Brackish groundwater response to eco-hydrological management

> Naardermeer wetland The Netherlands

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1. Introduction

Fens in The Netherlands

- species-rich vegetation
- high biodiversity
- international importance

Deterioration past decades

- drainage for agriculture
- GW extraction for industry / drinking water





Example: Naardermeer wetland

- located on flat river plain
- bordered by upland recharge area
- providing GW seepage at its foot

Fens depend on this GW seepage:

- permanent wet conditions
- alkaline, nutrient-poor water



2. Natural flow pattern

→ GW seepage at foot of upland recharge area
→ ... fen development



3. Disturbed flow pattern

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- a) Drainage on river plain (agriculture)
 - → … lower actual SW (+ GW) levels + Peat subsidence
 - ... cascade of infiltration seepage systems
 - ... Naardermeer now loses water to downstream polders



b) GW extraction upland recharge area (industry / dr.water)

- \rightarrow ... lower GW levels recharge area
- \rightarrow ... less seepage in Naardermeer







Drainage + GW extraction

deterioration fen biodiversity

4. Restoration plans

Fen restoration now underway

- \rightarrow reduction GW extraction
- \rightarrow raising SW levels

(upland recharge area) (river plain)

But.... no consideration of brackish GW present 📩



Brackish GW related to a former sea arm to the north



... several floods took place in historic times



... brackish water then recharged the aquifer from above ... by density driven flow (fingering)



Post, 2004

... with largest densities concentrating at aquifer bottom



5. Brackish GW interference

Brackish GW may interfere with restoration

- → fens need fresh GW
- → brackish GW nutrient-rich

We modelled effects of:

a) Drainage + GW extractionb) Restoration scenarios

on present distribution brackish GW ,, future ,, ,,

Model:

- 2-D vertical section
- density dependent groundwater model (MOCDENS3D)
- run time 250 years

 \rightarrow a) Historic effects of Drainage + GW extraction



Chloride (mg/l)

Verification:

•compare present Chloride distribution with model

 \rightarrow



model pattern comparable to field measurements

Model results







- 1. Continue current management
- **2. Stop GW extraction** (upstream)
- 3. Raise SW levels

(upstream) (downstream)







3. Raise SW levels





6. Conclusion

Continuation current hydrological management

- Naardermeer becomes fresher
- Fen vegetation will (eventually) improve
- Stop GW extraction + Raise SW levels
 - Still freshening, but slower
 - Vegetation will improve slower



 \rightarrow restoration has drawbacks



Counter-intuitive results !

Restoration slows down (natural) freshening

Policy & management should incorporate these findings

- adjust actions
- add compensation measures
- •...

