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LONG TERM PERPECTIVES FOR WATER MANAGEMENT IN DRAINED PEATLANDS; EXPERIENCES IN PEAT-POLDER SYSTEMS IN THE NETHERLANDS

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SUMMARY

In the Netherlands, many peatlands were drained since the 16th -17th century and used for peat extraction and dairy farming. Since then the rate of land subsidence rates varies between 3 mm – 2 cm per year, depending on local conditions. This requires regular adaptation of water management and hydraulic infrastructure. Different stages of water system (or polder) development can be distinguished. Awareness of the actual stage of development in a drained peatland site enables to predict the next stage in its development. This recognition allows a better decision making on required adaptation strategies such as continuation of the actual agricultural land use, adaptations in agricultural zoning (see Rahmadi *et al*., 2011) or transformation into e.g. restored wetlands (Schouwenaars, 2011). Based upon historical analyses of water management in the peatland polder systems in the Netherlands, trends in development are described. A typology is presented which may serve to identify the actual stage of development of peatlands after drainage. Drainage will continuously require adaptation measures and creates an increasing dependency on human interventions to reduce risks for flooding. The technical infrastructure becomes more complex and fragmented and the costs for water management increase gradually. The presented typology allows a better understanding on the actual stage of development of a drained peatland at a given site. It also gives a tool to predict the future stages in development.

Keywords: *water management, land subsidence, infrastructure, polder typology*

INTRODUCTION

An important feature of the low lying coastal zone in northwestern Europe is the presence of vast areas with organic peat soils. In the Netherlands, many peatlands were drained since the 16th -17th century and used for peat extraction and dairy farming. Since then the rate of land subsidence rates varies between 3 mm – 1 cm per year, depending on local conditions. (Schothorst (1977), Hoogland *et al.* (2012).
Started with the introduction of the individual windmills and later intensified by better pumping equipment, rates of land subsidence have increased considerably in the second half of the 20th century (see Figure1 and 2)
This process of land subsidence requires regular adaptation of water management and hydraulic infrastructure resulting in a continuous further fragmentation in peatland-poldersystems.

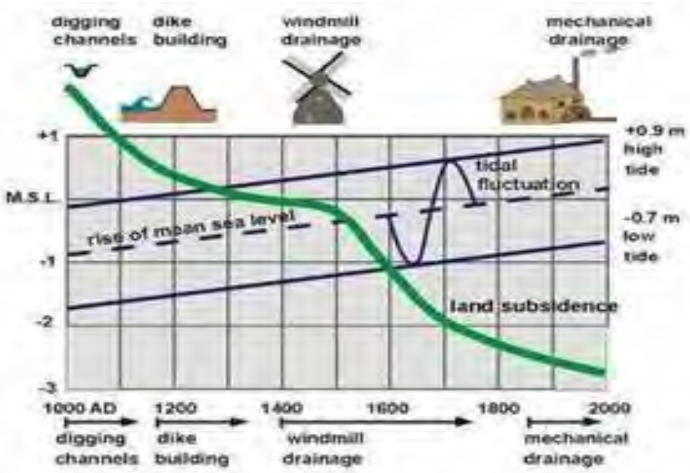

Figure 1: Historical development of drainage and land subsidence in the Netherlands (Atlas van Nederland, 1996)

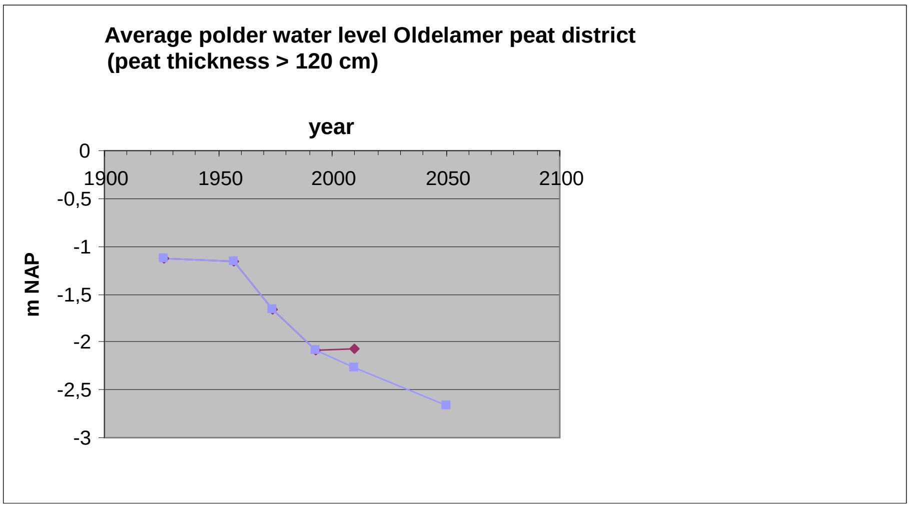

Figure 2: Lowering of polder water levels as a consequence of land subsidence n the Oldelamer peat district (m NAP is meters below sea level) (Hartman *et al.,* 2012)

When the degree of drainage in different parts of the polders is different, either in time or in intensity, also land surface levels will start to differ. Once this process has started, it is hardly possible to scale up the polders again. Here, the creation of larger polders units with a common water level, would lead to unacceptable differences in drainage levels and farming conditions. On the contrary, high rates of land subsidence in some parts of these peatlands urged to install pumps in these lower parts in the polders. In this way, these parts with lower water levels were isolated from the original polder and so called sub-polders were created. An illustration of the consequences of this process of fragmentation is presented in Figure3 and Figure 4.

