NAM

Asset Groningen
*W*ell, *R*eservoir & *F*acilities *M*anagement plan 2013

Document #: EP201307211252

Table of Contents

Executive Summary

The main objective of the Well, Reservoir and Facility Management (WRFM) Plan is to maximize the asset lifecycle value; to reduce future development uncertainties and to meet or exceed production, reserves and cost forecasts. This is illustrated in *Figure ES.1*.

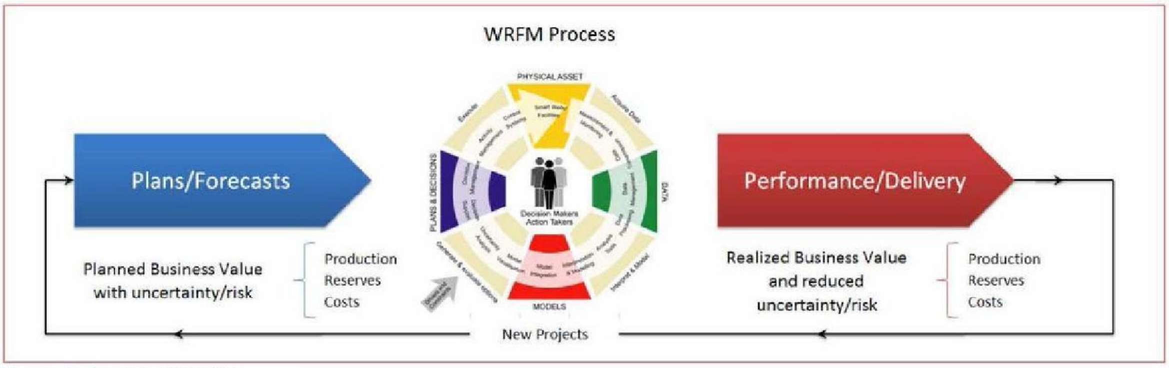


Figure ES.1 – The WRFM process

WRFM is often described by means of the Smart Field Value loop, i.e. how data acquisition plans and data gathering is being managed as input to the surface and subsurface System Models. These System models are used in multi-disciplinary reviews, to optimize daily operations and to find opportunities (and threats). The opportunities and threats are collected and prioritized in one common opportunity register (LIP-T) and planned for execution in the Integrated Activity Plan (IAP). After execution new data is collected to update models and Short and Long Term forecasts, i.e. the loop is closed. As a yearly cycle the WRFM plan is updated and next year's well and/or cluster activities are planned in the IAP. Progress against plan is tracked on a monthly basis through the BPR process; with LIP-T, WRFM KPI's and WRFS tracker sheet.
With the GLT renovation and the long term focus of the asset, the basis was made for high quality WRFM practices for the Groningen System.

With new technology installed on the renovated clusters during the GLT renovation, on-line "exception based surveillance" (EBS) has become common practice for facilities and wells; On-line sand monitoring and annulus pressure monitoring have shown to be very effective already for several years. Tools as CAnS (Capacity Analysis System) and WellMon were introduced to facilitate effective on-line facility and well monitoring using data filter techniques to sample the right quality production data. In 2010 CAnS was phased out by Wikker which will further improve and automate data validation and monitoring.

The Groningen WRFM plan contains a short description of the Asset, followed a description of the current status of the various elements in the WRFM process, including a summary of the WRFS plan. It shows our strategies, focus themes and improvement initiatives.

In 2010 efforts were made to LEAN the WRFM/WRFS planning:

- The WRFM plan was expanded to include WRFS activities (to be updated annually)
- The WRFS plan has been slimmed down to become a strategy document only; describing justification, frequency and responsibilities etc. It will be referred to in the WRFM plan as a reference document (EP201102208019), to be updated only if the strategy changes.

1 Asset Background

Please see Appendix A for a more elaborate description of the Groningen System (Groningen, Grijpskerk and Norg; reservoir, wells and facility descriptions).

The Groningen Production System consists of the Groningen Field and the two Underground Gas Storages at Norg and Grijpskerk. A third Dutch UGS at Alkmaar, operated by TAQA, also forms part of the Groningen System for capacity purposes.

The UGS's provide additional capacity and working volume to support the declining Groningen field capacity. As illustrated in *Figure 1.1* the total volume produced from the UGS's during the winter is currently re-injected during the summer, the injected gas originates partly from Groningen and partly from the small fields in the Netherlands and partly from imports.

In the future with declining capacity of the Groningen Field, the field will produce with a higher load factor and the UGS's will play a larger role in providing the swing production (see *Figure 1.2*). The periods of re-injection will be longer and may become "opportunity based" in the winter.

