX

Hydrophobic means that the surface detest the water. This means that the surface and the material creates a rough structured surface and thereby the small variations creates angles that collect the water into a higher drop as shown on illustration 66.4.

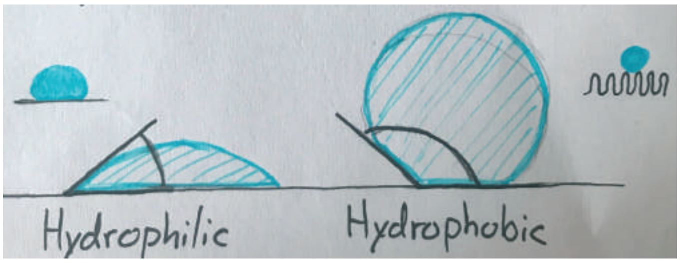


Illustration 66.4 - Hydrophilic and Hydrophobic

Knowing from the desk research about how the water reacts with the natural forces, it was investigated how the principles could be implemented in the ribs. The ribs were explored with the approach to attract the water to the drain within the soil.

As seen on illustration *67.1* ribs are placed on top of the concept to give the construction strength. The sides of the drain is closed In the lower half of the drain. Between the in and outside wall is small tubes that run from the bottom of the pipe to the middle of the drain. These tubes will function with the capillary power as water leaders. They will transport water from the bottom and up to the penetration holes between the ribs.
This construction puts high demands for the production. Knowing that the price is an essential factor, the ribs are explored further related to a relatively cheaper production.

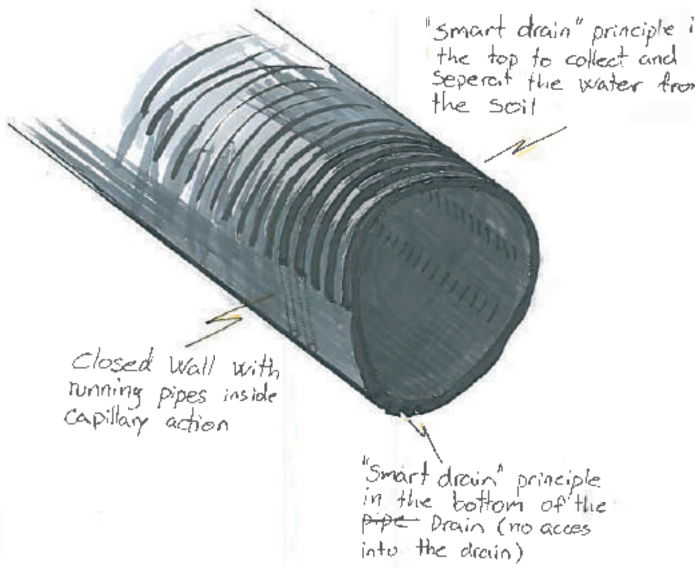


Illustration 67.1 - Ribs with capillary power

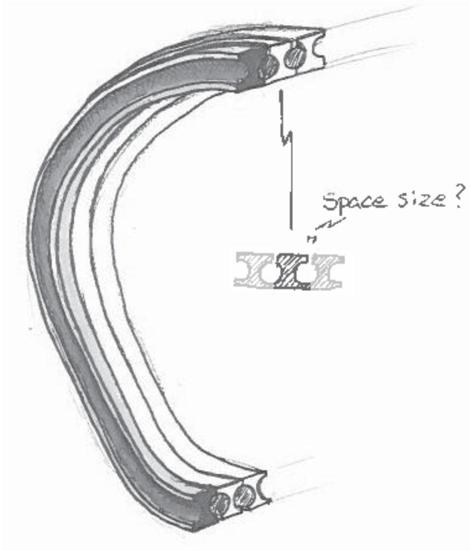


Illustration 67.2 - Separated ribs

Illustration 67.3 - 3D printed model merged ribs

As it can be seen on illustration 67.2 it is chosen to split the ribs to lowering the production cost. By splitting the ribs into separate components means it can be injection molded and afterward merged as shown on illustration 67.3. The model is 3D-printed to give hands-on indications of the construction and the dimensioning.
As one of the demands saying it should be possible to implement it with an existing method from the contractors.
The ribs are divided once again and placed with a distance to each other. It means that the inner pipe is separated from the ribs and can be produced by extrusion in a flexible material as seen on illustration 67.4 a 3D-printed model.

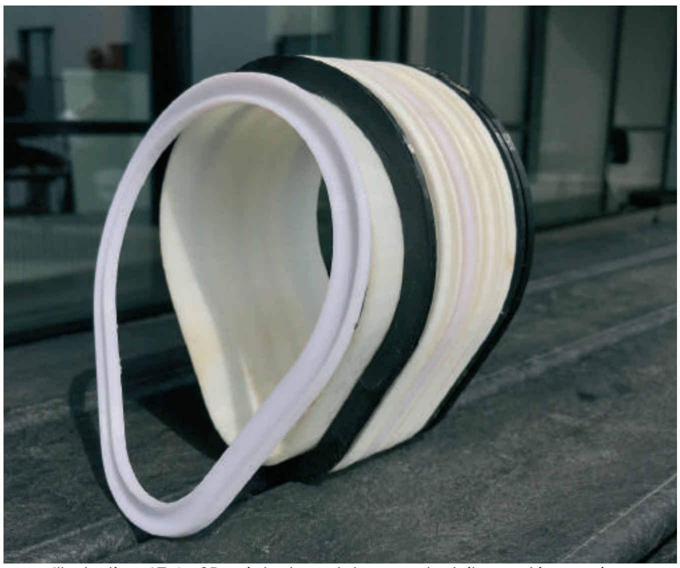


Illustration 67.4 - 3D printed model separated ribs and inner pipe

The concept now consists of 2 parts as seen on illustration *67.4,* the inner pipe with a flexible material that can be extruded and a rib which is placed with a distance that allows the drain to be flexible. With a flexible, drain the concept will fulfill the requirement of being possible to implement by a contractor.

5.6 CONCEPT CONSTRUCTION

This section will describe how the current concept is constructed and the functions of it.

The concept consists of two components as shown on illustration 68.1 the rib which is green and the inner pipe which is black on the illustration. The drain will be flexible by choosing a material for the inner pipe that has a low enough elasticity module to provide flexibility. The rib should have a higher elasticity module to provide strength to the construction. The choice of material is described later in section 6.1

The ribs function is to provide strength to the construction and at the same time filtering sand from the water when it penetrates through the rib.

This is done by two ribs working together as one, see on illustration 68.2. By placing the two ribs against each other, the top of the ribs will create one-millimeter space where the water can penetrate through. This will work as a filter as it only allows sand from one-millimeter and below to get in. When the water has penetrated through the one-millimeter filter, it gets into the chamber of the rib. Inside the chamber is space which allows corns below one millimeter to either drop to the bottom of the rib or penetrate with the water through the penetration holes into the drain.

With a large area for the water to penetrate through means more water into the drain. And with a clean surface and a shape that increases the velocity with 15% as described in section 5.4. The flow will be high enough to transport the incoming sand.

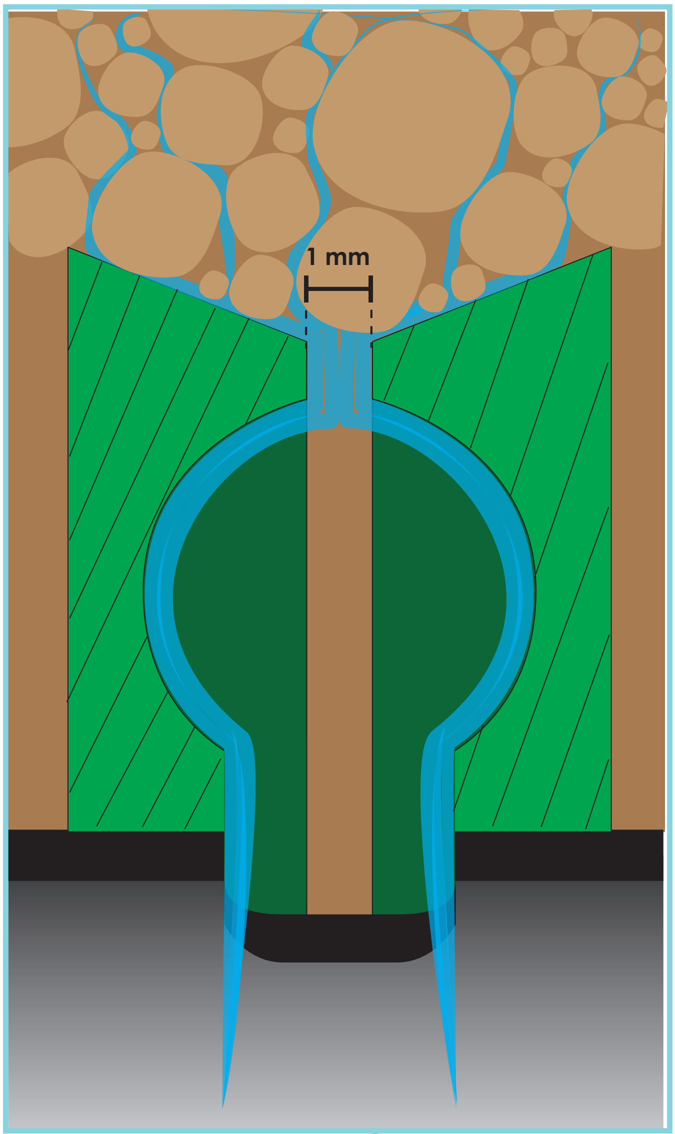


Illustration 68.2 - Zoom two ribs working together

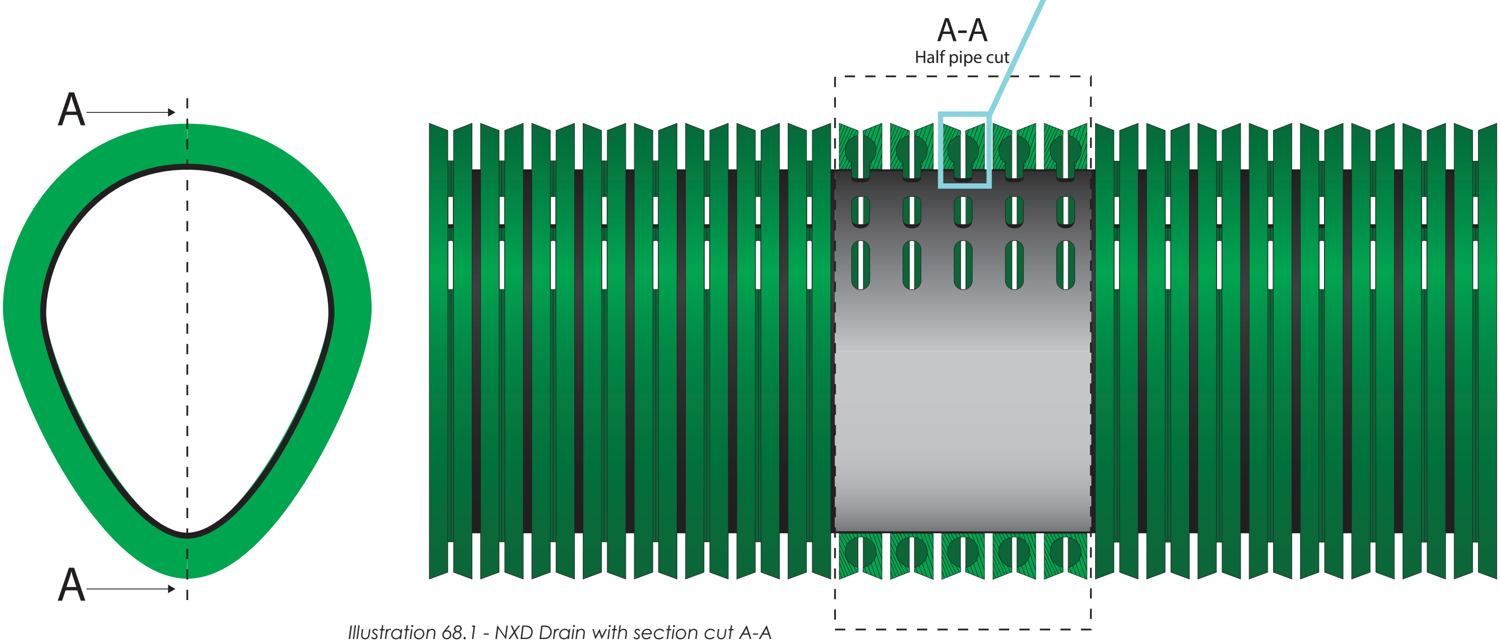


Illustration 68.1 - NXD Drain with section cut A-A

5.7 STRENGTH TEST

This section will test the strength and see how the current concept from previous page will deform in its context. The 3D-printed model was tested in comparison with a corrugated drain. The test was set up with NXD Drain on 100 mm and an corrugated drain on 100mm. The drains were placed in the soil where a tractor drove over it as seen on illustration 69.1.