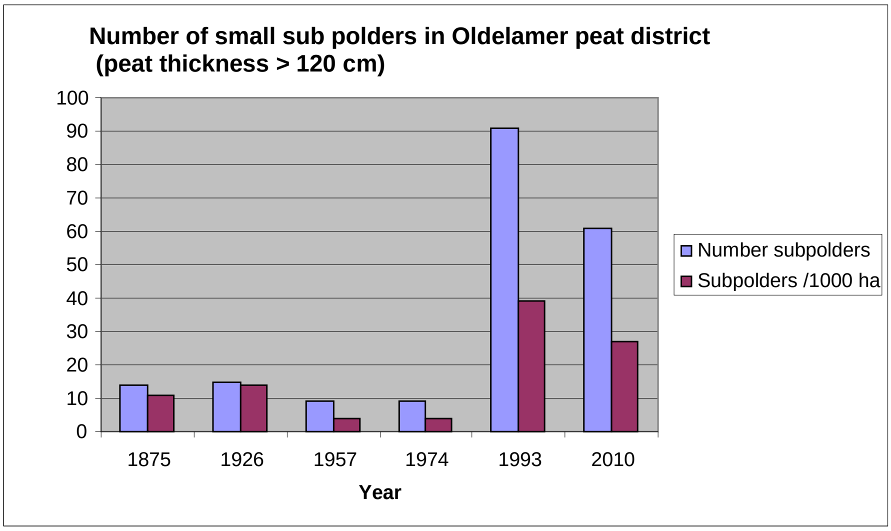

Figure 3: Fragmentation of the polder system in Oldelamer peat district as a consequence of land subsidence (Hartman *et al.,* 2012)

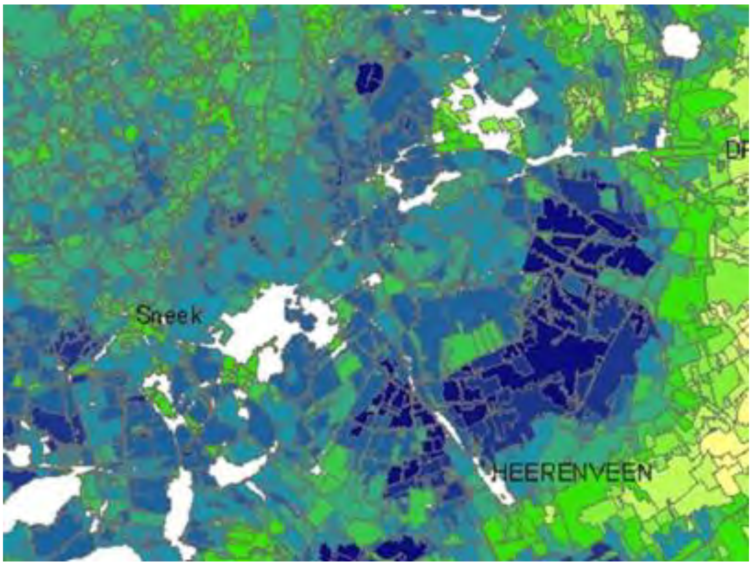

Figure 4: Fragmentation of the peat-polders systems in Fryslan, where in during the 20st century the average polder size has reduced from ca. 100 ha to only 20 ha

INCREASING COSTS FOR WATER MANAGEMENT

Land subsidence resulted in the necessity to construct dikes to prevent the lower parts to get flooded by water from the canal (or boezem) system. In contrast to what is commonly expected it are not the extra pumping costs but the high costs for dike construction and maintenance that cause the major increase in costs for water management in peat-polder systems. This is illustrated in Table 1.

Table 1: Extra costs for water management in peat-polders in the Netherlands over 200.000 ha and cumulative for the period 2010-2050; van den Born *et al.* 2016)

extra pumping costs	€ 0, 4 million
extra dams (and weirs)	€ 24, 8 million
larger dike constructions	€ 178, 1 million
Total	**€ 203, 3 million ***

* The total increase corresponds with ca. € 1000 per ha in 40 years, which equals an average of € 25 / ha/yr. Hence, the costs increase annually with € 1,25 per ha.

The actual annual costs for water management in the peatlands in the Netherlands vary from € 200 per ha per year (in the Fryslan peat district) to more than € 500 per year per ha (as estimated for the Utrecht peat district by van den Born *et al.,* 2016). For Fryslan, the increase of costs for water management due to land subsidence is estimated at ca.1% per year (Hartman *et al.,* 2012).

