Controlled drainage

In controlled drainage, the groundwater is not immediately discharged but (partly) retained in the soil. By varying the level of the drainage basins, the draining intensity can be regulated.

1. Introduction

Traditionally, Dutch water management for agriculture has always been directed at rapid drainage and discharge. Conventional drainage reduces the probability of water damage to roots and in some cases it even increases crop production. Disadvantages of conventional drainage could be downstream inundation due to the drainage velocity of precipitation surpluses in periods with abundant rainfall and damage to agricultural crops due to drought in periods with insufficient precipitation. Besides, the conventional drainage of arable land can be detrimental to nature conservation areas nearby. In controlled drainage, the groundwater is not immediately discharged but (partly) retained in the soil. By varying the level of the drainage basins, the draining intensity can be regulated. Controlled drainage then becomes a tool for taking more effective advantage of specific (expected) weather conditions and maximizing the advantageous effects of drainage while minimizing the (possible) disadvantageous effects where possible. Controlled drainage is a very promising measure for uniting agriculture and areal spatial development.

There are two methods for accomplishing controlled drainage. In its most simple form, surface water (runoff) is drained into open ditches and flashboards are used to regulate the water levels in the open ditches. In a more advanced form, the connections are made underground and drainpipes are connected to a collecting pipe, which empties into a 'control reservoir' or control well. The water level or the drainage base is set here. We refer to this as Climate Adaptive Drainage. Because the basic principle of drainage is to regulate the water level or water table, controlled drainage is often called 'level-driven drainage'. In this Delta Fact, we only use the term 'controlled drainage'. The reason for this is that we would like to emphasize the essence of this form of drainage, which is called 'Controlled Drainage' abroad.

The text and the rest of the information in this Delta Fact is mainly based on the STOWA publication 2012-33 ' More water with controlled drainage'. A more comprehensive document with background information called 'Controlled drainage as a link in future water management ' (Alterra report 2370/STOWA 2013-38) provides more extensive detail on all aspects of controlled drainage addressed in this Delta Fact.

2. Related topics and Delta Facts

Topics: conventional drainage, submerged water drains, storing/retaining water, water intake

Delta Facts: soil as a buffer, soil moisture-based irrigation, dynamic level control

Keywords: storage area, standardising secondary dikes, water storage.

Delta Facts: The stability of peat dikes

3. Strategy: hold, store, supply

Controlled drainage is a technique that can be applied to realize the strategy of **hold**ing water in the soil. However, controlled drainage can also be used for water **supply**.

The drainage intensity can be regulated with a '(compound) controlled drainage' system called Climate Adaptive Drainage. Setting the drainage level to 'shallow' slows the drainage as it retains more water in the soil for a longer period, which reduces the soil's water requirement on external sources (water conservation). A 'deep' drainage level increases and enlarges the drainage, resulting in more rapid soil dehydration.

4. Schematic

In conventional drainage in the Netherlands, the drain outlets are higher than the water level in the receiving ditch (figure 1, left side). In the example, the drains are positioned at a depth of 1.00 meter, 10 centimetres above the water level of 1.10 meter in the ditch. The drainage base is equal to the level of the drains and cannot be controlled. By positioning the drains below the water level in the ditch, the

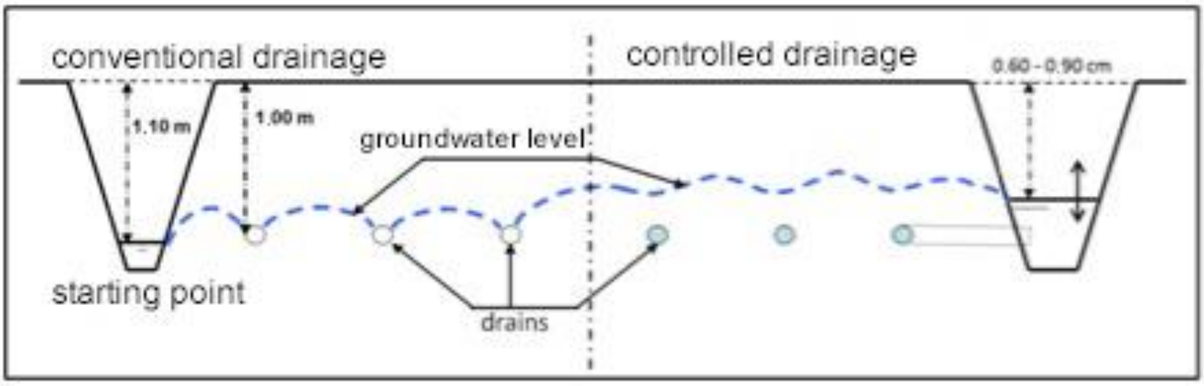

Figure 1. Conventional drainage mostly used in the Netherlands (left); can fairly easily be changed to controlled drainage (CD) by raising the upstream water level in the outlet ditch (Source: STOWA 2012-33).