This allowed the team to see how the drain deformed.

The corrugated drain deformed to a flat ellipse shape as seen on illustration 69.2. The deformed shape will create an even lower flow in the water than before, because of the larger surface in the bottom.

The test with NXD Drain showed a small deformation Illustration 69.3. Because the ribs were not attached to the inner pipe, they slipped apart, and the distance became uneven. It showed the importance of fixing the ribs to the inner drain.

Because of a very small deformation, it was concluded that the ribs could be even smaller for lowering the material cost for further and deeper detailing of the concept.

Illustration 69.1 - Strength test with tractor

Illustration 69.2 - Deformation of existing drain

Illustration 69.3 - Deformation of NXD Drain

Pressure test

The 3D printed model and the corrugated drain was brought to test facilities at Aalborg University. Using a pressure machinery enable the team to define how high a pressure the drains can resist before deformation. See illustration 69.3.

The regular drain began to deform at a pressure of 80 kg where the 3D-printed model of NXD Drain first began to deform at a pressure of 140 kg.

Given that the model was made in 3d print, the same construction in the same materials would probably be even stronger. The reason for this will be that when it is injection molded the material will be constant and complete. Using a 3D printed model it is built with layers on top of each other and thereby the possibility of unevenness in the product.

Illustration 69.3 - Deformation of Right: NXD Drain Left: Corrugated drain

5.8 DETAILING FOR PRODUCTION

The final concept is detailed with the intention of preparing for production. The most optimal production method for the ribs will be injection molding because of its design, cost and knowing that a high number is needed. This step is illustrated as step one on illustration 70.1. The second step shows the extrusion of the inner pipe with no difficulty as it is merely a smooth pipe that matches the extrusion method well. Step three illustrate the last action, the assembly of the ribs and the inner pipe to the final product. Different methods for assembling the ribs are explored.

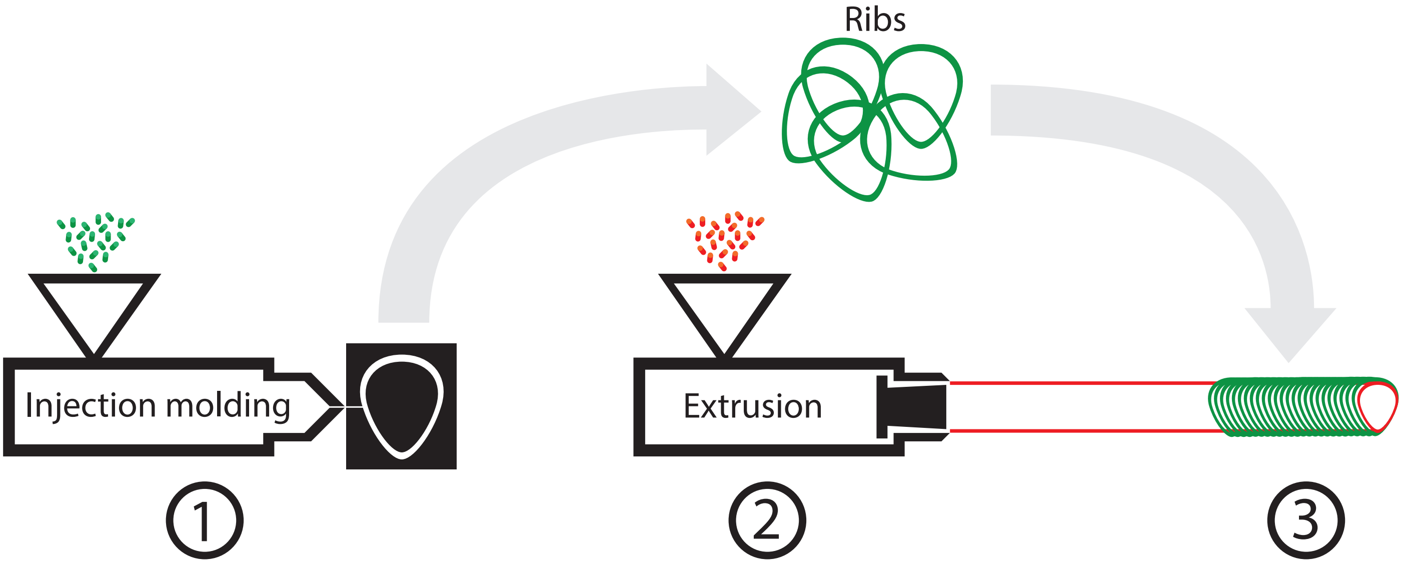


Illustration 70.1 - Initial production setup

For the attachment of ribs it has been concluded that the ribs should be divided into two so that they can be mounted immediately after the extrusion, as shown on illustration *70.2*.

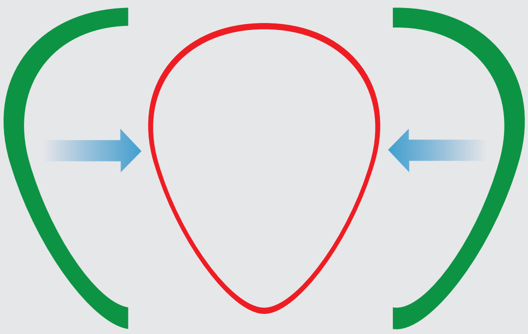


Illustration 70.2 - Ribs divided in two

Five selected methods with potential for attaching the ribs are listed below:
First method is to applying glue on the contact surfaces of the ribs and then compress it together around the pipe.
Second method is to fusion the ribs on the pipe using ultrasonic welding. But time is a question as the technique requires more time to merge the parts.
Third method is to place the ribs on the pipe and then laser-weld it where the ribs and the pipe meets.
Fourth method is to fusion the parts within the same process of stamping the holes in the corrugated drain, see section 2.7. It is the intention to stamp the holes with a hot tool that simultaneously will merge the materials.
Fifth method is to make snap fits that attach the ribs together and snap fits that attach the ribs to the pipe.

For environmental reasons, the possibility of using recycled plastic was investigated. The leading manufacturer of recycled plastics in Denmark is Letbæk Plast A/S. NXD took contact to Martin Holm, who is the head of research and development at Letbæk Plast. A meeting with Martin Holm was arranged in Tistrup, where the factory belongs. NXD Drain was presented at the meeting, and the team NXD became clearer on who they are and what they can offer. Through a tour around in the factory, their production methods were shown. Letbæk Plast are able to injection mold and plastic extrude. Since both needed methods for producing NXD Drain and the possibility of using recycled plastics, Letbæk Plast became a possible collaborator.

Throughout the meeting it was concluded that the most cost- and time-optimized assembly method would be the fifth suggestion, using snap fits. This was chosen both because no extra material will be applied but also because Martin Holm introduced us to a upcoming law. The law will say that all manufactured plastic products which consist of different plastic materials must be able to be split with the intentions of recycling.

5.9 SNAP FITS

The following section describes the development of snap fits. With the knowledge from Letbæk Plast A/S for the desired production techniques, the final detailing of NXD Drain became possible. Knowing the rib has to be divided into two parts and mounted by snap fits, the rib was further detailed in proportion to where it should be divided. This section is based on: Knowledge form Letbæk Plast and CAD-Modeling.

The selected and best way of splitting the rib was chosen to be on the horizontal level as it can be seen on illustration *71.1*. By splitting it, horizontal means the forces will go through the snap-fit with a lower impact compared to splitting it vertical. At the same time, the space for water penetration will not be disrupted on top of the drain where it is most needed. Now, the drain consist of 3 parts, two top ribs which creates the filter and one solid bottom rib to fasten them.

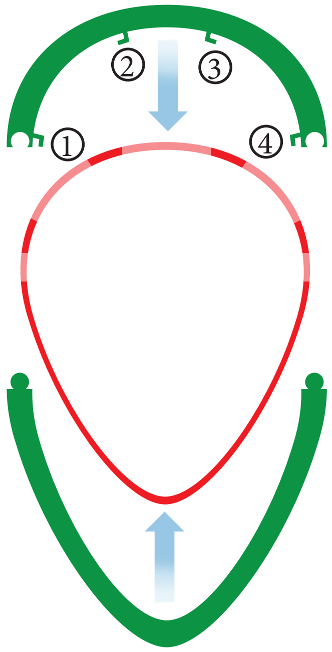


Illustration 71.1 - Splitting horizontally

The snap-fit has to fasten the three parts together and function as one rib. The bottom rib is designed to lock the construction when the top ribs is pressed on it, as seen on illustration *71.2*. Both top ribs are identical, which means they can be produced in the same tool. This reduces the cost of handling the items and the costs of tooling.
The bottom rib is designed as one part, which enables the lock of the two top ribs. Making it as one part also increase the strength of the rib.

In each top rib four snap-fits are applied as seen on illustration 71.1. When the ribs is snapped together around the pipe, the four snap-fits is pressed through the penetration holes and subsequently locks the inner pipe firmly to the rib. This ensures the correct position of the rib relative to the pipe. In the same time they also ensure that all the water that has penetrated through the filter will be served directly into the drain. This can be seen on the 3D-printed model on illustration *71.3*.