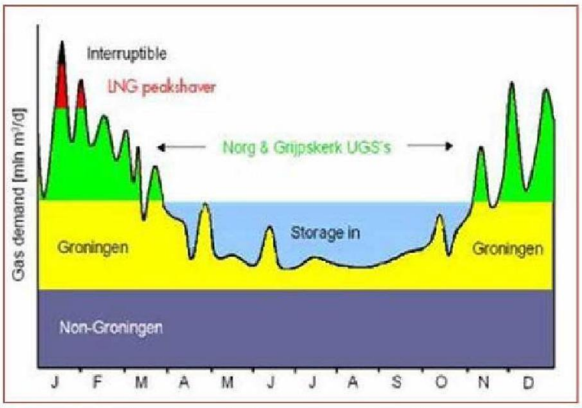


Figure 1.1 – Groningen balance capacity role

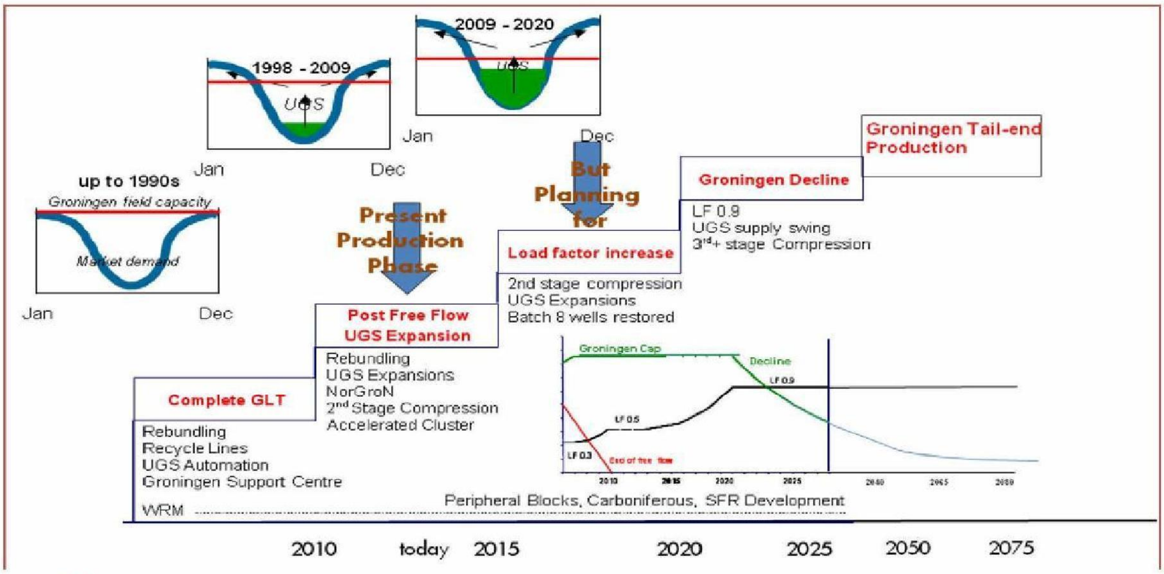


Figure 1.2 – In the future Groningen's load factor will increase and the UGS's will play a more important role

The future of the Groningen system will be shaped by 8 themes, an overview of these is shown *Table 1.1*.

Table 1.1 – Key themes for the future of the Groningen System

	Key Themes for the Groningen System	
1	**High load factor Operations: High reliability and Availability**	- Use smart automation GLT/UGS's - Seamless operations-maintenance organization - Smart data management - Facility and Wells performance monitoring Integrated Model calibration SPARC modeling (availability, reliability) - Groningen Support Centre: Condition based monitoring Daily
2	**WRFM**	- Periphery depletion - Aquifer behavior - Subsurface complexity requires more detailed models/improved reservoir and monitoring: IPSM models Groningen –UGS Advanced Reservoir monitoring: - Improved seismic imaging/4D seismic - Subsidence- MoReS models calibration
3	**Development Opportunities**	- 2 / 3rd stage compression - Development of the Carboniferous (20 mrd GIIP) Drilling through the depleted Slochteren Improved seismic imaging Fracturing Costs - UGS Expansion - Infill wells in periphery
4	**CAPEX Management**	- Optimal and flexible project delivery - Optimum well concepts - Further develop GLT-UGS technology
5	**Opex Reduction**	- Electricity optimization
6	**Environmental /Legislation**	- Gas quality - Subsidence monitoring - Energy conservation - Long Term Operability studies
7	**Earthquake Monitoring**	- Monitoring of the induced earthquakes is captured in the "Beheersprotocol voor Borging van het Seismisch Risico binnen grenzen" - Studies, research and data gathering into induced earthquakes is captured in the "Studie en metingen plan voor geïnduceerde aardbevingen 2014"

1.1 The Groningen Field

The Groningen field, discovered by the well SLO-1 in 1959, is the largest gas accumulation in Western Europe. It is located primarily in the Netherlands. The main reservoir comprises fluvial and aeolian sands of the Slochteren Formation (ROSL), which is part of the Permian Rotliegend Group. The gross reservoir thickness increases from some 70 m in the SE part of the field to 240 m in the NW. The ROSL comprises a fairly homogeneous mixture of fluvial and aeolian sandstones. The average porosity ranges from 10% to 25%, with the highest values in the central part of the field. The average permeability is 200 mD. Maximum porosity measured on cores is as high as 33% and permeability 6300 mD. The production mechanism of Groningen is gas-depletion drive.

With the completion of the GLT project in 2009 there are currently 258 producing wells located on 25 clusters. The earlier standard size clusters (SSC), situated in the south of the field, have wells with predominantly 7" production casings. These were originally completed with 5" tubing, but during later workovers some wells have installed 5"x5½" special clearance (SC) tubing.

The later king size clusters (KSC), located mostly in the centre and north of the field where the average reservoir porosity is generally higher and inflow performance better, have 7⅝" production casing and were originally completed with 5½" and during later workover 5½"x6" SC tubing were installed. In the 80-ies infill wells were drilled with 9⅝" production casing and 7⅝" tubing. One well, PAU-6, drilled in the 90-ies, has a 9⅝" completion.

Many of the wells have either internal plastic coating or a machined internal wall to improve tubing roughness and vertical flow. SET workovers took place in 2002 (EKL-2) and 2004 (ZVN-12 & ZVN-5) to replace 5½" tubing with 6" expandable and 7⅝" tubing.

Most clusters are well-constrained, rather than facilities constrained.

1.2 Underground Gas Storages

1.2.1 Grijpskerk

The Grijpskerk field was discovered by well GRK-1A in 1990. Originally, the Grijpskerk Main reservoir was operated as a conventional depletion field under the Groningen-Drenthe HiCal contract. Subsequently, the field was shut-in for conversion to an underground gas storage (UGS) and a total of six additional wells were drilled in Blocks 1 and 2 during 1995 – 1996. Post 1996, to increase working volume and capacity two more wells were drilled in Block 1. Those eight wells together with the existing GRK-1A and GRK-2 wells are currently used in UGS operation.

The facilities at Grijpskerk consist of ten producing wells and one observation well (GRK-3), a 80 mln Nm3/d production facility with two silica gel drying units and one 38 MW injection compressor installation. Four manifolds, each with a maximum capacity of 24 mln Nm3/day (whereby the HIPPS systems are the limiting factor). Fiscal metering for up to 84 mln Nm3/d has been installed. Additional metering is needed for expansion beyond this capacity.