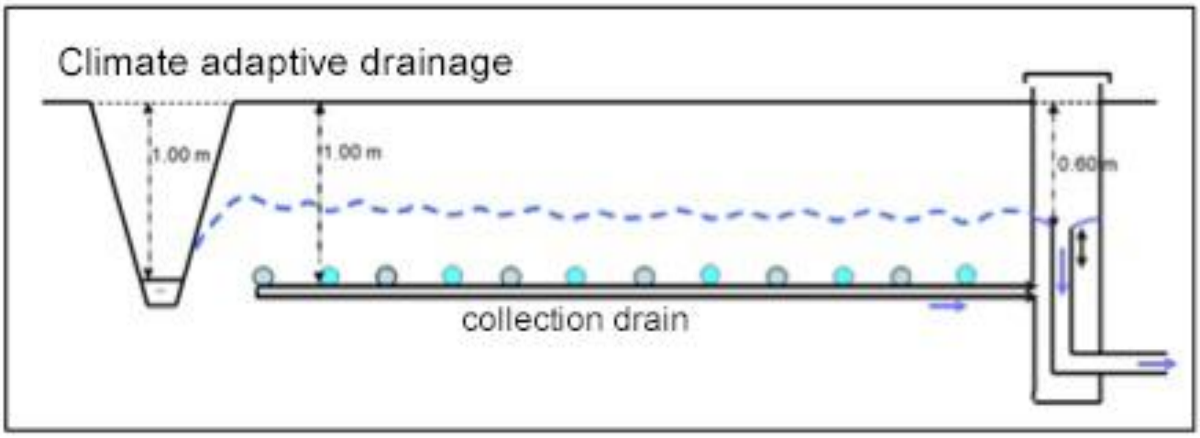

Figure 2. Climate Adaptive Drainage (CAD) where the drains are connected to a submerged collection drain and the level is controlled by means of the position of a vertical pipe in the control reservoir (right) and not by the level in a possible watercourse (left) (Source: STOWA 2012-33).

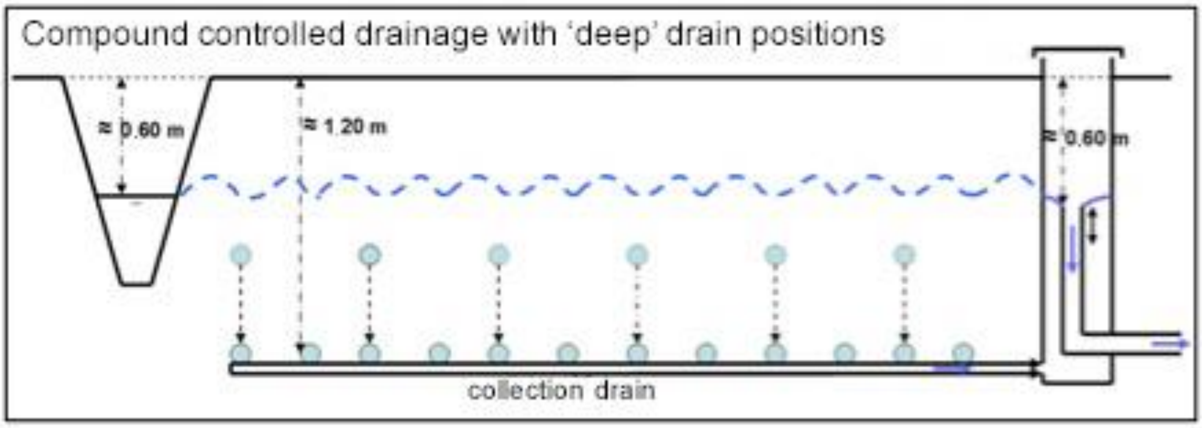

Figure 3. Left controlled drainage (CD) that is created by adjusting the control level in conventional drainage (CD) with a gate of flashboard risers. Right: newly constructed, Climate Adaptive Drainage (CAD) where the drains are installed deeper and closer together in the ground. The level (the drainage basis) is 60 cm below ground level in both cases but the scope of adjustment is 20 cm larger in the CAD because the drains are positioned 20 cm deeper. (Source: STOWA 2012-33).

drainage base can be adjusted and regulated by means of increasing or reducing the level (figure 1, right side). The result is a form of controlled drainage (CD). A current example is 'submerged drains' in peat meadows, intended to advance the infiltration of ditch water into the peat soil during dry periods, to preserve the peat meadows. Likewise, this also advances the drainage in wet periods, which is a welcome advantage to the farmers.

Climate Adaptive Drainage (CAD) is a system whereby the drains are connected to a collection drain (figure 2). The collection drain has an outlet into a ditch or control reservoir where the level – the basis for drainage – can be controlled. In the figure above, the drainage base is 0.60 m.

Controlled Drainage can be executed in different forms, depending on the starting point. Conventional drainage can be remodelled into Controlled drainage by adjusting the reservoir level management (figure 3, left side). The water level in the collecting ditch is increased until it is above the level where a series of 'shallow' drains flow into the ditch; the drainage outlets are 'drowned'. In the newly constructed CAD, the drains can be positioned deeper into the ground (figure 3, right side). This means that the drainage base can be set at a deeper level. This makes it possible to drain more water and it speeds up the drainage process. Having the drains closer together (smaller distance) decreases the drainage resistance and therefore increases the drainage velocity even more. It stands to reason that the response time of the CAD (Climate Adaptive Drainage) will be shorter than the response time of CD (Controlled Drainage) based on conventional drainage.