Hence, it is obvious that in these peatlands the normal process of upscaling driven by technology and cost effectiveness, -which is notable in most polders - is seriously hampered by the process of further fragmentation caused by land subsidence. Schouwenaars (2002) describes the specific problems related to land subsidence and fragmentation in the Echten polder in Fryslan.

DAIRY FARMING IN PEATLAND POLDER SYSTEMS

In the Fryslan peat district with a total area of 80.000 ha almost 70% is used for agriculture. Intensive drainage facilitates at the ca. 1000 dairy farms offer suitable conditions with forage production rates of ca. 10.000 kVEM per ha per year. For an average farmer this represents a production value of ca. € 1800 per ha per year. (Provincie Fryslan 2014, Factsheets Veenweidevisie)

The far reaching impact of intensive drainage for agriculture is the high oxidation rate of the peat soils. As a consequence in 2050 in almost half of the total peat area (i.e. 35.000 ha) the remaining peat layers have a thickness less than 0.4 m. (In the Dutch Soil Classification System soils with less than 40 cm of peat in the top 80 cm are no longer classified as peat soils).

Van den Born *et al.* (2016) present figures for production rates on peat soils in the Netherlands varying form 9.3 ton dry matter for intensive farming to 5.5 ton dry matter for extensive farming.

A NEW TYPOLOGY FOR DEVELOPMENT STAGES IN PEATLAND POLDER SYSTEMS

In historical analyses of polder development in Fryslan a logical sequency can be observed for stadia in development or adaptation of polder and boezem systems. In Table 2, some elements of this typology are presented, based upon a general theoretical analysis of the development of polder systems and illustrated by the specific analysis of the Tzummerpolder as presented in Schouwenaars (2011).

Table 2: Summary of development stages in peatland polder systems, adapted from the Tzummerpolder study after Schouwenaars (2011)

Development stage	**Period (year A.D.)**	**Type Code [1,2]**	**features**
Phase 1a: **Empolderment** *Phase 1b:* **Upscaling of polders**	1000-1100 1150-1500	S1 S1-D1 S1-D2	Small dikes with sluices closed dike-ring with sluices Larger dike rings with an inner boezem (Westergo)
Phase 2: **Enlargement of the boezem system**	1200-1300 1505	S2-D2	Damming of Marne and Middelzee estuaries and creation of a larger outer boezem system for Westergo. Construction of Oude Bildtdijk as new sea defence for Westergo, no longer a sea defence along former Middelsee.
Phase 3a: **Construction of dikes along the boezem** *Phase 3b*: **Upscaling polders and reduction length of dikes along boezem**	1800 – 1950 1900 - present	S2-D2-Bp1 S2-D2-Bp2	Construction of dikes along the boezem inside the polder systems. The discharge canal system of the Tzummerpolder is interconnected with those of neighbouring polders and parts of the inner boezem are no longer essential, enabling removal of dikes
Fase 4a: **Pumping of inner boezem and polders** *Fase 4b:* **Up saling of pumped polder systems**	1850 - 1900 1920	S2-D2-Bp2-M1 S2-D2-Bp2-M2	Construction of windmills in the Tzummerpolder Steam engine pump near Tzum, enabling further combination with drainage of neighbouring polders
Fase 5a: **Creation of sub-polders and further fragmentation induced by subsidence**	From 1900 onwards	Mp1, Mp2 etc.	Construction of sub-polders
Fase 6a: **Partial pumping of the boezem system** *Fase 6b:* **Complete pumping of the boezem system**	1928 1968 Planned 2020 planned in 2030	Bm1-S2-D2-Bp2-M2 Bm1-D2-BP2-M2	Construction of steam pumping station in Lemmer Construction electric pumping station in Stavoren Construction pumping station in Harlingen Construction pumping station Lauwersoog

1. Letters refer to the type of construction. **S** is Sluice; **D** is Dike; **Bp** is inner Boezem inside polder; **M** is pumped (either wind- or fuel driven); **Bm** is boezem system with pumps;
2. Numbers refer to the development stage. The number 1 is used for the first constructions, number 2 for the first upscaling phase, number 3 for the following upscaling phase etc.

CONCLUSIONS

Drainage will continuously require adaptation measures and creates an increasing dependency on human interventions to reduce risks for flooding. The technical infrastructure becomes more complex and fragmented and the costs for water management increase gradually.

Different stages of water system (or polder) development can be distinguished. Awareness of the actual stage of development in a drained peatland site enables to predict the next stage in its development. This recognition allows a better decision making on required adaptation strategies such as continuation of the actual agricultural land use or transformation into e.g. restored wetlands.

The presented typology allows a better understanding on the actual stage of development of a drained peatland at a given site. It also gives a tool to predict the future stages in development.

It will contribute to a better analysis of expected developments in water management and to be prepared in time for implementation of adaptation measures.

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