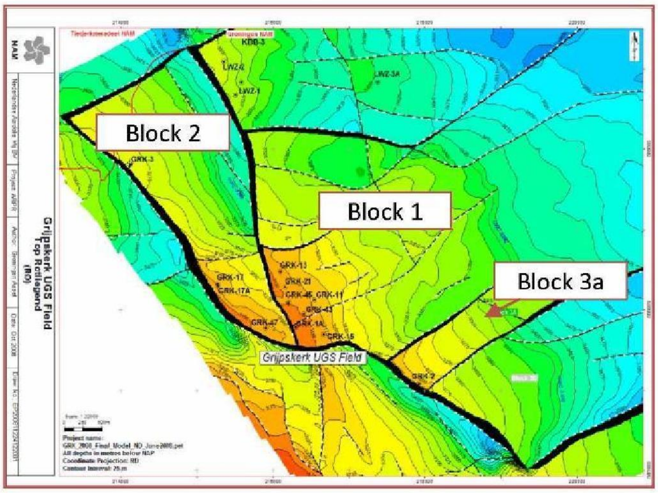


Figure 1.3 – Geological map of the GRK field

Grijpkskerk completions consist of a 7-5/8" Cr13 tubing with SSSV at +/- 100 m, inside a 9-5/8" production casing. Above the SSSV the tubing size is 7". Most wells have been completed with a 7" cemented liner across the reservoir. GRK-45 and -47 have 300 m Baker Slimpack screen across the reservoir section. Wells GRK-13/15/17a/43 have 7" pre-packed WWS installed below the packer, as part of the tail pipe as a contingency for sand control. In case of unacceptable high levels of sand production, a wireline retrievable WWS can be installed to plug off and actuate the 7" WWS, as done in GRK-13 and GRK-15. In wells GRK-17a and -43 the WWS have been left open. It should be noted that this contingency measure is no longer recommended since it has been found difficult to remove the wireline retrievable WWS- plug again from the screen because of fines blocking the lock-mandrel (NOR-5 and GRK-15).

1.2.2 Norg

The Norg field is located in the northern part of the Drenthe Concession. Originally, the field was operated as a conventional depletion field under the Groningen-Drenthe HiCal contract. Subsequently, the field was shut-in for conversion to an Underground Gas Storage (UGS) and a total of five additional wells were drilled.

Currently Norg has eleven wells in total. Seven UGS wells (7 5/8") have been drilled from three well clusters (i.e. Cluster 2, 3 and 4). In addition to these production/injection wells, there are four observation wells. Each cluster is provided with an inlet manifold and is hooked up to inlet separators and production coolers, which are in turn connected to two processing trains. These inlet facilities can accommodate the flow of five wells per cluster, with a maximum capacity of 24 mln m3/d. The plant has space for two additional well clusters with corresponding production manifolds. The nameplate plant capacity is 80 mln Nm3/d. Due to limited production cooler capacity the actual capacity is only 48 mln Nm3/d (2 * 24) at a design ambient temperature of 5 Deg. C.

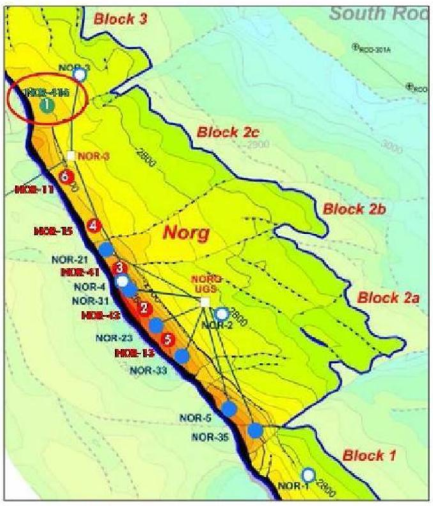


Figure 1.4 – Geological map of the NOR Field, including leaning well NOR-416 (green) and the Norg expansion wells (red)

2 HSSE

A good HSSE performance is critical in the WRFM process. This paragraph addresses the most important HSSE issues with respect to WRFM.

Critical Activities

A list of key critical activities executed in an asset with respect to WRFM is shown below in *Table 2.1*. This list also shows the accountable discipline and serves as a checklist for the technical authority before approval of any of these activities.

CA #	Activity	Potential Impact	Explanation of signatories (TA2)	Accountable discipline
17	Establish safe operating boundaries. Safeguard the technical integrity of the well and avoid uncontrolled fracturing of subsurface formations, including CRI operations	Loss of Well Integrity. Uncontrolled injection fracture growth. Shallow aquifer contamination and loss of structural integrity.	As Technical Authority for the lifecycle of the well, the PT has to check that the following activities have been carried out to establish safe operating boundaries (maximum allowable annular surface pressure, max closed in pressure, max injection pressure, erosion and corrosion limits, etc) to prevent loss of well integrity. 1. Checked that tubing stress analysis is carried out for life cycle operating conditions to ensure well integrity, e.g. stimulation to ensure well integrity, selection of completion components, e.g. packer, tubing hanger etc. 2. Checked and agreed with project WE that: • Tubing and casing stress analysis are compatible • Casing setting depth has sufficient formation strength to contain pressure at the shoe through flow behind casing, casing leaks • The barrier concept is sufficiently addressed to ensure well integrity. • The well kill philosophy is addressed 3. Assessed whether injection will be under matrix injection or fracturing conditions. Assessed lifecycle suitability of target formation. Conducted PWRI-Frac analysis to check integrity of reservoir cap rock. 4. Checked that cement bond log has been properly interpreted. WS Responsibility 1. Checked that relevant MAASP is indicated on the respective annulus. 2. Checked that trigger levels (below MAASP) are indicated for bleed off. 3. Checked that bleed off lines are available.	PT
23	Prepare and maintain data to support emergency response. Arrange duty cover for ERO.	Lack of data or wrong data during emergency response may aggravate the emergency	Checked that the following activities have been carried out to support emergency response: 1. PT leads to update the ERO "Traffic Light Spreadsheet" on a quarterly basis for their asset and check and ensure that the ERO critical well information is up to date and readily made available to support emergency response eventualities. 2. ERO critical well information has been defined as Well status (including well head information. Note "as built" diagrams are validated by WS.); Well integrity data; MAASP data; FBG, leak-off data; CBL/VDL; Reservoir Pressures; Well Kill information; Well rates; Petrophysical data; Reservoir fluid composition; Gas plume calculations and Geological data. 3. PT and EPX leads to arrange weekly duty cover for the Emergency Response Organisation; ensure that a rota is in place for the T-D and EPX disciplines; see 1st link for guidance on both ERO maintenance and duty cover.	PT
24	Operate wells within safe operating envelope. Safeguard the technical integrity of well. Revise operating boundary as required.	Loss of containment, asset damage, loss of well	1.Monitor the well to ensure it is operating within design envelope 2. Review MAASP/MAWOP and revalidate as required (e.g. changing circumstances) 3. Conduct Technical Reviews / Investigations for any excursions as dictated by the Well Failure Model. Advise on tolerable times to repair. 4. Conduct Risk Assessment and prepare deviations to standards. Maintain valid Well Status Diagram.	PT