The depth of the drains and the water levels employed by the water boards in the area determine the active regulation of Controlled Drainage. In the case of high ditch levels, water can be discharged from the control ditch or reservoir by means of a simple pump. To retain water, the level in the ditch can be set higher than the usual ditch level. In dry periods, water can be supplied by pumping water into the control ditch or reservoir.

In 2011-2012, field tests were executed at three locations in the Netherlands with regard to innovative forms of compound controlled drainage, which has come to be known as Climate Adaptive Drainage (CAD) (figure 4).

With CAD, the water level in the control reservoir can be adjusted remotely and wirelessly, with a smartphone for instance. This form of 'real time control' is

Figuur 4. Installation for Climate Adaptive Drainage (CAD). (Source: STOWA 2012-33).

emerging in surface water management but in essence, it can also be applied in Controlled Drainage (gate control of the ditch).

The suitability of realizing Conventional Drainage, Controlled Drainage and Climate Adaptive Drainage according to current policy objectives and the intended (or unintended) effects of Conventional Drainage, Controlled Drainage and Climate Adaptive Drainage on agriculture and nature are indicated in table 1. The assessment is based on the results of field tests in the Netherlands, field tests elsewhere, model studies and/or expert assessment.

The criteria for assessing the suitability of 'Controlled Drainage' and 'Climate Adaptive Drainage' are:
A = Field tests in the Netherlands
B = Field tests elsewhere
C = Model studies
D = Expert judgement

+ = positive effect *0 = neutral* *- = negative effect.*

	Conventional	**Controlled Drainage**					**Compound Controlled Drainage**				
Objective	Suitability	Suitability	A	B	C	D	Suitability	A	B	C	D
Draining	++	++	x	x	x	x	++	x	x	x	x
Increasing water availability	-										
Reducing the drainage peaks											
Water supply via infiltration											
Reducing runoff N											
Reducing loss of N leaching											
Reducing runoff P											
Reducing loss of P											
Increasing load bearing capacity											
Mitigating nutrient mineralization of peat											
Impact on agriculture (crop production)											
Impact on nature											

1. *By applying Climate Adaptive Drainage (CAD) (expert judgement)*
2. *Depending on local circumstance, including soil type*
3. *By clearly defined management agreements between water manager and farmer*

Table 1. Suitability of different forms of drainage for different objectives, the impact on agriculture and nature. Reference for suitability assessment is the undrained situation (Source STOWA 2012-33).

5. Performance

(Climate) Adaptive Drainage makes it possible to set a base for drainage, which will enable us to take adequate advantage of the changes in the meteorological and hydrological situation – given expected drought or flooding for instance. By increasing the drainage base (higher level) more water is kept in the soil and in dry conditions, irrigation can be postponed. The reverse is also possible as the level can be lowered quite easily, making it possible to start cultivation activities at an earlier stage. An added advantage of CAD is that fewer ditches are required on the plot as collection drains replace them. For the farmer, this means there are fewer spray-free zones.

Besides the agricultural advantages, holding on to more water also has positive effects on the quality of the water. These effects were derived from calculations with a nutrient leaching model. Because of improved water management, in general, better use is made of nitrogen and phosphate. Due to the decreased drainage of water, the quantities of nitrogen and phosphor leached from the water are also reduced. In the field, farmers are ascertaining that the nutrient loss through drainage is much slower.

Furthermore, the model calculations are forecasting an increase of de-nitrification (nitrate breakdown) owing to the higher water level and the low position of the drains as compared to conventional drainage, which will reduce the nitrogen load to the surface waters. Phosphate however, will become more mobile due to the high groundwater levels, which will increase the probability of phosphate rinse off and leaching. Then again, we are able to control the phreatic surface quite well and can prevent the groundwater level from reaching the surface, where phosphate concentrations are highest. This has a positive (reducing) effect on the phosphate load of the surface water.

Reasons for using (C)AD

STOWA-publication 2012-33 provides an extensive summary of the reasons why Climate Adaptive Drainage could be applied in the Netherlands. It distinguishes between four themes:

I Water quantity

1. Water boards can better fulfil their mission in relation to the availability of water and in relation to inundation if they incentivize farmers to change over to (C)AD.
2. With (C)AD, farmers are more or less autonomous on their farms and ‘complementary’ to regional water management, which enables them to actively manage water quantity. Examples are provided in the field of holding on to groundwater, root damage, thickness of the rainwater lenses and combatting salinity, adjusting drainage depth in crop rotation, establishing accurate ground water levels for bulb farming, accurate setting of the drainage base for CAD based on weather expectations and actual moisture conditions, and underground irrigation as a more efficient and less costly alternative for irrigation.
3. With proper management, (C)AD can deliver a structural contribution to combatting drought in nearby nature reserves or conservation areas without limiting agricultural business management.

