

Long Term Subsidence Study part 2: review summary

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- This note reviews the results of the Long Term Subsidence study as documented in ([link1](#), [link2](#)).
- After 30 years of monitoring subsidence development over the Ameland field none of the geomechanical models put forward in the LTS study could reproduce measured subsidence within reasonable statistical limits.
- The most likely model places the Ameland subsidence bowl about 1 km east and the peak subsidence rate about 5 years later then where it was measured. It failed in particular to reproduce the distinct shift of the subsidence bowl over time towards the southern aquifer. This shift/concentration gathers speed over time and is hence highly relevant for the reliability of subsidence predictions for the vulnerable Wadden Sea area:

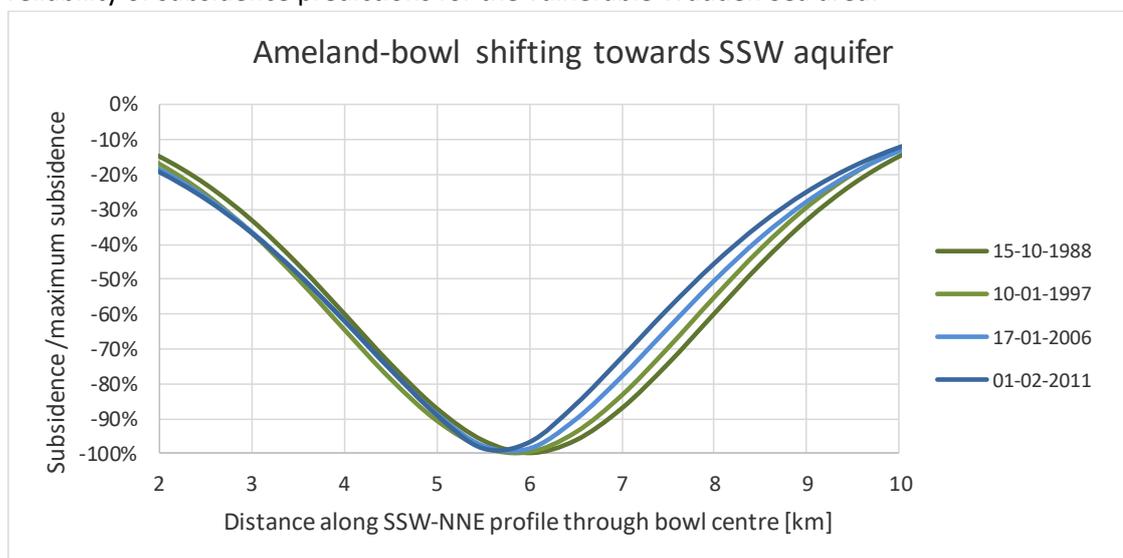
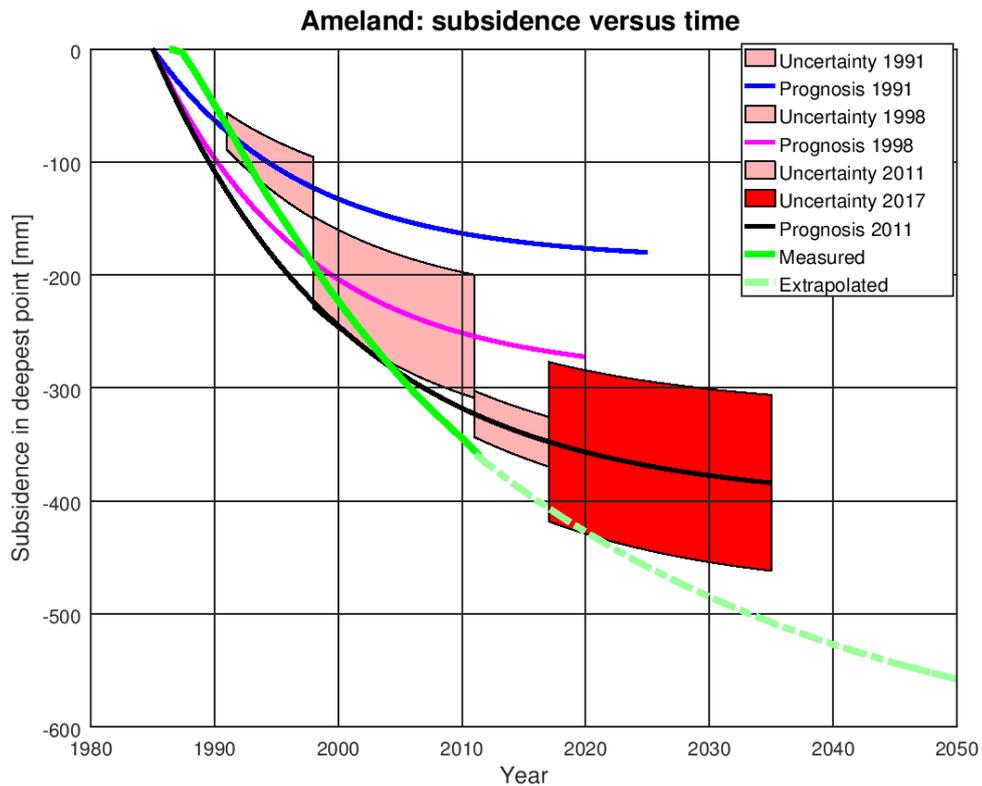