Table 2.1 *– Overview of 3 important safety critical activities*

Well Integrity Management System (WIMS)

WIMS was developed in 2007 as a global platform through which the integrity status of any well could be accessed from any computer on the NAM network. It is also used for the Groningen field and it enables an objective comparison between the well integrity statuses of different assets and also allows a quick overview of which wells need attention. These wells all have an action code attached to them according to the Well Failure Model (accessible through help-file in WIMS). This is also the major benefit of WIMS: it is an excellent tool to ensure proper action is taken on safety critical issues regarding the integrity of wells and therefore plays a key role in WRFM. *Figure 2.1* shows a screenshot of WIMS.

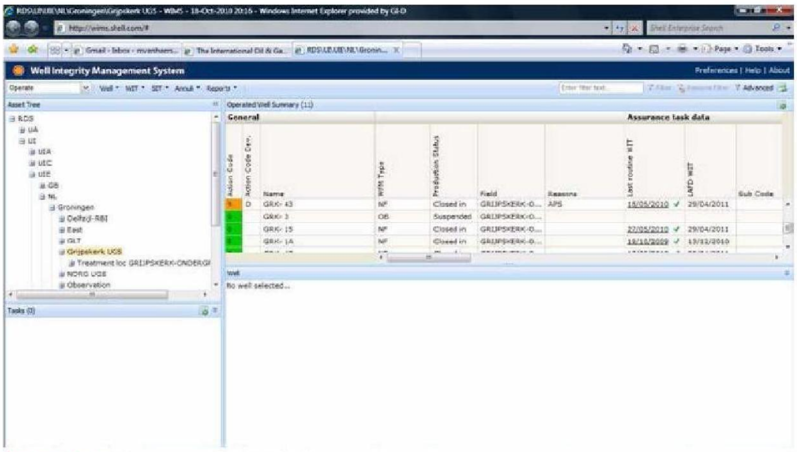


Figure 2.1 *– Screenshot of WIMS*

Regulatory and Statutory Requirements

For regulatory and statutory requirements please see section 3.1.

3 WRFM Strategy

The Groningen Asset Well, Reservoir and Facility Management strategy is to maximize the short and long term value of the Groningen Production System in terms of Capex, Opex, capacity and working volume through optimization of the Groningen production strategy, well related activities, facility renovation and expansion programs.

The main themes have been identified for the future of Groningen:

- *Short Term Capacity Optimization and Planning*
  As the pressure of the Groningen field declines, the requirements for well surveillance and short term capacity measures are expected to require increased attention, to be prepared for winter 2013/2014 and beyond;
- *Availability*
  Ensure the required down time allowance (DTA) is achieved in order to meet the current and future security of supply criteria in joint study with GasTerra;
- *Long Term Operability (LTO)*
  Development and optimization of system production strategy in conjunction with GasTerra;
- *Long Term Distribution (LTD)*
  Analyses and de-bottlenecking of the current and future gas transport system of both NAM and GTS in joint study with GTS;
- *Energy Sourcing*
  Electricity optimization will become more important in the future, as the free flow capability in Groningen ends and all flow becomes dependent on compression. Hence, electricity will become a major Opex element.
- *Ultimate Recovery*
  To maximize the long term value of the asset, the surveillance plan is optimized to increase understanding of reservoir and aquifers and to update the field's depletion policy (see sections 3.5 and 4.2).

3.1 Legal Requirements

The legal requirements as agreed with the ministry of Economic Affairs for the Groningen Asset (Groningen Field and Norg- and Grijpskerk UGS's) are described in *Table 3.1*.

Field	Legal Document	Legal Requirements	Next Reporting Date	Accountable Staff
Groningen				
	Winningsplan	Regular registration and reporting of well pressures depending on relevance. Reporting incidences of subsidence to the Dutch Government as per Winnings/ Opslagplannen [70] (section 2.5.3.1, 3.5.2.1., 4.5.2.1). Monitoring of earth tremors (occurs continuously through the seismic measurement network that is under supervision of th KNMI, section 2.5.3.2)	Dec-13	CDL Groningen
Grijpskerk				
	Opslagplan 29-Jun-04 nr. ME/EP/UM/4032796		Dec-15	CDL Groningen
	Article 7	NAM reports to Ministry of Economic Affairs every 5 years on maximum allowable injection pressure. Last reporting on Nov 2010	Dec-15	Sr RE
	Article 8	Annual reporting on the integrity of the UGS to Economic Affairs before year end	Dec-13	WRFM Lead
	Milieuvergunning 13 december 1994 nr. E/EOG/MW/94091489	Annual reporting estimate of the average reservoir pressure to SodM before year end	Dec-13	Sr RE
Norg				
	Opslagplan Besluit 18 juni 2004 nr. ME/EP/UM/4032690		Dec-15	CDL Groningen
	Article 6	NAM reports to Economic Affairs every 5 years on the maximum allowable injection pressure. Last reporting was in Nov 2010	Dec-15	Sr RE
	Article 7	Annual reporting on the integrity of th UGS to Economic Affairs before year end	Dec-13	WRFM Lead

Table 3.1 – Overview of legal requirements and respective reporting dates

3.2 The key value drives for lifecycle asset value

The current role of the Groningen System is to act as a balance provider:

- Balance provider for volume & capacity;
- The system is permitted to fail only 1 hr in 20 years (security of supply);
- Swing producer for NW-European market;

The business target for Asset Groningen is to provide production capacity to meet the annual capacity demand (Groningen Bestelbrief Capaciteit (GBC)). Actual production is the result of market demand, heavily influenced by spot sales and ambient temperatures. Gasunie Transport Services (GTS) is formally responsible for the security of supply in the Dutch gas system. The main value driver for Norg- and Grijpskerk UGS's is maximizing the value of current asset; installed wells and facilities, to provide capacity and working volume to support GasTerra's requirements. Throughout the year, NAM/GasTerra/GTS have frequent contact to optimize the use of the Groningen field vs. the UGS's, to optimize both production and injection plans.