II Water quality

(C)AD can contribute to sensible management of the essential but (increasingly) scarce production requirements of water and nutrients by:

1. regulating the water resources for promoting denitrification and crop growth and in doing so, promoting nutrient absorption;
2. managing the groundwater levels as such that the runoff and leaching of phosphor remain as is or decreases;
3. managing as such that emission of nitrogen and phosphorus to the surface water decreases and (C)AD contributes to the realization of CAD objectives.

III Production conditions

With (C)AD, farmers are able to:

1. actively manage and regulate the water on their plots;
2. realize a more uniform groundwater table on a plot;
3. hold onto water to prevent damage due to drought and reducing or preventing the need for irrigation;
4. actively anticipate heavy rain showers to reduce or prevent inundation and root damage;
5. install drainage facilities on plots that ‘do not require drainage’, with the objective of holding on to water;

6. filling up ditches around plots to increase the agricultural product potential and to reduce the direct runoff of N and P and the drift of insecticides from the surface level to open water.

IV Nature

Having (C)AD in agricultural areas that function as protection zones around nature conservation areas helps to prevent dehydration in the nature reserves. Because groundwater levels in arable land can temporarily be lowered rapidly with (C)AD if necessary, water levels in surrounding areas can be set at a higher level. On average, the groundwater levels are slightly shallower and both nature and agriculture can benefit from this. The advantages are evident when Conventional Drainage is replaced by (C)AD. However, when installing (C)AD on undrained soil, there is a risk of a (emanating) dehydration effect on nature reserves nearby. The decision to introduce (C)AD in undrained agricultural plots in protection zones should be carefully considered.

Substantiation and relativity from research

Considerable research into various aspects of (C)AD is found in Stuyt et al. (2013). The results vary. The most important research aspects are provided below, per theme.

I Water quantity

Controlled drainage only works when there is something to control. Most of the lower regions in the Netherlands do not qualify because of the small margins within which water levels are strictly imposed. In higher areas of the Netherlands Controlled Drainage only has added value on plots where there is a structural problem with seepage or areas of shallow groundwater levels: soils that require drainage. It regularly happens that plots ‘on sand’, which does not require drainage, are (conventionally) drained. Farmers do this in order to drain the excess water deposited by heavy summer showers more rapidly; Controlled Drainage is not an option here.

It does seem like Controlled Drainage can be sensibly applied in transition zones between different forms of land use, for instance nature reserves that border on agricultural plots.

II Water quality

Research has shown varying effects of (C)AD on water quality that partly depends on the hydraulic preconditions:

- Model research by Van Bakel et al. (2008) shows a substantial reduction of the nitrogen(N) load and a considerable increase in phosphorus (P) load in the surface waters of the sandy soils in Noord-Brabant and Noord-Limburg due to Controlled Drainage. More intensive drainage and deeper positioning of the drains can undo the P increase.
- A five-year field test in Ospel (Limburg) could not substantiate nor falsify the hypothesis that Controlled Drainage results in a reduction of N and P loads in the surface waters.
- Field research in the project 'Nitrogen at the correct level', executed in Southwest Netherlands showed that Controlled Drainage on sandy soils could contribute to a reduction in nitrogen loss through runoff.
- Biennial field measurements in 2010 -2012 at Colijnsplaat (Zeeland) of Climate Adaptive Drainage in sandy soil with saline seepage clearly show that (C)AD discharges less water, nitrogen and chloride (Schipper en Van der Schans, 2012).
- In project 'Interactive phosphate management Molenbeek' an estimate was made about the quantity reduction of nitrogen and phosphate in the surface water from 17 kg N and 0.25 kg P per hectare drained surface per year. Switching the pump off sooner could increase this. The reduced runoff and possible utilization of the farm water have not been added, as it is difficult to quantify.
- Biennial field measurements in 2011 -2012 by Rozemeijer et al. (2012) in a trial field in Oost-Nederlands Plateau showed that Controlled Drainage did not result in a reduction in nitrate loss into the surface water. It did show a reduction in phosphorus in the drain off but possibly not in the total runoff and drainage. The results of this trail are linked to the region concerned (customer specific) and are non-transferable to other regions.

III Production conditions

The effect of Controlled Drainage on crop yield depends on the soil qualities, the location characteristics, the design of the drainage system and the management strategy. In one year, the effect of controlled drainage on crop yield strongly depends on weather conditions during the growth season. In essence, Controlled

Drainage could ensure a higher crop yield because water can be held on the plot, making it available for the crop if there is no rain for a prolonged period. However, if a growing season is extremely dry it is impossible to hold water in the soil and the effect of Controlled Drainage with regard to this aspect will be negligible.
Then again: if sufficient rain falls during crucial periods in the growth season to provide the crop with the necessary water, the drainage water that is stored by means of Controlled Drainage is unnecessary and Controlled Drainage will probably have little effect on the crop yield.

The effect of Controlled Drainage on crop yield will be at a maximum when a wet period in the growing season is followed by a dry period, which is followed by a wet period etc. These kinds of conditions are best suited to holding water in the soil if possible so that the crop is able to benefit during dryer periods. Such regular alternation of dry and wet periods occurs more often at some locations and in some years than in other locations and in other years. In order to map all these effects requires long-term research - in combination with field tests – to establish the average effects on crop yield.