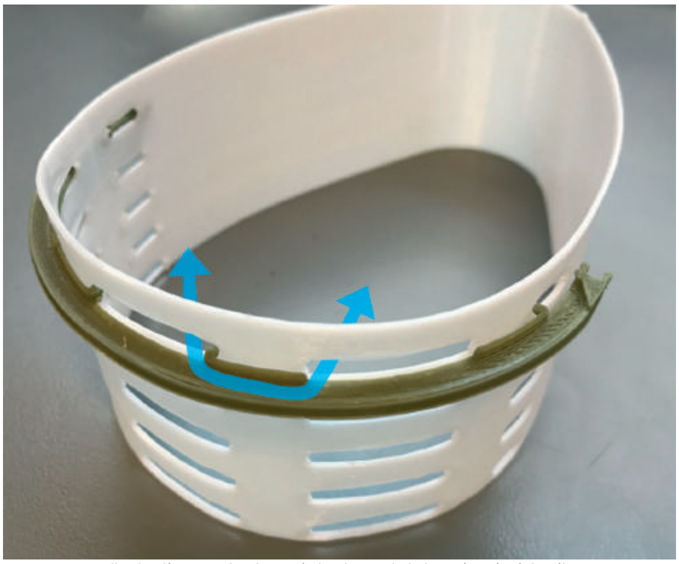


Illustration 71.3 - 3D-printed model showing inside rib

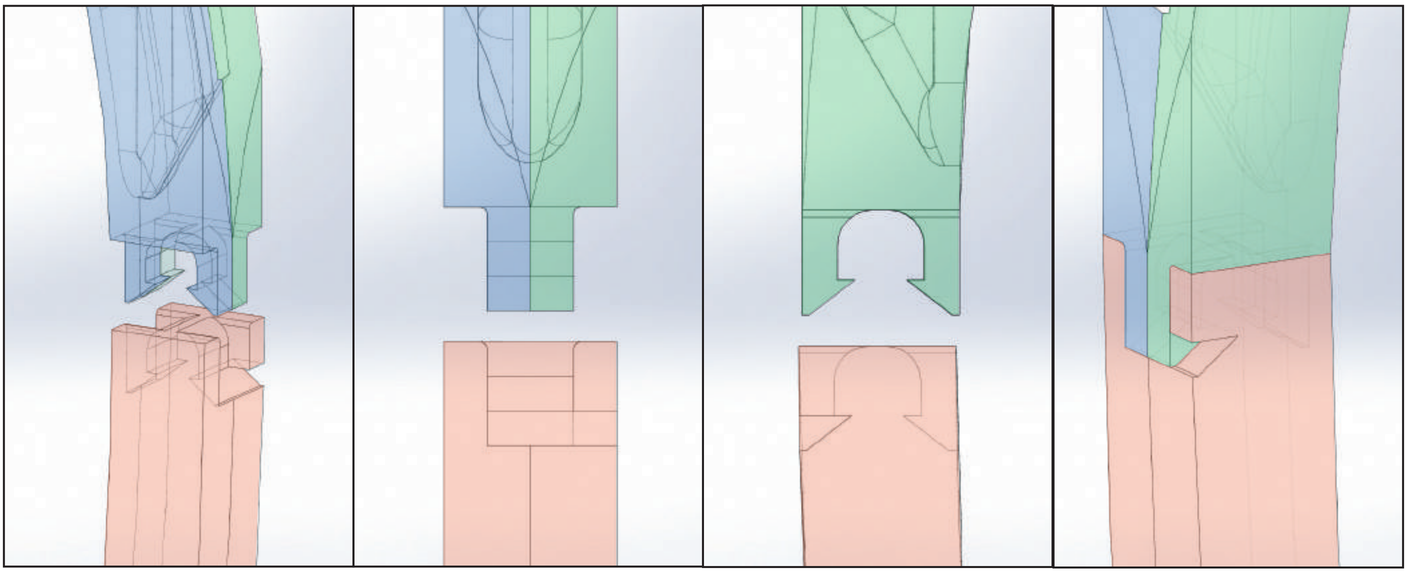


Illustration 71.2 - Snap-fit for locking the rib - Three components, two top ribs and one bottom rib

5.10 WATER PENETRATION

This section describe the size of NXD Drain's penetration area. The areas are calculated through the CAD-model and compared to two existing drains penetration areas.

With the final design of the ribs it is possible to calculate how much water the drain can handle. The numbers will be compared with the two competitors, a corrugated drain with the outer diameter on 80 mm and the inner on 71,5 mm and a top slotted drain with ribs outside and a smooth surface inside with a diameter of 105 mm.
While the bottom rib is made as one solid part, the top rib is the only one with the penetration holes as seen on illustration 72.1. The area of the penetration groove, number 1 on illustration 72.1 is:

1:	144 x 1	= **144** mm^2

This means the penetration area is 144 mm^2.

The penetration area of the inner pipe is calculated by the sum of the five holes area as seen on illustration *72.2*. Number 2 and 6 on the illustration is identical with each an area of 28 mm^2. Number 3,4 and 5 on the illustration is similar with each an area of 67 mm^2.
Finding sum of the penetration area:

2,6:	28 x 2	= 56 mm^2
3, 4, 5:	67 x 3	= 201 mm^2
1, 2, 3, 4, 5, 6:	56 + 201	= **257** mm^2

The penetration area is compared with the two exicting drains. The corrugated drain has five holes dimensioned 1,8 x 10 mm for each hole. The smooth drain which has four holes dimensioned 1 x 20 mm For each hole. This means the existing drains has a penetration area on:

Corrugated drain

1,8 x 10	=18 mm^2 x 5 pcs.	= **90** mm^2.

Top slotted drain

1 x 20	=20 mm^2 x 4 pcs.	= **80** mm^2.

Comparing the ribbed drain which has the largest penetration area on 90 mm^2, with the 144 mm^2 from NXD Drain gives an increased water penetration of 60 %.

Illustration 72.1 - Penetration groove between the two top ribs

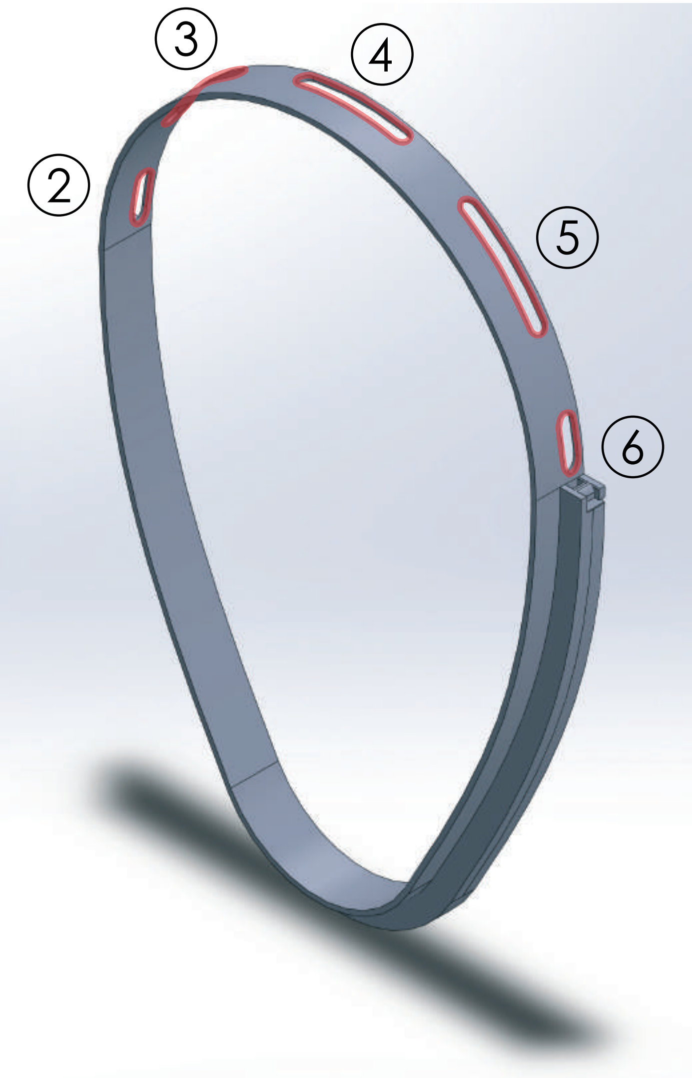


Illustration 72.2 - Penetration holes whitin the inner pipe

5.11 FITTING

The following section is explaining the development of the fitting for connecting the NXD Drain. Acting out is used to give hands-on experience of how the existing drains are connected, and ideas to what can be changed. This section is based on: Empirical knowledge from visit and Acting-out (Sperschneider and bagger, 2003).

The fitting for connecting the corrugated drain, can be seen on illustration *73.1*. Connecting the corrugated drain was observed through the second visit at Skjoldager dræn & entreprenørforetning.

The fitting for connecting the smooth top slotted drain, was tested by the team NXD through acting out. As shown on illustration 73.2, the pressure needed for snapping the drain into the fitting required a very high pressure. No one from the team could achieve it without flipping the drain from horizontal to a vertical pressure.

When using the fittings in the context, the drains are laying on the ground or in the trench when two pieces have to be connected. It means that they can not flip the drain to achieve the needed pressure for snapping the drains together. It could also be concluded through the visit at Skjoldager that they could not obtain the necessary pressure to snap the fittings together with the drain. Instead of using the snap function in the fitting, was their coping strategy to seal the connection with several rounds of gaffer tape as seen on illustration 73.3.

The fitting should be possible to attach with drains laying horizontal on the ground or in the trench. Through the gathered knowledge is the team trying to re-design the fitting to use its functionality.

Illustration 73.1 - Fitting for ribbed drain

Illustration 73.2 - Test of fitting for smooth top slotted drain

Illustration 73.3 - Gaffer tape as coping strategy

To get an idea of how the interaction with the fitting is, did the team acting out a scenario. The interaction turned out to be uncomfortable for the body as shown on illustration 74.1. Through the acting out was the team ideating on a new attachment approach. The team found the best way of connecting the fitting by using the body weight. Thereby, using the same snap function as developed to the rib, allows the contractor can stand on top of the fitting as shown on illustration 74.2.

Between the two connected pipes is a protuberance on one millimeter. This is made for matching the inner diameter which means that the fitting will not cause turbulence or disturb the flow in the drain, see illustration 74.3. The fitting is intended as a product where NXD Sight is incorporated. To prepare the fitting to NXD Sight is the protuberance made 20 mm wide. This allows space for incorporating the technology for NXD Sight.

Illustration 74.1 -Uncomfortable Snap-fit for body

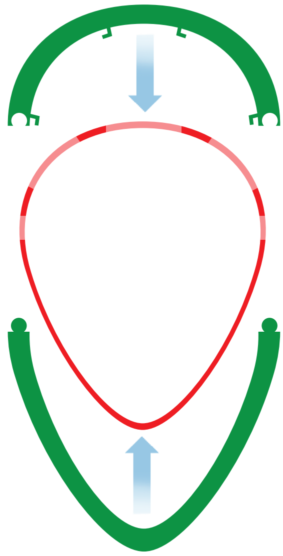
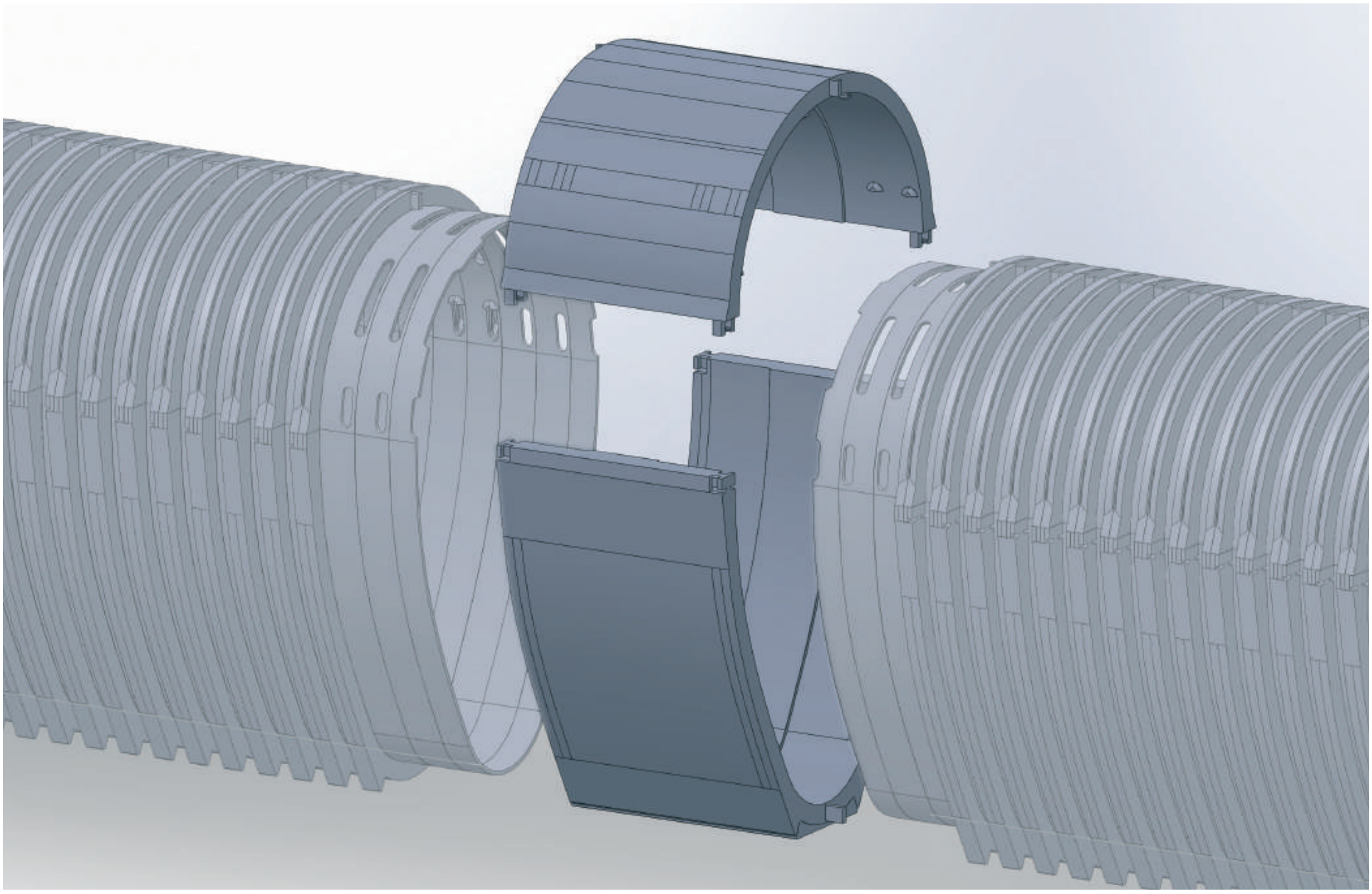


Illustration 74.2 - Snap-fit principle from the rib



5.12 STAKEHOLDER EVALUATION

The following section describes an evaluation of the NXD drain at two stakeholders: Farmer Gunnar Laden and Consultant Christian Christensen from LandboNord. As the product almost was done, was the team in need of evaluating the product with specialist within drainage and arable production. The evaluation had the purpose of getting the last comments to the product and business.