In the future, when the Groningen field moves into the depletion phase, the role of the Groningen asset will change. To maximize the long term value, continuous attention is given to reserves and ultimate gas recovery. Good understanding of the reservoir behavior is the basis for the Well and Reservoir surveillance plan, which concentrates strongly on pressure monitoring and gas water contact movements. In 2012 the Groningen Field Review was completed to account for the above requirements. (Previous GFR completed in 2003).

3.3 The key development decisions to be taken

For the Groningen asset, optimizing asset value in terms of Capex means that the expansion plans are continuously being optimized and annually updated; in line with the capacity requirements and aiming to prevent investments from being executed too early. This is done with a joined GasTerra – NAM annual capacity study, with a proposed timeline for implementing the various projects as an outcome.

Currently, the most attractive opportunities are the expansion of Norg UGS (in both capacity as well as working volume) and the Groningen capacity measures 2nd and 3rd stage compression and rejuvenation of batch #8 clusters of Groningen. Next to these, other "building blocks" that are being considered are:

- Development of Groningen peripheral blocks (e.g. work-over and hook up of observation well KHM-1, North-West periphery, South-West periphery);
- Development of Carboniferous resources;

3.3.1 Norg Expansion

To enable the future expansion on Norg as currently forecasted by PRISMA, significant efforts must be made to lean the reservoir. Before being converted to a UGS, the Norg field contained Hical gas. As a UGS it is supporting the LoCal market (Groningen quality gas). Since 2/3 of the reservoir is filled with HiCal gas, a larger part of this volume will have to be replaced by LoCal gas (i.e. leaning the reservoir). To accelerate leaning, in 2012 a new well, NOR416, was drilled in Block 3, north of the current UGS wells. Higher Wobbe gas is being produced from this well since December 2012, enabling movement of LoCal gas to the north.
To track the progress of the leaning of the reservoir regular Wobbe Index measurements on the gas stream from the leaning well and other wells are being done, especially late in the winter at the end of the working volume.

The Norg expansion plan (capacity and working volume) consists of a:

- New intra-field pipeline (NorGron) between Norg UGS and the Groningen ring (planned entry point: Overslag Sappermeer); ongoing, planned to be operational Q4 2014.
- 3rd compressor is required for shifting larger volumes (above 4.8 mrd m3 per year).
- Some 2 more capacity wells are required during years 2014 (see *Figure 1.4 – **Geological map of the NORG Field***)
- New well areas (Cluster 1 and 4) have to be built with additional safety measures like a deluge system and improved gas & fire detection. These will also be retro-fitted at the existing well areas.
- The capacity of the gas treatment plant will need to be upgraded.

Tracking of the performance of the newly installed equipment will need to be carried out. Especially the compressor performance will need to be tested, monitored and evaluated regularly.

3.3.2 2nd Stage Compression

The installation of 2nd stage compression in the Groningen field is planned for the majority of the 20 production clusters that have 1st stage compression installed (scope reduction is part of a separate study, which also includes a re-examination of the batch #8 clusters). An accelerated installation of 2nd stage compression in Schaapbulten has been completed. An IPSM model, built as part of the GFR 2012 model update, is used to optimize the schedule and scope of 2nd- and 3rd stage compression as well as the timing of hooking up infill wells, based on capacity and project execution considerations.
The quality of the history match has an impact on the robustness of the decisions made. Maintaining a good quality history match hinges on availability of reservoir surveillance data, in particular pressure (SPTG), free water level (PNL) and performance (MRCT/PLT) measurements from the field.

3.4 The key uncertainties and opportunities to be managed

As Asset Groningen is playing a very special place in the European Gas Market as the balance provider for volume and capacity for future gas demand, which strongly impact the expansion plans. The largest uncertainties for the asset are related to the changing gas markets. A yearly joined NAM – GasTerra capacity study (PRISMA) is used to optimize future investment plans. With sensitivities for future market variations, an expansion plan is selected for the Business Plan.

The Asset Leadership Team have weekly meetings (ALT) and the business risks are identified and managed by the Asset Leadership Team. Furthermore, there is opportunity to discuss and get management steers during bi-weekly Groningen Development Strategy Coordination meeting.

3.5 The Depletion Policy

The Groningen Field is produced under a depletion production mechanism, and the main area of the Slochteren Formation is produced within a narrow pressure band. Production from the field is balanced to keep these pressure differences within the main area of the field to a minimum. Exceptions to this are the relatively small peripheral blocks at the southern and western extremes of the field. In these blocks, the reservoir pressure lags behind that in the main area of the Groningen Field. Dedicated production wells are planned in these areas.

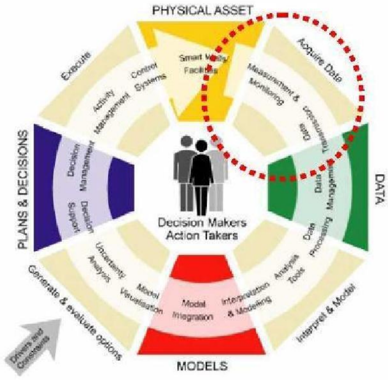
Towards the North (Waddenzee Area) and West the reservoir is connected to several aquifers. Water ingression from these is monitored with regular PNL logs in observations wells. The impact of these aquifers on the depletion of the field is at present modest and possibly constitutes a gas production risk. Later in the life of the field larger volumes of formation water might be produced in the wells in the northern and western clusters.

The field is used as a swing producer, with offtake set by demand. As a result there are large daily and seasonal fluctuations in the offtake from the field. The field offtake is limited by the Groningen Cap, a regulatory maximum production volume for a 10 year period (at present set for the period 2006 to 2015 at 425 mrd Nm3 sales).