If all other factors are comparable, it is expected that Controlled Drainage will have the largest effect on water conservation and crop yield if the drainage pipes are installed deep in the ground, at small drainage intervals. In situations where drains are positioned relatively shallowly and at larger distance from each other, and/or the hydraulic permeability of the soil profile is low, Controlled Drainage will have to be carefully managed to avoid negative effects on crop yield.

IV Nature
As far as known, no field research has been done with regard to the effects of (C)AD on nature. From model research by Deltares, on behalf of Natuurmonumenten, Staatsbosbeheer, Brabants Landschap and Landschap Overijssel, it follows that under certain conditions the effects would be positive. At present, only 10-20% of the arable land around nature reserves is drained. With more drainage, the dehydration of nature reserves will increase. An inventory by Deltares shows that there has been no research into the effects of (C)AD on nature.

The model results by Deltares indicate that the installation of new (C)AD will only be favourable to nature if it is combined with a substantial increase of surface water levels and wider ditch beds. Expectations are that in many areas there will be insufficient water supply available to maintain higher ditch levels in dry periods as well. Another point of concern is the management of (C)AD with deep drainpipes: if farmers temporarily adjust the settings to (too) deep in order to execute activities, much groundwater can be drained off in a relatively short time. This is highly unfavourable for nature and it will be hard to replenish.

Natural resource managers are appealing to water boards to combine measures around nature reserves as such that the water objectives of agriculture and natural resources are realized. For nature conservation, it is imperative that the water levels in the ditches are increased and that the ditch beds are made wider. A (C)AD system in neighbouring agricultural plots prevents wet damage. In dry periods, both agriculture and nature reserves can benefit from the higher groundwater levels.

6. Costs and benefits

In its ideal form, a Climate Adaptive Drainage system is more expensive than a Controlled Drainage system. The pipe diameter could be larger than the usual 60 mm and, because the drain distances are remarkably shorter, more pipe length is required. In CAD systems, the additional costs come from the collector drain and one or more control points required. The question is whether the decrease in drain distance of a CAD system is really necessary in the Netherlands. It is possible that slightly larger drain distances can be used without any substantial adverse effects in performance. A more detailed cost-benefit analysis can be made quite easily, based on a simple model analysis.

In practice, it appears that due to all the above, the (C)AD is certainly more expensive than CD. Water board Peel en Maasvallei estimates an additional charge of van €1000 per hectare (personal statement by J.M.P.M. Peerboom). The appropriate question is: what does it yield, for whom, or how much money is saved on irrigation for instance? No solid calculations have as yet been executed. Reasonable estimates can be made with regard to some of the posts related to this kind of calculation, for instance computer modelling of the effects on crop yield, while other effects cannot currently be estimated at all, such as translating the quantity of water conservation in terms of monetary value. In a realistic cost-benefit analysis of (C)AD, not only the effects of (C)AD as opposed to CD should be considered but the effects of CD with respect to undrained plots ought to be taken into account as well. In addition, it is important to ascertain what the deciding factors are in choosing for the installation of a (C)AD system: reduction of risks by installing a (C)AD (a kind of insurance) is a very different reason for consideration than an economic cost-benefit analysis.

Various publications provide estimates of the additional costs involved in this kind of drainage compared to conventional drainage.

- Water level on the exact height desired: the possibilities of Climate Adaptive Drainage (July 2010)
- Climate Adaptive Drainage is about twice as expensive as a conventional drainage system. The extra costs are due to the construction of the main drain (€ 4-5 per running meter), T-pieces (€ 25-30 each) and the sump (€ 200-300). On average, the system costs € 2400 per ha. A conventional drainage system costs about € 1250 per ha.
- Controlled level drainage (flyer Peel and Maasvallei, Feb. 2008).

The construction of the main drain is estimated to be € 6.50 per running meter. If it concerns soil that really requires draining, special consideration should be paid to additional costs related to decreasing the draining distances.

- Policy framework phosphate for North and Middle Limburg (Noij et al., 2008) In the research, the costs for constructing controlled drainage is estimated to be € 750 per ha. and the construction of conventional drainage is estimated to cost € 140 per ha.

7. Technical specifications

Proper functioning of a (C)AD system stand or falls depending on whether it meets a number of the specified preconditions or not. First and foremost, accurate construction of the system is essential. Secondly, proper maintenance of the system is of crucial importance. Last but not least - by taking advantage of hydrological conditions - it is the management that determines how effective a measure is and, with that, the added value of the measure. These three preconditions require a different kind of knowledge and skill than a Controlled Drainage system.

On the other hand, the (C)AD does not totally come without risks. It could be a case of unsuitable plots, errors could be made in the design and construction, management execution is inadequate or the farmer and the water manager have opposing interests. The latter risk can usually be avoided if proper communication takes place and mutually acceptable agreements are made.