Visit at LandboNord

A visit is conducted with Christian Christensen from LandboNord. The purpose was to evaluate the NXD Drain and get final comments on the product and business associated with it. Christian pointed out that he liked the product and the vision of the project. He got following constructive comments to the drain:

- The drain need a sign which shows the contractor when the drain is placed right.

Christian got following comments to concept soil monitoring:

- The concept can create value for researchers as the politician blames the nitrogen emission to the farmers due to drainage. But the allegation is without a evidence of the emission comes from the drain. As the concept monitors the water-flow becomes the emission of water to the stream known. As this can be a help to researchers to determine the emission is it possible to the farmers to raise economic support from the state.

Visit at Gunnar Laden

A second visit was conducted at Gunnar Laden. The purpose of the visit was to get feedback on the NXD drain. The reason of getting an evaluation by Gunnar, was because of his knowledge about drainage.
Gunnar really liked the product and rethink of a traditionally drain pipe.

Gunnar Laden:
"This is geniuses!"

Gunnar got following constructive comments:

- Why is the pipe flexible? As the excavator is pulling the drain-box is it laying the drain uneven as shown on illustration 75.1.

Illustration 75.1 Result of flexible drainpipe and drain-box .

5.13 IMPROVEMENT OF RIBS

This section unfolds the last detail on the ribs. Through evaluation with stakeholders did a few important detail occurred. This section is based on: Interview with stakeholders and CAD-modeling

Though the visit and interview of consultant Christian from LandboNord and farmer Gunnar Laden was two details to the product pointed out. Christian emphasized the importance of visual indication of the drain is placed right. This started a ideation of how the drain can be placed where the contractor knows it is placed right. Through the visit and interview of consultant Christian from LandboNord and farmer Gunnar Laden, was two details to the product pointed out. Christian emphasized the importance of visual indication of the drain is placed right. This started a ideation of how the drain can be placed where the contractor knows it is placed right. The result is support feets on the bottom rib as shown on illustration 76.1. The support feet enables the drain to stand by itself.

Gunner pointed out the importance of stiff pipes compared to a corrugated pipe. The corrugated pipe will be placed unevenly by using drain box, resulting on affecting the slope as shown on illustration 75.1. A stiff pipe would keep the slope straight in the trench when it is placed. The team got the idea of making the drain flexible in the vertical direction and rigid in the horizontal level. This combination ensures a straight slope of the drain when it is implemented with drain box, but also a flexible drain when controlling the direction and to still get the drain in rolls. The result is pins placed on the rib as shown on illustration 77.1.

Illustration 76.1 - New rib shape to ensure the drain is placed right.

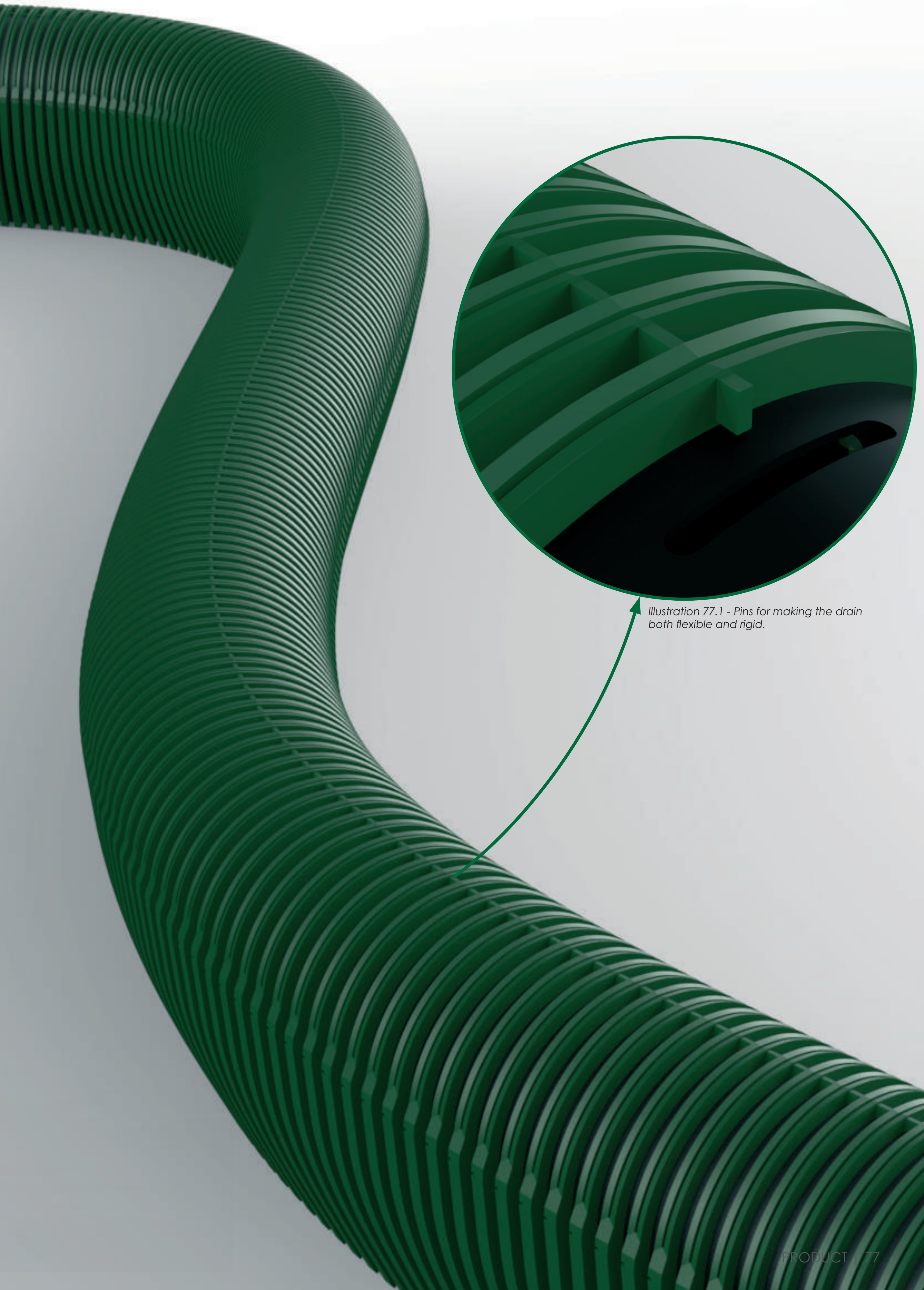


Illustration 77.1 - Pins for making the drain both flexible and rigid.

6.0 IMPLEMENTATION

THE IMPLEMENTATION SECTION UNFOLDS THE BUSINESS ASPECT FOR THE NXD DRAIN AND NXD AS COMPANY. FURTHER, IT UNFOLDS A SUPPLY CHAIN OVERVIEW, A DETAILED BUSINESS MODEL, PRODUCT COST AND BUDGETING.

6.1 MANUFACTURING

The following section will sum up the manufacturing of the different parts. The materials used for the parts is unfold as well is the production line. This section is based on: visit at Letbæk Plast.

The production of NXD Drain require two main production stations; injection mold and plastic extrusion line. The following machinery cost is estimated by Letbæk Plast.

Ribs

Section 5.5 describes the ribs and how they are separated in order to reach the requirements. This is resulted in two parts which have to be injection molded as shown on illustration 79.1 and 79.2 . As the drain require 100 bottom ribs and 200 tops per meter is a robot placing and preparing the ribs to connected to the inner drain shown on illustration 79.4.

ABS is chosen as material to the ribs due to the ability to injection molding but also because of the strength advantage. Tool cost: 100.000 DKK each part.

Illustration 79.1 - Top rib

Illustration 79.2 - Bottom rib.

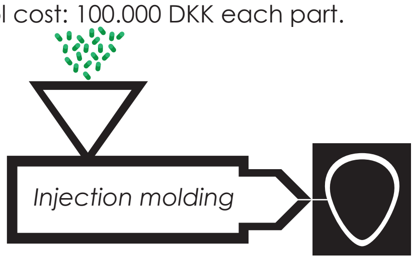


Illustration 79.3 - Injection molding.

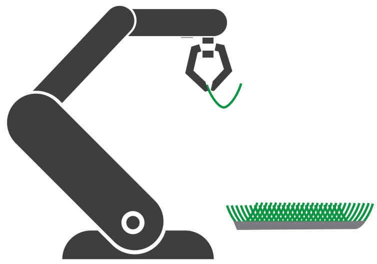


Illustration 79.4 - Robot placing rib in magazine.

Pipe

As the inner pipe has get a long length is extrusion chosen as production method. The disadvantage of the extrusion is a prototype tool has the same price as a real tool.

The inner pipe is made by PVC. PVC is suitable for extrusion further is the e-module able to make the drain flexible.

Tool cost: 325.000 DKK

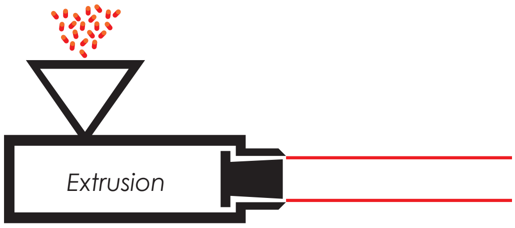


Illustration 79.5 - Extrusion of inner pipe.

Illustration 79.6 - Inner pipe.

Production line

The production line is divided in four stations as shown on illustration 79.6:

1. Extrusion of inner pipe
2. Machine for making penetration holes
3. Robot for placing ribs
4. Roll up/packaging machine

Section 6.3 describes the product cost related to this chapter.