The "Technische Levering Contract" requires the Groningen gas quality to be maintained within a Wobbe Index (WI) band of 43.46 to 47.2 MJ/Nm3. However in practice, because of requirements of the pipeline grid, the WI is maintained with narrower operational band of 43.46 to 44.41 MJ/Nm3. In the main area of the field, the quality of the produced gas is within this band of the WI. However in the periphery of the field, gas quality in some of the blocks has a slightly higher WI, which exceeds the upper band value. Production from wells with high WI gas is blended in order to keep the sales gas quality within the operational WI range.

As Norg and Grijpskerk are used for underground gas storages, the general policy is that the volume produced during the winter is re-injected during the summer months to ensure similar capacity for the following winter.

4 WRFM Data Acquisition



For a field of the size of Groningen, a sophisticated data acquisition strategy is of essential importance. The "old" Well, Reservoir and Facilities Surveillance Plan (last update for 2010, see reference [1]) describes which surveillance activities are being executed for the Groningen, Norg and Grijpskerk fields, with some background information, justification, frequency, data storage and responsible parties. In the future a slimmed down version of this strategy document (ref [2]) will only be updated if the surveillance strategy has been changed.

As the Groningen field contains 258 producing wells, located on 25 clusters, data acquisition is done by means of a large amount of sensing equipment at surface whose signals can all be monitored online via Exaquantum and/or PI. This data is being utilized on a day-to-day basis through various EBS (Exception Based Surveillance) sheets to efficiently monitor well integrity and performance and to calibrate models, which are then used for taking decisions as part of the short, medium and long-term optimization of the field. Through closer monitoring of the data produced from a well during production, it is possible to:

- Make a more accurate estimate of the reservoir size and improve recovery;
- Anticipate problems and increase efficiency;
- Make any necessary changes as work proceeds;

4.1 The testing, metering, sensing and control equipment considered critical to WRFM

The Groningen field and the UGS's make extensive use of a variety of sensors at its wells and clusters. This paragraph will start with an overview of a typical well and its relevant metering/sensing/testing and control equipment, see *Figure 4.1*, and will subsequently go into several of these in more detail.

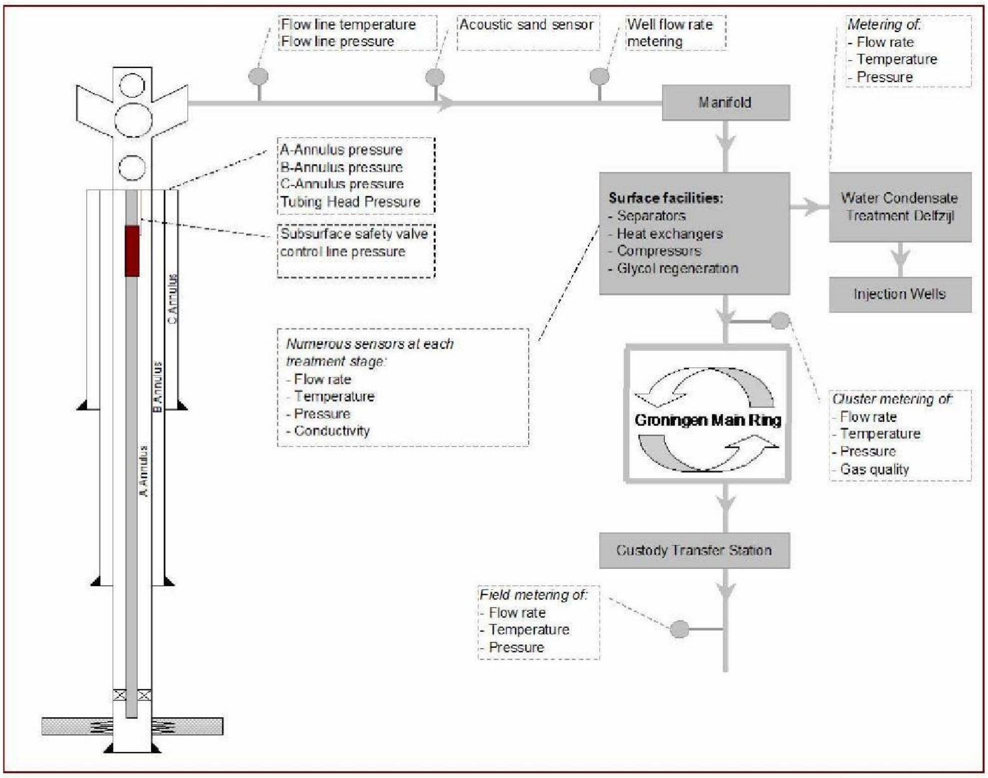


Figure 4.1 – Typical sensor equipment from well to gas transfer point

In total, there are over a 1000 signals being acquired/transmitted from a typical Groningen cluster, a large amount that requires careful management. This topic will be discussed in more detail in the next chapter (5). The following sections will go into more detail regarding three important types of sensing equipment being used in the Groningen asset:

- Sand detectors;
- Annuli pressure sensors;
- Gas quantity and quality meters;

4.1.1 Sand Monitoring

Due to high velocities, continuous sand production could pose a threat to the integrity of the well and production facilities. For this reason online sand monitoring was installed on all wells during the Groningen Long Term (GLT) renovation of all the field clusters (in the period 1998-2009). This was done as the wells would be producing at lower tubing head pressures than before and with the higher drawdown occasional high levels of sand production could be expected. The UGS wells were equipped with these detectors upon their startup in 1997-1998. In general, the Groningen wells produce low levels of sand, approximately 0.2 kg of sand for every million Nm3 of gas.

Figure 4.2 – Sand detector mounted on a flowline

The sand detectors are based on ultrasonic signals and register the collisions of sand with the walls of the flow line. The detector transmits signals of various strengths, depending on the amount of sand, to a computer that translates these to sand rates which can be monitored via PI and an EBS system (see *Figure 4.3* and *Figure 4.4*).