Furthermore, experience has taught us that a (C)AD is customer-specific. Good preliminary inquiry is necessary. The profile construction and the soil structure will be the determining factor in how deep and at what distance the drains will have to be positioned from each other. Based on a preliminary model investigation (Bakel et al., 2008) it was established that a (C)AD system could potentially help to combat dehydration and help to create a reduction in nutrient load for the sandy soil (in the south). Field tests confirmed this potential. Expectations are that this drainage will also show promising results on other sandy soils. The performance of Climate Adaptive Drainage on clay soil is as yet still unknown. At present, this matter is being researched (see currently active research projects). Research into a specific form of CD on peat soil has been taking place for a number of years now: underwater drains with the objective of slowing down the destruction of peat soil.

(C)AD is only effective on plots where there is no substantial groundwater seepage as the effect of controlling the water levels with these drainage systems will be (very) limited. The same can be said for surficial aquifers, as there is little 'to control'. Introducing a (C)CD at these kinds of locations is not recommended.

The latter also follows from a field investigation by Deltares into Controlled Drainage, particularly with regard to the effects on the water quality: CD did not result in reduced runoff and leaching of nitrate and phosphorus into the surface water during the discharge seasons in 2010 and 2011 in the trial field at Oost-Nederlands Plateau. The phosphorus loads did decrease via the drains but the reduced drain discharge is counterbalanced by the extra discharge of shallow ground water and extra surface runoff, which probably has a negative effect on the quality of the surface water. The hydraulic situation on and around the trial field is characterized by a relatively shallow alluvial aquifer with a substantial layer of almost impermeable marine clay (sea sand and clay). This is a characteristic feature of the hydrological situation for the sandy soil on the Oost-Nederlands Plateau. A thin phreatic aquifer means that the average travelling time of water infiltrating into the surface water is relatively short. In the sandy soil areas in the south of the Netherlands the aquifer layers are thicker and so the travelling time is longer.

8. Governance

(C)AD can enable water boards to achieve the policy objectives (for instance GGOR, KRW, anti-dehydration etc.). An important question for water boards to ask is: how do we translate these policy objectives into technical requirements? Water boards could decide to grant subsidies to farmers and private landowners for installing (C)AD (Blue Services). In this way, it also enables water boards to get more grip on the (regional) groundwater and surface water regime. In addition, it is possible to make (C)AD compulsory by adding it to the regulations of the water boards. Two water boards namely Peel and Maasvallei as well as Roer en Overmaas have added (C)AD to their by-laws. From 2018, all pipe drainage in the whole of Limburg must be converted to CD.

If water boards would like to promote or demand (C)AD, an important attention point is how they plan to check and enforce the execution of this regulation in practice. Coaching the farmers is probably a good idea. Setting the drainage levels depends on conditions: this requires a specific assessment that surpasses enforcement.

If too little attention is paid to information supply and enforcement, there is a chance that, after a few years, the conclusion is drawn that (C)AD has not yielded anything. (C)AD can only be a success if an attractive implementation plan simultaneously goes hand in hand with the changes in regulations (laws and prohibitions)(see Stuyt, 2013; page 459-488: KIWA BRL 1411), (non-binding) policy regulations and permits (binding, organizing supervision and enforcement) and when the effects of the construction of (C)AD are monitored and analysed.

9. Field experience (national and international)

In the Netherlands, the (C)AD systems have been installed in a number of experimental test fields provided by operational farms and the overall experience has been good. To see a number of reactions from the field, click here.

At a number of the test fields on the southern sandy soils, groundwater levels are measured and the effects on business management are recorded. In this way, the field experience is included in the research.

France, Belgium, Hungary, Romania and North America have also had positive experiences with (C)AD. Most of the systems abroad are climate adaptive drainage systems. Examples of foreign literature are Skaggs et al., (1995) and Giliam and Skaggs (1986).

10. Currently active projects and research

Field research is being executed into the (cost) effectiveness of CAD at various locations in the Netherlands, such as at Rusthoeve (Zeeland), in Ospel (Limburg), in Haghorst (Noord-Brabant), etc. An extensive overview is found in Alterra-report 2370/STOWA 2013-18.

For an overview of all currently running research and relevant completed research into the performance of climate adaptive drainage, click here.

11. Knowledge gaps and development

Knowledge gaps

(C)AD is very suitable for application in lighter soils such as sandy soil and silt loam. As yet, we have very little field experience with soils like heavy clay and heavy silt loam. This means that, among other things, the effect on reliability is unclear. The most recent experience gained on farms with heavy soil is currently being

Figure 5. Good dewatering by drain, installed in Texel sea clay (photo: L C P M Stuyt, 11 November 2013)

researched on a farm on the Dutch island of Texel. The plot being drained has a sandy surface layer of 50 – 70 cm thick. Underneath this, there is a layer of sea-clay that is hard to permeate. Drain depth is 80 cm, drain distance 7-8 cm on clay. The drain flumes have been filled with shells up to the plough break. The drain discharge was observed on 11 November 2013; all inspected drains are dewatering excellently (see figure 5).

Much field experience has been gained on ‘subterranean drains’ in peat soil, a form of CD that is mainly aimed at increasing the ditch water infiltration into peat soil during dry periods in order to reduce the destruction of peat. At present, there are still various field and model research projects into the applicability of underwater drains in peat meadows.

The effect of large-scale application of (C)AD on the probabilistic increase on downstream-accelerated discharge is unknown at this stage.