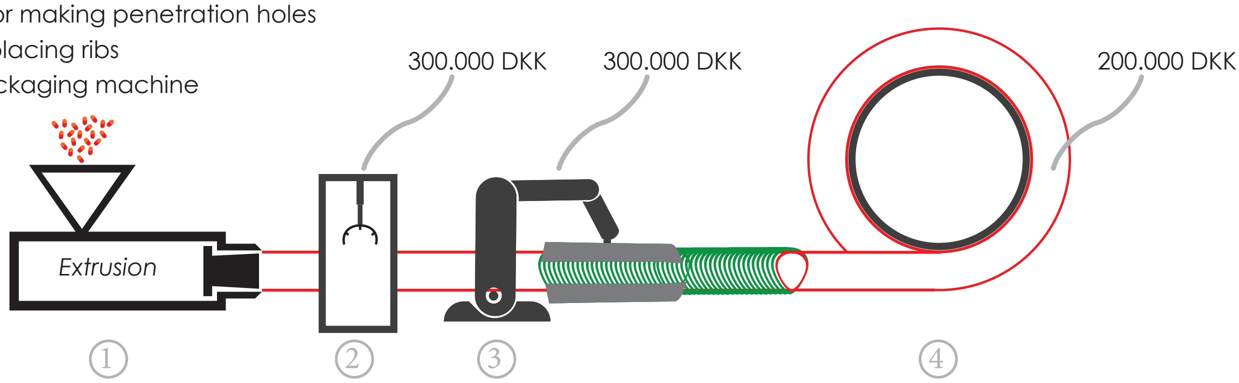


Illustration 79.6 - Production line.

6.2 LOGISTICS

This section unfolds the logistics associated to NXD drain. This is used for calculating a product price but also to determine the size of a roll drain. This section is based on: Research and networking.

Some requirements from the target specification is:

1. The roll has able to lift by the contractors (30 kg).
2. The roll has to fit the existing mount on excavator (Ø 600mm).
3. It has to fit the dimensions of a truck trailer to ship as less air as possible.

The freight is done by a 28.000 kg trailer. The dimensions of the trailer is shown on illustration 80.2.
From the production section is it possible to determine the length of the drain at 30 kg. As one meter drain got a weigh of 1.32 kg is the roll limited to maximum **22.7 meters** drain.
The 5 mm space between the ribs allows the pipe to roll in a circle of 695 mm which full fills the requirement of mount from the excavator.
The width of the truck is 2.48 meters. This allows the drain to be rolled two rounds which results in a roll width of 1.22 meter. Meaning two rolls can be placed in the width and 11 in the length as shown on illustration 75.1. The height of the truck is 2.7 meters which results in four rolls can stand in top of each-other as shown on illustration 75.2.
Through the calculations the team can conclude that the roll will have a length of 22.7 meters distributed on a outer diameter of 1.22 meter and height of 0.60 meters as displayed on illustration 75.3.

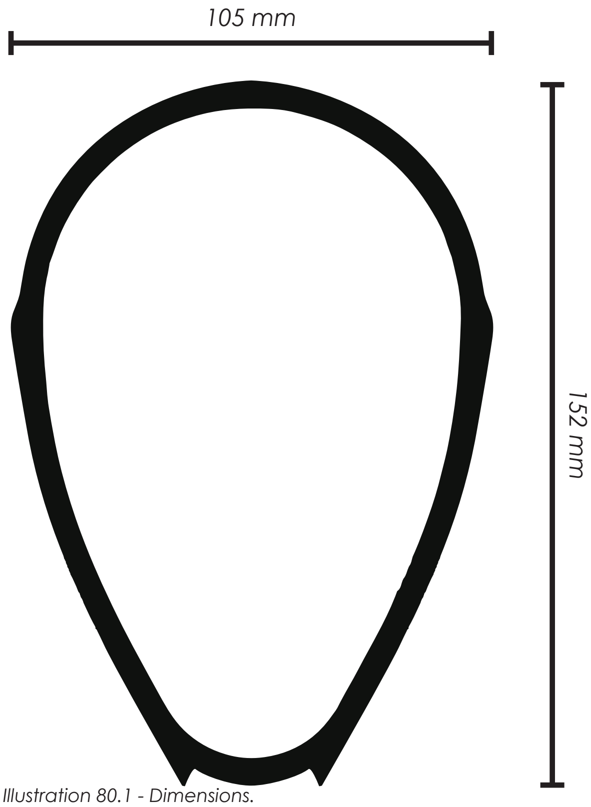


Illustration 80.1 - Dimensions.

Offer from contact at DHL
By getting in touch with DHL,the team got an estimation of the cost of the logistics. A trip from Aalborg to Copenhagen (416 km) with a 28.000 kg trailer is estimated to 5500 dkr. ex. vat. This makes an average cost of transport to 13.22 DKK per km.

The team can transport 1998 meter drain on one trailer. This makes the average cost of logistic for one meter to **0.0066 dkk. ex. vat**.

Illustration 80.2 - 28 ton truck trailer.

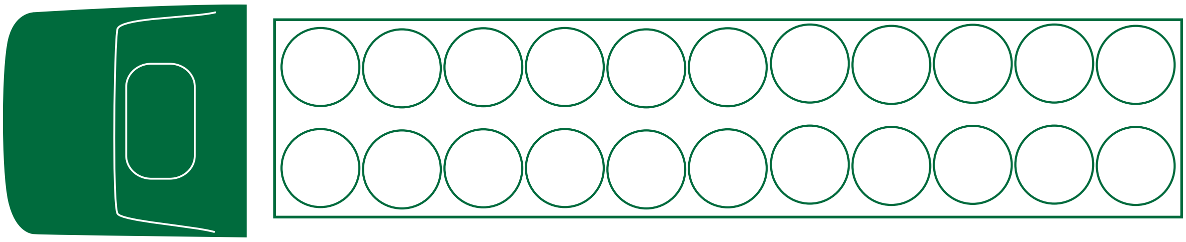


Illustration 81.1 - Truck trailer top view.

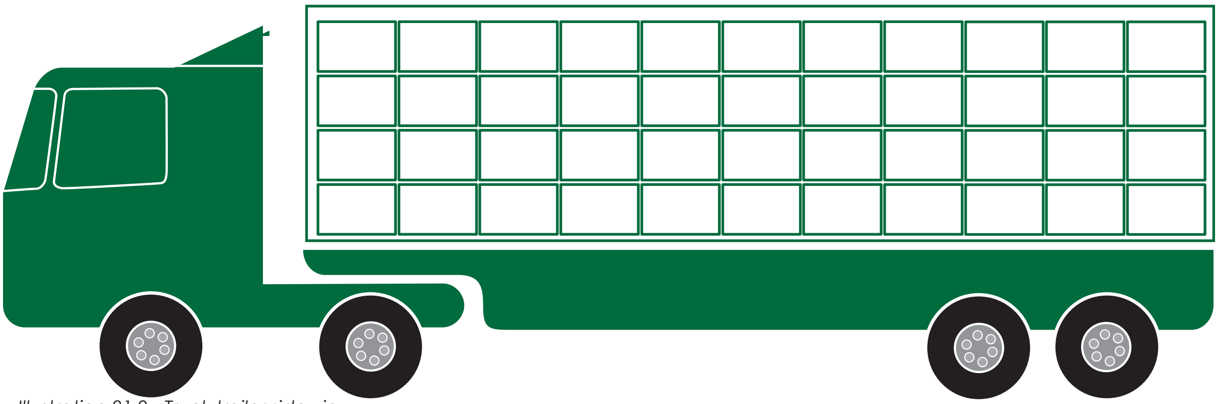
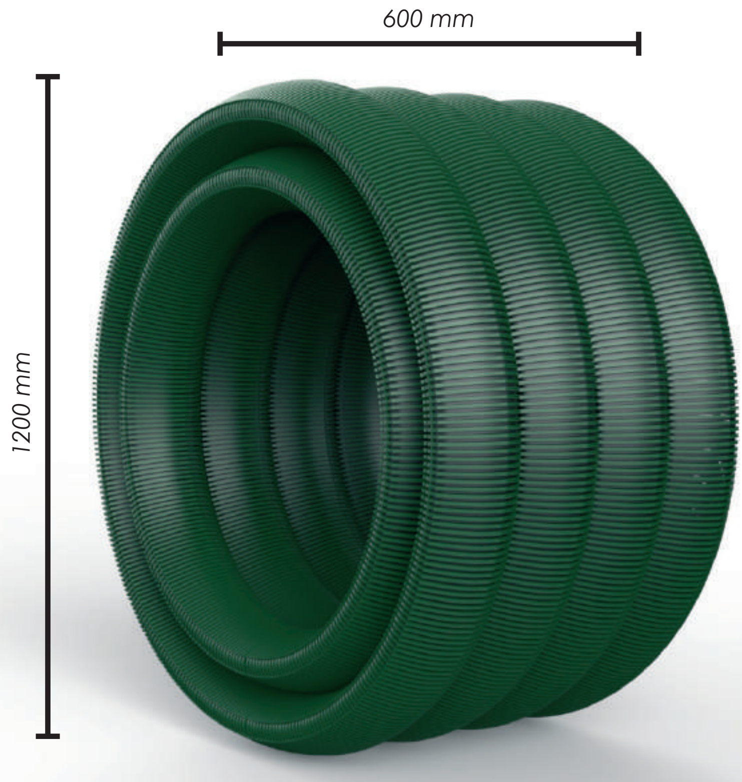


Illustration 81.2 - Truck trailer side view.

Illustration 81.3 - Final roll dimensions.



6.3 PRODUCT COST

The following section unfolds the strategy of NXD Drain. The section provides information of product cost, targeted market size and return of investment to both an investor and farmer.

NXD is aiming for market share of 5% in a time-line of three years from product launch. This means that NXD has to deliver drain pipes to 1350 hectares on year three.
To calculate the break-even of the investment and our customers return of investment is an estimation of the product cost done. To make the business case realistic is Letbæk Plast used as a case for manufacturing. Letbæk Plast could offer following:

At orders of 100.000

Tools

Bottom rib mould cost: 100.000
Top rib mold cost: 100.000
Innerpipe tool cost: 250.000 - 400.000

Extrusion

Innerpipe: 9.5 dkr/meter

Injection molding

Injection mold	2 cavity	8 cavity
Top rib	1.6 DKK.	0.7 DKK.
Bottom rib	2.8 DKK.	0.99 DKK.

Product total cost

As the drain require a high volume of ribs is the 8-cavity mold chosen. The parts needed for one meter drain: 200 top ribs, 100 bottom ribs, and 1-meter innerpipe. This makes the product cost of one meter to: **248.5 DKK/meter.**

The production price is far higher than expected. This eliminating outsourcing of the injection molded parts in Denmark. As the estimation from Letbæk Plast was received close to project deadline was it not possible to get an estimation from a low wage country. However, through the network of the team was an second rough estimation from Idé-Pro received.

Injection mold	2 cavity	8 cavity
Top rib	0.8 DKK.	0.24 DKK.
Bottom rib	1.38 DKK.	0.44 DKK.

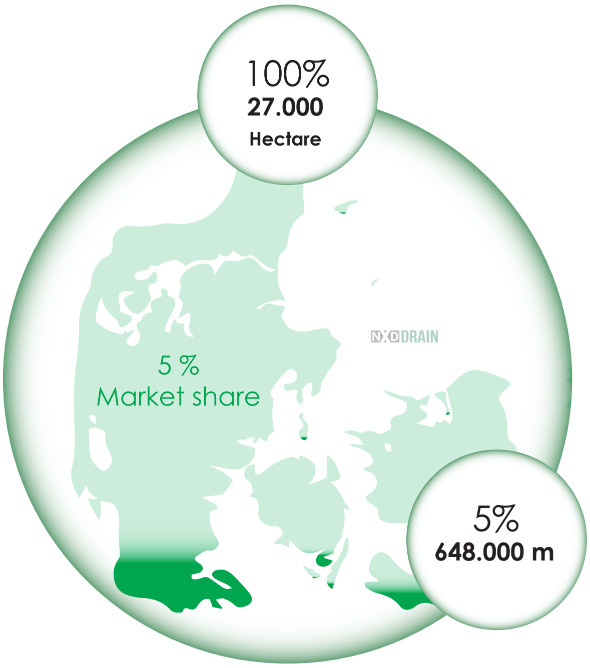
The product price based on Idé-Pro is: **101.5 DKK/meter**
As the production of the injection molded is a large mass-production did Idé-Pro supervise the team to look for production facilities in China. The tool and production is cheap in China and is approximately 40% cheaper.