Fig. 1: Normalized subsidence. Wadden Sea/Island & aquifer/gas at 4.5 km, Island/North Sea & gas/aquifer at 6.2 km.

- While aquifer depletion contributes as much to subsidence as gas reservoir depletion, it hardly affects pressure in the gas reservoir. Aquifer depletion can therefore not be inferred from pressure development in the gas reservoir. The subsidence contribution of aquifer depletion will remain unknown till measurements of rising gas-water contacts, aquifer pressure development or different subsidence rates above gas and water bearing reservoir, become available.
- Each scenario tests different assumptions, but not all plausible assumptions are tested.
 - Can skin-factors cause biased reservoir pressure distributions?
 - Is residual gas really the show stopper for aquifer depletion?
 - Is over- and underburden deformation volume-neutral?
 - Is the relation between overburden stiffness parameters and bowl shape correct?
 - Is the range of alternative hypothesis permutations adequately covered?
 - Can a time decay relation between aquifer and gas reservoir depletion combined with linear elastic compaction explain the modelled-measured divergence?
- Errors in such untested assumptions could account for the persistent χ^2/N overruns. Overall χ^2/N tests cannot distinguish between higher noise levels, evenly spread over space and time, and a model bias, such as underestimated aquifer depletion, under normal noise levels.

- ESIP/ Red Flag is a smoke screen, not an analytical tool. It can demonstrate acceptable subsidence for an infinite number of scenarios, but not for the one, unidentified, true scenario, that matches measured subsidence.
- No valid conclusions can be drawn from models, that fail validation against measured subsidence. This includes conclusions on the potential of 'Hand on Tap' production to keep future subsidence within acceptable limits.
- Scaling up noise models may force acceptance of historical differences between modelled and measured subsidence in the χ^2/N test, but does not guarantee, that future subsidence will not immediately run out of bounds again:



- Detection of specific errors in geomechanical models or its parameters, requires comparison of observed spatio-temporal patterns of differences between modelled and measured subsidence with those expected, if the errors actually occurred (B-method of testing).
- Conclusions
 - NAM steered LTS effort predominantly to scenario's and methods that could not possibly lead to uncovering the physical cause of excessive long term subsidence.
 - While measurements consistently point to slow aquifer depletion as the most likely cause of delayed subsidence, questionable testing procedures dismissed it as unlikely. Depending on aquifer volume, its depletion can account for many times more subsidence and earthquake potential than gas reservoir depletion alone.
 - The reliability of model based subsidence predictions is shown to be much worse than previously assumed. It does not allow reliable balancing of economic, safety and ecological interests prior to production.
 - As the true nature of consistently observed divergence between modelled and measured subsidence could not be identified, the ability of 'Hand on Tap' production to keep future subsidence within safe limits, is not proven.