In STOWA publication 2012-33, it is proposed that the possibility to retain water with (C)AD could be beneficial to the natural environment. From model investigations by Deltares, it follows that this can only apply in combination with a substantial increase in the level of surface water and ditch bed. This research also shows that remodelling a CD to a (C)AD, providing that it is accompanied by level increase, is more likely to have favourable effects on nature than newly constructed (C)AD on undrained plots. At present, there are no field test results that can support or alter the stated results expected from model testing.

Knowledge development

The management - adapting to changes in hydraulic circumstance – determines the effectiveness of a (C)AD. New users of (C)CD have to learn, learn from and with each other how to operate their systems as best as possible. Therefore, it makes sense to collect information about the way in which (C)AD is applied by users, what it yields and what their experiences are with the system. This can help to derive what the requirements are that a good design and good management of a (C)AD should meet under certain conditions. This new knowledge should be shared with as many colleagues and other parties involved as possible, for instance water managers, NGOs and the like.

Given the complex reality with large variables in soil composition and the hydrological qualities linked to this, and given the unpredictability of weather conditions, the field tests into the configuration effects and management of drainage systems on the quantity and quality of drainage water should be executed for a period of at least five years, preferably longer. Furthermore, measurements should be taken with the greatest possible care and be aimed at recording the water balances and substances. The complex reality necessitates an integral approach to field-testing. The question is which field knowledge is useful in this. More than likely, a series of pilots with farmers is a more sensible approach.

In the execution of field tests, solid preliminary investigation on the intended test field is important. Revitalizing the preliminary drainage research that was widely applied at the time of redistribution of land in the Netherlands is certainly recommended and even more so if it is suspected that a plot to be drained contains highly impermeable layers. A new development in diagnosing (existing) drainage is the use of thermal imaging to rapidly map the draining performance on plot level. This technology (the thermal sensitivity and resolution) has developed rapidly during the past few years; temperature difference of 0.1°C can be detected without any problem. Professional thermal image cameras have dropped in price quite considerably and can contribute to fast and accurate diagnosis of drainage problems. The accompanying software is programmed for fast and accurate reporting.

12. References & links

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This factsheet was prepared by Alterra, August 2011 and reviewed in November 2013.

13. Farmer's experience

Good experience with Climate Adaptive Drainage (source: folder Peel and Maasvallei, Feb. 2008)

The Neessen brothers drain in excess of 20 hectares of land according to the principles of adaptive drainage. With this system, the drainage pipes do not flow into a ditch but into a central drain that subsequently drains the water to the ditch. "With this system, we are able to drain slightly deeper", says Herman Neessen. Together with his brothers Peter and Jan, they run a mixed farm in the Limburgse Grashoek. The brothers cultivate asparagus, strawberry and other plants. Because the Climate Adaptive Drainage pipes are permanently under water, there are hardly any oxidation problems. Much of the sandy soil in Limburg is iron rich and therefore, susceptible to oxidation. Oxidation can result in blocked drainpipes. "The maintenance to Climate Adaptive Drainage systems is minimal anyway", says Herman. "Having the pipes spray cleaned annually is unnecessary." Additional costs are also minimal. The construction of a main drain costs 6.50 euro per running meter. At a length of 150 meters, it will cost 975 euro extra." Last year, Neessen had drainage with a central drain installed on a plot of 5 hectares, which can now be equipped with a 'smart pipe of Van Iersel': one kind of controlled drainage. Neessen does not have any experience with this system yet.

Frugal with fresh water (source: Akkermagazine, nr. 7/ July 2010)
Bert Timmermans from Aardenburg had a Climate Adaptive Drainage system installed on thirty hectares of land in the spring of 2008. Because the conventional drains were only six years old, it could be changed into a climate adaptive drainage system by connecting the drains to a new main tube. The reason for this Zeeuws-Vlaamse farmer to invest in this system is the small amount of fresh water available to his crop. " I'll irrigate if necessary, but that cannot always be done. For this reason and as a sort of a test case, I wanted to gain experience with climate adaptive drainage. It would be a waste if the fresh water of a precipitation surplus ends up flowing to the sea via a ditch. In this way, I will try to hold on to as much moisture as possible. Besides, with controlled drainage I do not have to crawl into the reeds on the side of the ditch to spray-clean the system. Because of the environment friendly banks along the ditch, the old system was very maintenance sensitive."

Higher yield because of water supply (source: Akkermagazine, nr. 7/ July 2010)
Hay Geurts from America (L.) had a Climate Adaptive Drainage system installed a year and a half ago. As a test of his own, he let water run into half of his potato crop by means of the drainage system. He did not infiltrate the other half of the plot with water as it is connected to a different drainage well due to a height difference. Result? A considerable difference in yield.

Last year's potato plants made way for this season's blueberry plants. Geurt's field looks even but it actually slopes up a good 30 cm at the back. With this height difference, the plot has been divided into three compartments that individually flow into different collection wells. In this way, the same water level can be achieved. ,, On this spot, we are standing in the middle of last year's potato plot ", Geurts points to between two of the compartments. ,,The whole plot was treated in the same way, with the same fertilizing and irrigation". The only difference was the infiltration with water from the Maas River, which is supplied by means of gates. On the one half, the farmer let the water infiltrate to fifty centimetres below surface level but did not do the same on the other half of the plot.