The top rib got the weight of 1.21 g and the bottom rib 6.32 g. As it can be seen on the production cost is the bottom rib almost twice as expensive as the top rib. This is due to the weight and thereby the cooling time in the injection mold machinery. For further development is it essential to look further on design of bottom rib to decrease the material used.

As the team not were able to get an offer from production facilities in China, is the offer from Idé-Pro used to estimate the return of investment. Even through the production is intended China.

Drain need for one hectare

Section 2.6 explains Gunnar Laden drainage approach. Gunnar is only using 1/3 of drain pipe due to his drainage depth of 2 meters. As the NXD Drain can penetrate 60% more and thereby create a higher water flow is the team advising the arable farmer to drain in a depth of 1.5 meter. Meaning one hectare in averagely needs 480 meters NXD Drain. The estimation is depended on the soil type, where soil with low capillary action, as sand fields, still needs to place their drain in a hight of 1 meter to make sure the roots can get water as described in section 5.6.



Investment

Table 83.1 displays the investment associated with the NXD drain. It estimated that the product needs approximately one year of development. This is to develop the NXD Sight and further detail NXD Drain to lower the production cost. But also to make necessary tests, "Landstest", to get the possibility for farmers to raise funding for their drainage project.

Activity	Price in DKK	Comment
Development 1 engineer	408.000	1. year
Consulting	500.000	
Tools	325.000	
Machinery	800.000	
EU Design Registration	5.675	
EU Trademark	10.875	
Total	2.049.550	

Table 83.1 - Investment.

Setting the product sales price to 105 DKK is the break-even in year four as shown on table 83.2.

Priceses in DKK	Market share	Turnover	Variable cost	Contribution Margin	Balance
Year 1	0%	0	0	0	-2.049.550
Year 2	1%	13.608.000	13.154.400	453.600	-1.595.950
Year 3	2.5%	34.020.000	32.886.000	1.134.000	-461.950
Year 4	5%	68.040.000	65.772.000	2.268.000	1.806.050

Table 83.2 - Return of investment.

Looking on the investment with the glasses of a farmer, does the product sales price seem a bit high. But with increased performance and the ability to lower the amount of drain, is the material investment to the farmer **50.400 DKK per hectare.** The return of investment is shown on illustration 83.1.
With a perspective in a production in China is the team predicting a price to 30.240 DKK/ha. Meaning the year of ROI can be decreased to 22 years.

Even through the year of ROI is high when producing in Denmark, is the NXD Drain cheaper in the long run. This is because NXD Drain last longer than the corrugated drain and it require less maintenance. Table 83.3 shows that NXD Drain, based on the Danish production, is creating more money to the farmer in year 47.

Year	Corrugated	NXD
46	18.998 DKK	18.260 DKK
47	19.824 DKK	20.086 DKK
48	20.650 DKK	21.912 DKK

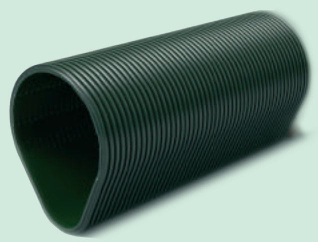
Table 83.3 - Earn money on

Corrugated Drain

12 DKK/m
9600 per hectare

Investment	Hectare
Contractor	10.000
Drain	9.600
Total cost	**19.600** DKK
	DKK/Year
31% Increased yield	1.826
Maintain/1 year	-1.000
Total	**826** DKK
ROI	**23,7 Years**

NXD Drain



105 DKK/m
50.400 per hectare

Investment	Hectare
Contractor	10.000
NXD Drain	50.400
Total cost	**60.400** DKK
	DKK/Year
31% Increased yield	1.826
Maintain/5 year	-200
Total	**1626** DKK
ROI	**37,1 Years**

Illustration 83.1 - Investment for farmers.

6.4 VALUE CHAIN

The following section explains the value chain associated with NXD Drain and NXD Sight. The values to the stakeholders are explained and illustrated.

In: The farmer has requirements to the products from NXD as their customers make environmental demands to the arable farmer.
Out: NXD delivers products for arable farming. NXD Drain is going to fully utilize the crops. NXD Sight makes an insight in the drain condition and further, it provides the farmer and researchers with valuable data about the soil condition.

In: Knowledge from NXD about drainage.
OUT: Provide arable farmers with NXD Drain and NXD Sight.

In: The researchers are state-owned companies, as SEGES. The DATA from NXD Sight is valuable as they can see the water emission in the streams, and thereby determine where the emission of pesticides originated from.
Out: Data about water outlet in the streams or lake to the researchers. The data can be used for determining who are emitting pesticides, ocher, and chemicals. Requirements to NXD about materials, functions, and cost.

In: The researchers are state-owned companies, as SEGES. The DATA from NXD Sight is valuable as they can see the water emission in the streams, and thereby determine where the emission of pesticides originated from.
Out: Conclusion for political decisions.

In: A feeling of getting food products where they know the crop is utilized 100%.
Out: Stands according to food and environment.

In: Stands from consumers. Knowledge about emission of chemicals into stream and lakes. The data is used for political decisions according to arable farming and environmental change.
Out: Rules and guidelines to arable farming. Founding to farmers for buying products like NXD Drain and NXD Sight as they provide valuable data according to the environment.

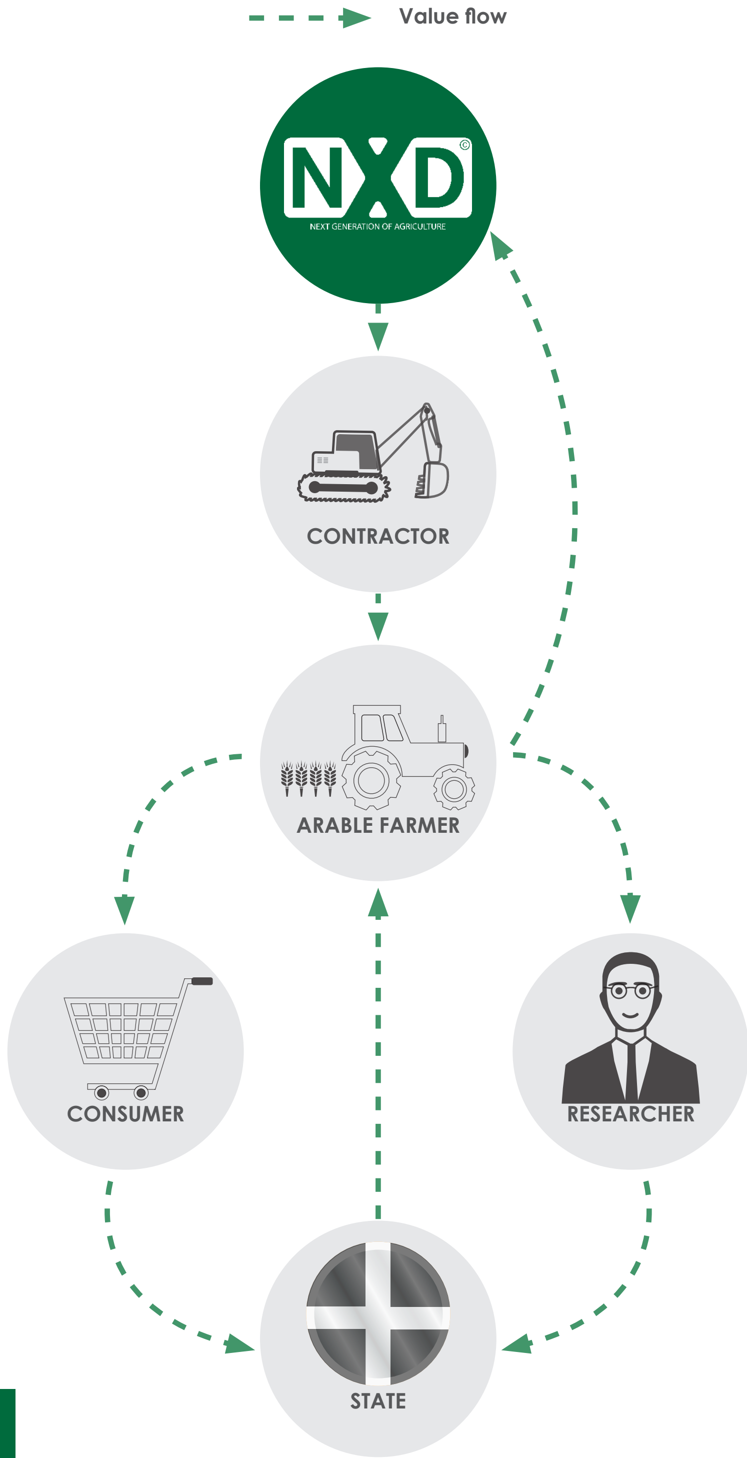


Illustration 84.1 - Overview of value chain with relations.

This section gave an overview of the value chain. It can be concluded that even through NXD is providing the products to the contractor is the main values targeted the arable farmer, researcher and in the end the consumers. The requirements from the farmer to NXD is highly depended on stands from the consumer and state. Further, is NXD depended on providing environmental data and products to make the farmer able to get economic support from the state.

6.5 SUPPLY CHAIN

The following section displays the supply chain of NXD Drain. The supply chain is made to get an overview of the customers and suppliers. This section is based on: Research.

Suppliers

Illustration 85.1 unfolds the supply side of NXD drain. The team have decided to outsource the production of NXD Drain. This is partly because of the manufacturing methods not have any strategically importance and partly because of the volume which has to be manufactured (Slack, et al., 2010). The pros of outsourcing the NXD Drain is that the supplier have more experience and knowledge of the different operation required. As well the flexibility might be better as the supplier may be larger with more capabilities than in-house production. This is a benefit to NXD as drainage require a large amount of drain in specific periods. Some of the cons of outsourcing can be the control of the production. In example can a larger costumer control supplier. This can have consequences of our production as NXD is lower in the hierarchy.

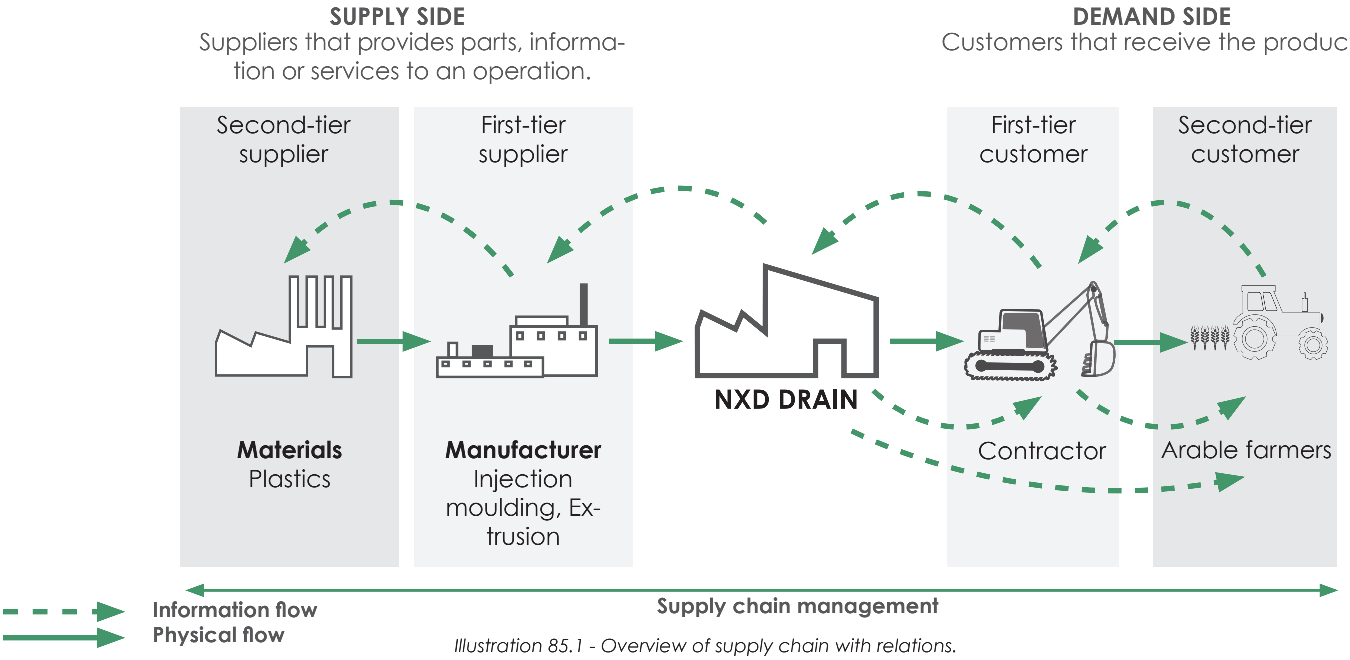


Illustration 85.1 - Overview of supply chain with relations.