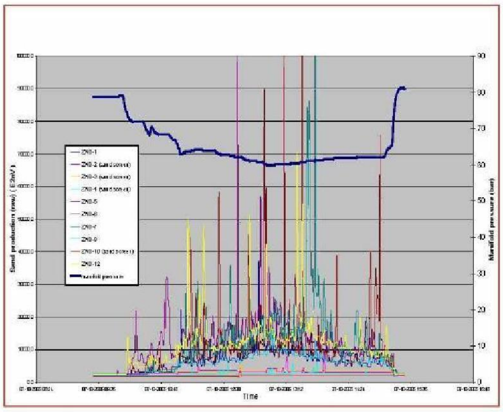


Figure 4.3 – Sand detector signal in PI processbook

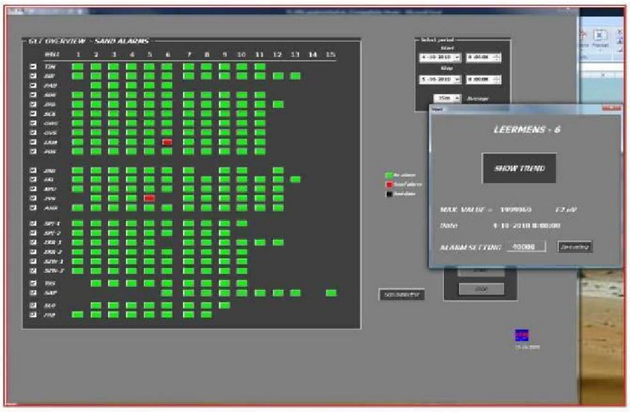


Figure 4.4 – Screenshot of EBS for sand alarms

There are two manners through which the issue of possible sand production is being addressed:

- *'Pre-conditioning'*
  Before the winter season, as required selected wells are produced at the same pressures as would be expected during a cold winter; this involves significantly lowering the tubing head pressure, which allows the perforations to be cleaned from 'loose' sand. Also, problem wells will become visible before the winter at a moment when action can still be taken;
- *Add/Re-perforating*
  Some of the wells, especially those that were perforated to target only the high porosity streaks, were initially not able to reach sand-free levels with compression. These wells were add/re-perforated in order to reduce the drawdown and flow per perforation;

The sand detectors are of particular importance at the UGS's, as the risk of sand production there is higher due to the effects of cyclic loading. These sensors were calibrated in Q1 2010 in order to improve the translation of raw sand signal into a sand rate in [kg/hr]. Sand calibration will be completed on Grijpskerk in Q1 2014, the results of the calibration will be compared to the 2010 results, and from there a decision will be made on the requirement and frequency of future calibrations.

4.1.2 Managing Annuli Pressures

Dependent on the well completion and casing design, the wells will have two or three annuli (see *Figure 4.1*). To identify potential integrity issues such as pressure communication between casings and the effect of increasing pressures due to salts squeezing against casings, the pressure of each annulus is being monitored and before the pressure reaches a maximum pressure (MAASP – maximum allowable annulus surface pressure), it is bled off by typically ±20 [bar].

The signals from the annuli pressures are being monitored with a 'traffic light system' (EBS, see *Figure 4.5*), which triggers a red alarm above a pre-determined threshold. In this manner timely action can be taken; for the Groningen clusters which have a remote bleed-down possibility, this means that the operator carries out pressure bleed-down from the control room. For all UGS wells, except NOR-416, the pressure bleed-down has to be done on site by an operator who also registers the activity in eWIMS. NOR-416 has a remote bleed-down system installed, all other Norg wells will be modified the same as part of the well area project.

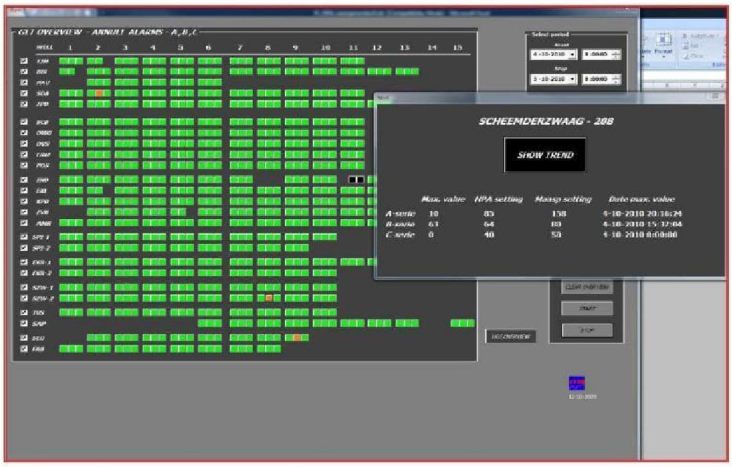


Figure 4.5 – Screenshot of EBS for annuli pressures

The alarm values are based on Maximum Allowable Annulus Surface Pressure (MAASP) calculations and test results carried out on all clusters. During these tests a 'fingerprint' was obtained of the pressure characteristics of the annuli during well production.

4.1.3 Gas Quantity & Quality Measurements

Gas Quantity

Groningen gas production is metered at three different levels:

- Individual wells;
- Per cluster;
- At transfer stations (overslagstation (OV)), fiscal metering;

Different accuracy is required for the various flow meters depending on if the measurement is being used as fiscal meter or not. *Table 4.1* shows the required instrument accuracies as well as the actual values that are currently being achieved in the Groningen field (production accuracy for UGS's).

	Groningen			UGS Area			
	Individual Well Level	**Cluster Level**	**Overslag Level**	Wells NOR	Fiscal NOR	Wells GRK	Fiscal GRK
Classification	not officially classified	not officially classified	Class I	Class III	Class I	Class III	Class I
allowed error	10 [%] (class III)	10 [%] (class III)	1 [%]	20 [%]	1[%]	20 [%]	1[%]
Flow meter type	Ultrasonic	Ultrasonic	Ultrasonic	Ultrasonic	Orifice (will be Ultrasonic)	Venturi	Orifice
Instrument Accuracy	1 [%]	0.5 [%]		1 [%]	1 [%]	>1 [%]	0.5 [%]
System Accuracy	2 [%]	2.0 [%]	1 [%]	2 [%]		-	
Accuracy Stability, recommended calibration once per 8 years	0,5% per 8 years	0,5% per 8 years		0,5% per 8 years		-	
Maintenance frequency (i.e. visual inspection and online test)	As required	once every 2 years	twice per year	once per year	4x per year		4x per year

Table 4.1 – Overview of metering equipment

The accuracy of the installed metering equipment exceeds those prescribed by the Metering and Well Testing Minimum Standard and hence, calibration is preferably carried out as little as possible. This is also due to the fact that calibrating a metering sensor requires a shut-down of the well or, when calibrating a cluster meter, a whole cluster. This is undesirable and hence, other methods are being used to ensure that the high accuracy is being maintained. An EBS is in place to monitor the difference of cluster- to OV (fiscal)-meters and between cluster- and individual well-meters, see *Figure 4.7*.