Half a kilogram difference

After the Asterix consumption potato plants had died off (in October), Geurts compared the potato yield of the infiltrated side with that of the non-infiltrated side of the plot. Geurts: ,,I repeatedly took the same row, so that I could be certain that the potato plants had had the same treatment." The plants that did receive water supply via controlled drainage proved to have a 500 gram higher yield per plant than the other plants. ,,Per hectare, the yield difference is 20,000 kg. It is remarkable that the plants in the middle between two drains yielded 12 kg and the plants right above the drains yielded 9kg." Geurts thinks that this has to do with the bulging of groundwater between the drains. He thinks that research should be done regarding the yields that accompany controlled drainage in the Netherlands.

Less irrigation

Geurts is satisfied about the performance of his climate adaptive drainage system. The ditch in the middle of his plot was filled up. This means that the farmer now has less spray-free zones. The system saves him from having to irrigate once or twice per year, which also saves him work and evaporation of water. Compared to conventional drainage, Geurts also has less maintenance to execute. The system rinses itself clean, because when I empty it out, it flows out at quite a speed. Moreover, we hold onto about 30 centimetres more water in the soil than before. The fertilizer in the top 30 centimetres of water would otherwise run off into the ditch via the surface water, which is now no longer the case." At construction, Geurts was granted a subsidy of 60 percent as he lives on the edge of a nature reserve called Maria Peel. The costs of the main drain were around 10 euro per metre and the wells cost 250 to 300 euro.

Remote control water management (source: Nieuwe Oogst Saturday 21 July 2012)

Peter van der Veeken (52) is the third generation on the dairy farm in Rijsbergen. He milks 65 cows and has about 45 hectares of ground. There is no possibility for expansion. „This does not mean that I stop the technical development in my business and this is why I said yes to participating in the pilot project rather quickly", says Van der Veeken. „My grassland has yielded more and yielded a better quality. The grass has a higher nutritional value. I have also noticed that I am much more focused on water management. Before, I never really stopped to think about it." Irrigation will decrease substantially on his farm. „This does not only mean a cost reduction, it also means that there will be a lot less working and carrying. I also have more control over how moist the soil under my crop is. If I keep the water level at 50 centimetres below the roots, the capillary action ensures that the plants get sufficient water. Aside from the fact that I enjoy it, being aware of water management gives me satisfaction. All farmers should have this awareness."

14. Overview of current research

Name Research project	New Limburg Level
Parties involved	Waterschap Peel en Maasvallei, Provincie Limburg
Contact person	Jacques Peerboom
Research locations	-
Name Research project	Infiltration through controlled drainage
Parties involved	Waterschap De Dommel, PPO, AGV, Alterra
Contact person	-
Research locations	Haghorst
Name Research project	Interactive phosphate management Moelenbeek
Parties involved	Commissioner: ZLTO Execution: Royal Haskoning, Louis Bolk Instituut Waterschap Brabantse Delta
Contact person	-
Research locations	-
Links/documents	Folder
Name Research project	Mitigation of dehydration Groote Peel
Parties involved	Waterschap Aa en Maas, Ministerie van EL&I, DLG, ZLTO, Staatsbosbeheer
Contact person	Albert Vrielink
Research locations	De Groote Peel
Links/documents	Folder, Film 1, Film 2
Name Research project	Trial Fresh Water Storage
Parties involved	Commissioner: provincie Noord Holland. Execution: Oranjewoud, Acacia Water with Alterra and Deltares. Other parties involved: Hoogheemraadschap Hollands Noorderkwartier (HHNK), LTO Noord, KAVB, gemeente Texel en Waterwerkgroep Texel
Contact persons	Rowena Kuijper, Wendalin Kolkman
Research locations	Texel

15. Overview of completed research

Name Research project	Controlled Drainage (2008-2012)
Parties involved	Waterschap Peel en Maasvallei, Ministerie van V&W, Rabobank, STOWA, Alterra
Contact persons	Jacques Peerboom, Lodewijk Stuyt
Research locations	Ospel
Links/documents	Folder, Artikel 1
Name Research project	Nitrogen at the correct level (2007-2010)
Parties involved	Financiers: Waterschap Brabantse Delta, Provincie Noord-Brabant, LIB, Evides Execution: Studieclub 'Rundveehouderij Heerle/Huijbergen'
Contact person	René Rijken
Research locations	Heerle, Rilland

Name Research project	Controlled drainage (2010-2012)
Parties involved	Financiers: EU, Rijk, Provincie Zeeland, ZLTO, Waterschap Scheldestromen, Execution: Alterra, PPO, Grontmij, Barth Drainage
Contact person	André van de Straat
Research locations	Proefboerderij Rusthoeve
Name Research project	Climate Adaptive Drainage (2010-2012)
Parties involved	FutureWater, Kuipers Electronic Engineering, De Bakelse Stroom, Van Iersel
Contact person	Peter Droogers
Research locations	-
Links/documents	Website

16. Disclaimer

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