Flow

The physical flow from the second-tier supplier is materials which is needed for the injection moulding and extrusion. Where the manufacturer, first-tier supplier, delivers the finished product to NXD. NXD distributes the drain to contractors and are reaching the end-user, the arable farmer, through them.

Beside the physical products, is NXD in charge of teaching and explaining both the contractor and arable farmer with knowledge and information about drainage. This has to ensure that a proper drainage with NXD Drain is done.

6.6 BUSINESS MODEL

This section displays the business model of NXD. The busniess plan is based on both NXD Drain and NXD Sight. This makes an overview of the whole NXD busniess and activities. The model have been used to create an overview of the different perspectives within the organization. The model was a great tool to align within the team. The business model is shown on Illustration 52.1. The section is based on: Desktop research, Business Model Canvas(Osterwalder & Pigeur, 2010).

CUSTOMER SEGMENT

Niche market: The NXD Drain is targeted a specific customer group; contractor and farmer.

Multi-sided platform *(i.e. serving multiple customer witch is interdependent)*: The multi-sided platform is with eye on NXD Sight. The researchers (SEGES) is interdependent of the farmer to get data about the water emission to the stream. As well, is the farmer interdependent of the researchers to get economic support for implementing the product.

VALUE PROPOSITIONS

Performance: NXD Drain increases the yield and thereby the harvest of the crops. Beside this, is NXD drain improved in water-flow, strength and sediment filtration.

Newness: NXD Drain and NXD Sight transforms drainage from a passive tool to an active tool by providing important soil and drain information to the farmer and researchers.

CHANNELS

Direct(Web sales and sales force): Sales men will contact and seek for contractors to use NXD Drain.

Indirect(Partnership): Sale though partnership with researchers (SEGES) and in combination with other products for precession farming.

CUSTOMER RELATIONSHIPS

Personal assistance: The sales man will represent NXD and is a direct link to the customer. Beside this, is customers and researcher able to contact the research and development team at NXD.
The contractor is the link to the end-user which will assist the farmer in the choose of drain.

REVENUE STREAMS

Asset sales:
The contractor is buying the NXD Drain as asset sale. Possible to decrease price based on volume.

KEY RESOURCES

Physical: NXD has to deliver a high amount of drain when the field condition allows drainage. This require the manufactures to deliver in time and NXD to store the drains.
Intellectual: The NXD Sight data is depended on partners which has to pass on the data to the farmer.

KEY PARTNERSHIPS

Optimization and economy of scale:
Supplier and manufactures of NXD drain. The NXD Drain is depended on the production resources from the manufactures. This has to be optimized and scaled according to the growth of NXD Drain.
Software consultants who has to maintain and update NXD Sight to stay tuned in the precision faming.
Department of Agriculture and Food is a key partner as they is using the data from NXD Sight for researching.

KEY ACTIVITIES

Research and development: Further development of precision farming and the data behind.
Research incorporation with state: Based on the data, conclude import evidence for water and nitrogen emission to streams for politician purposes.
Sales and distribution: Sale and distribute the products to customers.

COST STRUCTURE

Cost-driven structure:
An large cost is manufacturing which is in the cost-driven category as the product has to fit a production to keep down the implementation cost to the farmer.

Value-driven:
NXD Sight is creating a value to the farmer and researchers therefore is the manufacturing and software maintenance not that cost depended compeered to the drain.

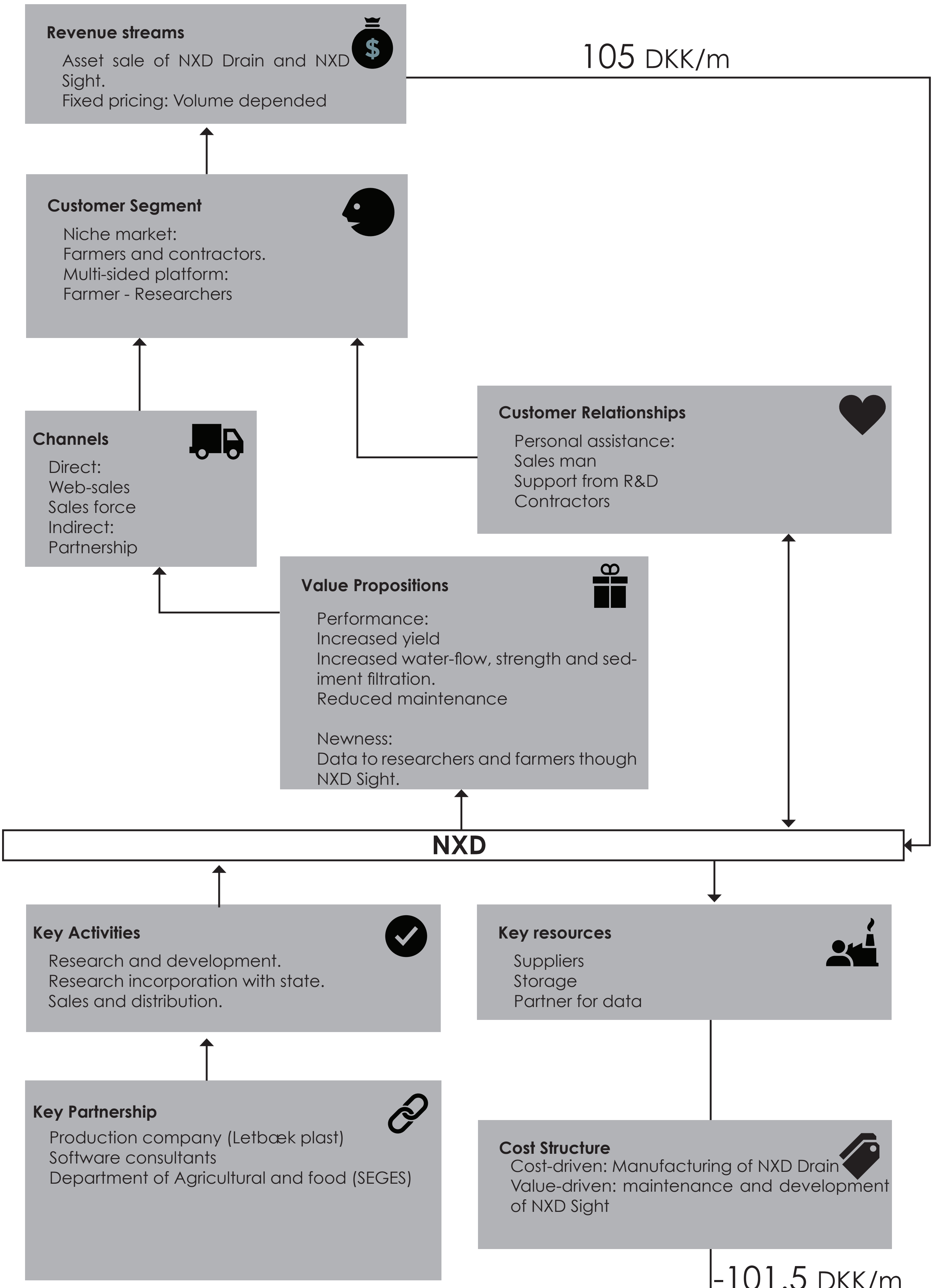
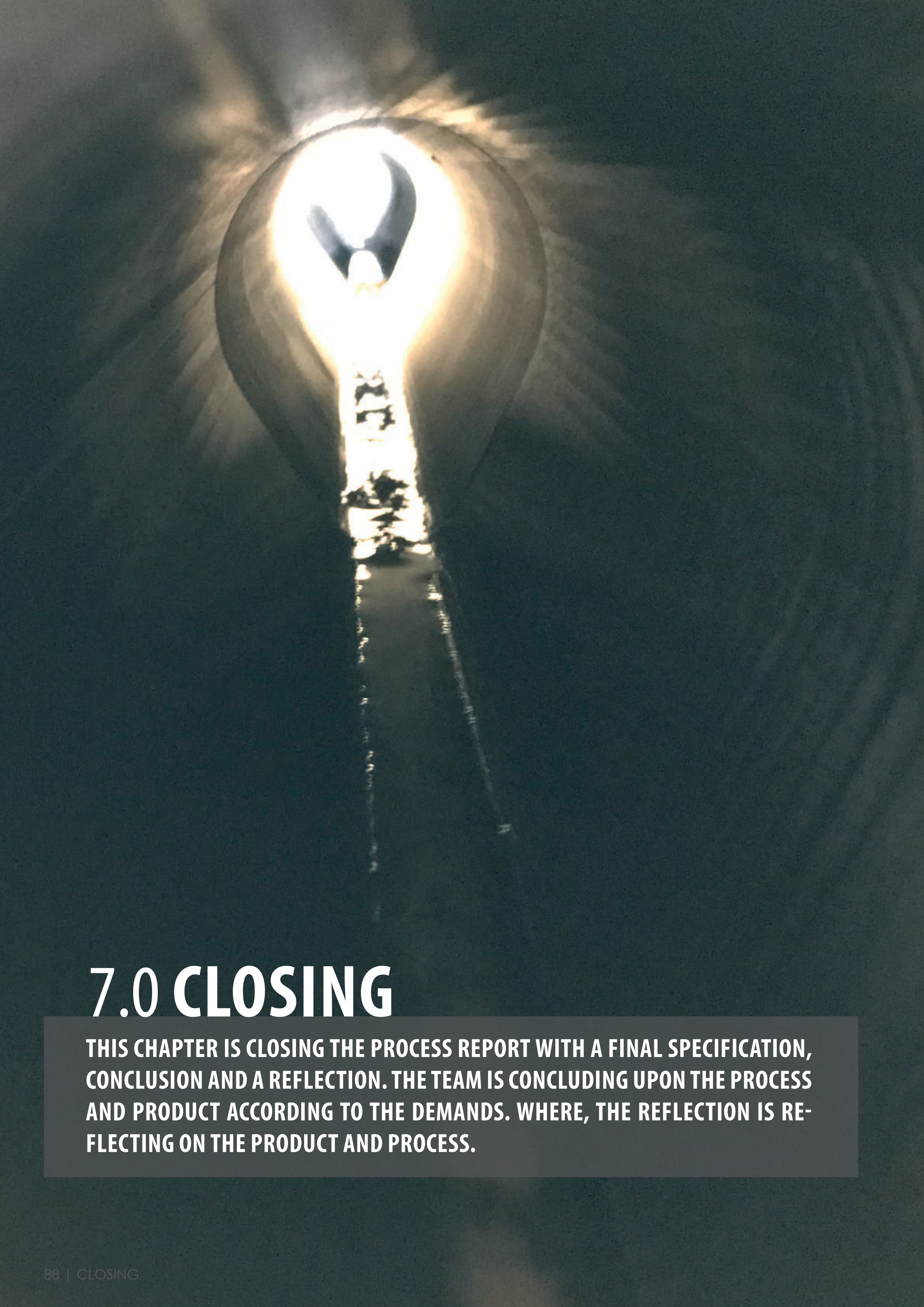


Illustration 87.1 - Business model overview



7.0 **CLOSING**

THIS CHAPTER IS CLOSING THE PROCESS REPORT WITH A FINAL SPECIFICATION, CONCLUSION AND A REFLECTION. THE TEAM IS CONCLUDING UPON THE PROCESS AND PRODUCT ACCORDING TO THE DEMANDS. WHERE, THE REFLECTION IS REFLECTING ON THE PRODUCT AND PROCESS.

7.1 PRODUCT SPECIFICATION

FINAL SPECIFICATION			
No.	Metric	Units	Value
NXD DRAIN			
1	Size of penetration holes	mm^2	144
2	Implementation cost	DKK/ha	50.400
3	Lifetime of drain	years	>60
4	Speed of 1 litre water on 1 meter (Water flow)	m/s	1.1
5	Inner drain size	mm^2	9534
6	At least one point Drain diameter	mm	>40
7	Resist flushing at 200 bar	Binary	Yes
8	Resist applied pressure (10cm)	N	1400
9	Diameter of a roll	mm	
10	Weight of roll	kg	30
11	Surface roughness inside drain	mm x mm	
12	Distance of ribs	mm	5
13	Plastics can be separated	Binary	Yes

7.2 CONCLUSION

This master thesis project has focus on the development of a design solution for the agricultural sector. The project team, NXD simulates a startup development company, which are dealing with design solutions and innovation within the farming industry.

The early focus of the project was on construction sites. After the ideation of possible solutions, it was decided to look in other directions even though much knowledge and research was collected.
The agricultural sector was investigated as both team members have interest and a good understanding of the context. Trade magazines were explored to get an insight of real dilemmas and highly debated topics. Drainage is highly debated as farmers are struggling with flooded fields and lost yield. As both team members knew people who are struggling with drainage, the team found the topic exciting to investigate.

Limited research is done within the drainage topic, and most of the knowledge is based on experience. This means the problems of drainage is based on empirical knowledge conducted through desk research, visits and interviews with stakeholders as contractors, farmers, organizations and agricultural consultants. According to Rittel and Webber, is the initial problem for the master thesis was a wicked problem, flooded fields, as it was ill-defined and open-ended (Rittel and Webber, 1973). Through the process, the team turned the problem into a tame problem solved through a quantitative development.

For decades the development of drain pipes has been low. Beside of few attempts to keep sediments outside the drain by adding a filter material surrounding the drain. This has resulted in new problems as clogged filters.
The best drain on the market for solving the problems is a rigid top-slotted drain, with a smooth inner surface, thus creating a larger flow. However, the usage is limited as the contractor's machinery cannot effectively implement it.
Many farmers are unaware of what makes a good and effective drainage of their fields. Through research, it can be concluded that proper drainage can increase the yield by 31%. One of the key parameters for farmers is the cost of drainage. Because contractors can drain time effectively, the corrugated drain is widely used, as it is the only drain fitting the machinery. NXD Drain enables an effective drainage implemented with the low-cost drainage methods.

The machinery for arable field operation has grown the last years. This has consequences to the drain as they have to resist a high pressure. Therefore the NXD Drain has an increased strength of 75% compared with the corrugated drain. NXD Drain is designed to: absorb 60% more water, increase the velocity by 15% in low flow situations, and in a combination of controlling the incoming corn size is it self-cleanable.

The team NXD has redesigned the traditional geometry used for drains. The new shape enables the NXD Drain to increase the velocity by 15% at low flow situations. The increased water flow ensures the penetrated sand is led away and thereby preventing sand blockades.

The fitting for connecting NXD Drains ensures optimum ergonomic movements while connecting the drain. The fitting are prepared for implementing NXD Sight. NXD intends to revolutionize the whole meaning of drainage. This is done with a vision of changing drainage from a passive tool to an active tool. The solution is aiming the trend - digital- and precision farming. NXD Sight is intended to provide the farmer with knowledge of his drain- and soil conditions. This will change the today's drainage from unpredictable to predictable, where the farmer can act before the field is flooded and thereby utilize the crop 100%. This gives the farmer the best opportunities to ensure the best possible condition for the crops and the environment.

7.3 REFLECTION

This section will reflect upon the master thesis process and product.

The use of SCRUM manages the master thesis project. SCRUM-sprints are planned 14 days ahead by using a Gantt chart. This provided an overview of the process and was the basis of the prioritized backlog. The backlog was visualized on the whiteboard as an active tool for delegating the tasks. The combination has worked well. However, the team missed more specific objectives of the different SCRUM sprints. The team progressed well according to the milestones as clearly defined objectives where expected. By creating more specified objectives doing the process could have resulted in higher progress doing the project.

With a reframe one-month within the project period the importance of finding an exciting and relevant topic was high. The importance of the reframe was essential to the team as the enthusiasm was decreasing. An important action was to kill the project theme and visions. Involving stakeholders early, made the team aware of the relevance of the topic. This created fast progress in the process and an increased the engagement to the project.

Doing the research, many important findings have been highlighted. These enabled the team to see and understand the most essential aspects of the project. The use of findings made the team able to create a need specification. As limited research have been made within drainage, has the findings and needs been used for aligning with stakeholders such as consultants and farmers. By gaining a wide knowledge of drainage was the team able to communicate essential findings and knowledge to contractors and drainage experts. This made the team feel as experts within drainage as the team equally knowledgeable as the experts.

The target specification is used to ensure the technical and functional requirements were met. Thereby, it has been a great guiding tool for the project. As the target specification is based on quantitative metrics, a need for an innovative approach occurred. The team decided to use the Product Reasoning Model for ensuring a radical change of meaning and soft value requirements. However, the early use of the tools created an interference, as the team had a hard time determining which innovation-vision they were describing. Using the tools in a period made the team able to define which kind of innovation each tool have to describe. The Product Reasoning Model - radical change of meaning. The target specification - performance innovation.

The research lead the team to a faster and shorter concept development period as usual. This is because the research defined specific quantitative demands to the product. Several attempts of unfolding the solution space radically happened, where the outcoming ideas very futuristic. To get a radical solution space could the team advantageously have revealed functions from bionics.

The end product full fills the demands specified, except for the demands related to NXD Sight which is delimitated. The team had trouble defining the water velocity. Several attempts of test to determine the velocity were executed. However, the team was not in possession of tools that could accurately measure the velocity. The proof of a higher velocity is based on former studies. For further development, it will be beneficial to make a large scale test, proofing the drain performance.

To make the master thesis project realistic and to keep the opportunities for the team to proceed with the project after closing the school project, the team has contacted Letbæk Plast. They were selected as the manufacturer for NXD Drain, as they have the needed facilities for producing it. Through meetings with their head of R&D, Martin Holm, the team was told that the solution could be made very cheap as we need a high volume of parts. A problem appeared first in the very end of the project when the offer on the production was presented. The alignment between Martin and the team was not identical in comparison to the price. The team compared the price to the meter price of the existing drains, where Martin compared the price to other products in the same dimensions.
In hindsight, an aligning regarding expectations about the price would have been beneficial. This has been brought as learning for future projects.
However, a fast estimate of the component cost from Ide-Pro, made clear that the team should have asked for an estimated price earlier in the process with Letbæk Plast. In addition, the team could have calculated the cost price of manufacturing in China for comparison.

NXD Sight

The intentions with NXD Sight is to change the whole meaning of drainage, from a passive product to an active tool for the farmer. It will provide the farmer with knowledge about the water flow within the drains and moisture of the soil outside the drain. As a solution like this requires power, the team see a potential partner in Fieldsense who already deal with data about the field, just above the surface. They will be able to deliver power and the platform of data which will provide the information to the farmer.

In addition to the farmer, there will also be an interest in the data from other organizations such as Seges, who develop, test and secure within, among others, the amount of nutrient emission. This will provide an opportunity to get economic support to the product from the state. This has to be investigated further as it could be a key to the strategy of how the product will be sold.

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7.5 LIST OF ILLUSTRATIONS

All illustrations is own illustrations beside:
5.1: Colourbox.dk
15.2: Olesen, 2009.
25.1: Olesen, 2009.
27.1: *https://www.youtube.com/watch?v=0wS2R26ofg8*
27.2:http://www.maskinbladet.dk/artikel/75-horte-om-draening-i-kolding
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50.1: Fieldsense.dk
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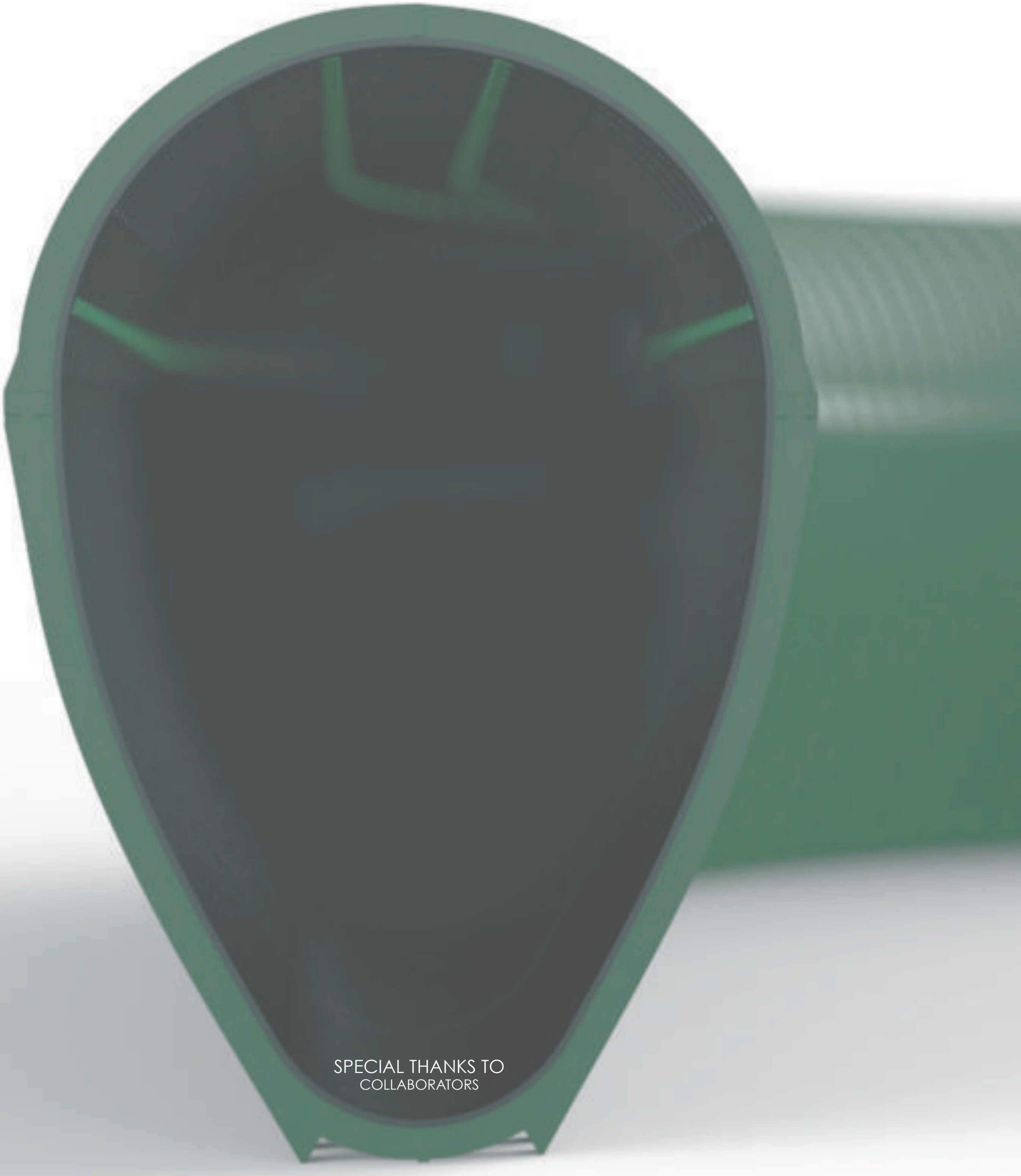

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