***Figure 4.6** – Ultrasonic flow meter*

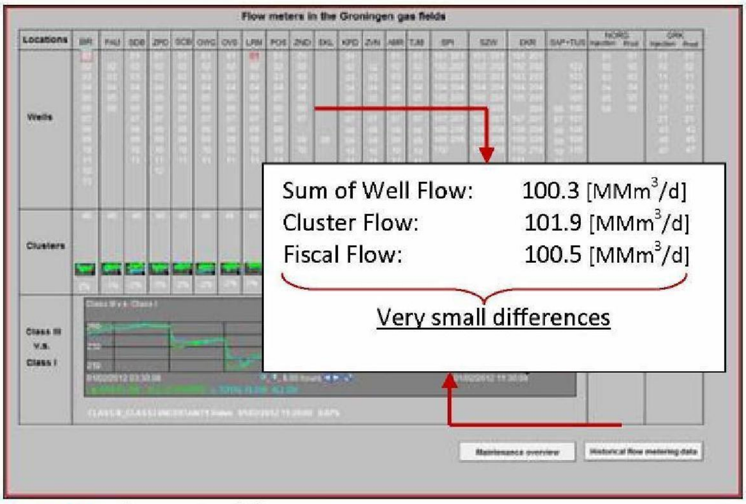
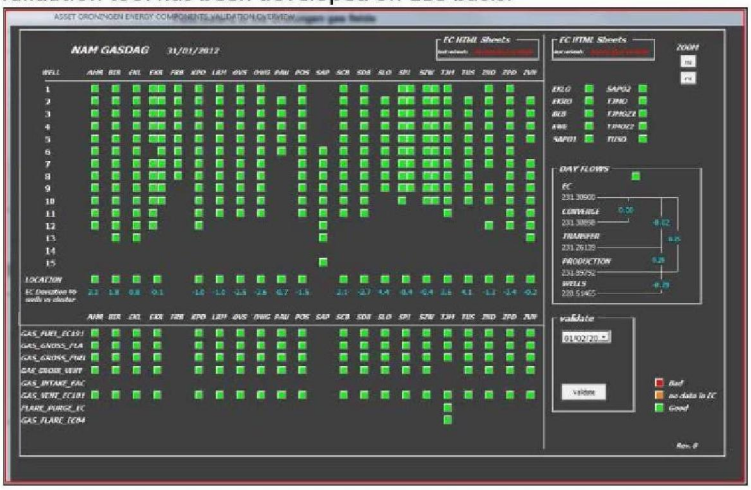


***Figure 4.7** – Flow meter differences*

Since 2010 the hydrocarbon allocation is done by EC (Energy Components). Earlier this was done by MEDEA. For Groningen hydrocarbon allocation (HCA) is done from the OV's (fiscal meters) to clusters based on cluster meters and within the cluster to wells based on well meters (earlier this was based on well split factors). In the past the well allocation was not as critical as the reservoir models have been matched to the cluster production with one Super-well. With the introduction of EC the HCA is based on individual well meters. An EC validation tool has been developed on EBS basis:



In the future when the reservoir model will be based on individual well performance, the HCA on well level will be more important.

Well Testing

According to the Minimum Standard all gas wells should be tested on a quarterly basis, with a metering accuracy of +/- 20%. As all production/injection wells in the Groningen system have individual flow meters with a high accuracy (<5%) and the liquid flows are monitored on cluster levels (produce relative dry gas; CGR: 0.8 m3/mln m3 and no significant free water), a waiver has been approved for not executing well tests.

However, cluster tests are executed once every 3 years for all Groningen clusters for GenRem calibration. For Norg and Grijpskerk UGS's, dependent upon the level of depletion, tests to confirm maximum sand free rates for all wells should be carried out towards the end of the production season. This data is used to update the sand free rate correlations which are used for capacity forecasting purposes. During these tests, flows are measured by the individual flow meters and cluster meters; the sand production is measured using the in-situ Clampon sand monitors. In 2012 injection tests were completed on the majority of the UGS wells to validate the well injection models. These tests showed that only minor adjustments were required to match the models. Therefore in 2014 further injectivity tests should only be executed if there is concern about the performance of a well (and only as much as the injection plan allows for, which was not the case in 2013).

Liquids in Groningen are measured on cluster level. An IT-tool has been developed to enable easy monitoring of water and condensate production and calculated WGR and CGR for each cluster, see *Figure 4.8*.

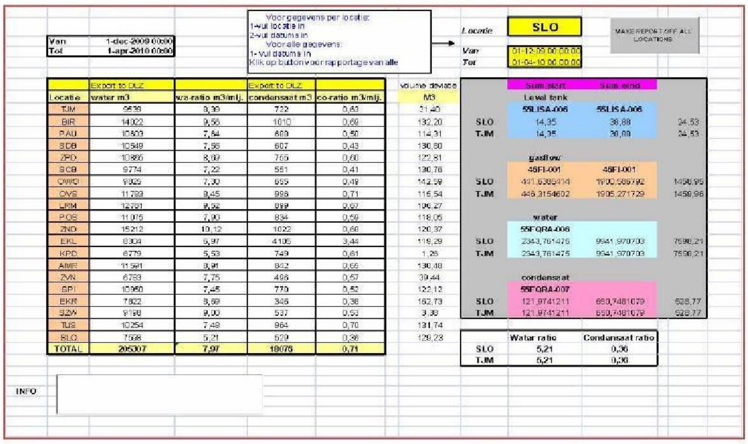


Figure 4.8 – Monitor for Groningen water and condensate production on cluster level

Gas Quality

By contract, the Groningen Field must deliver gas with a certain minimum calorific value (quality). As the different clusters do not all produce gas of the same calorific value, it is important that this gas quality can be measured constantly in order to enable a bean up or down of a cluster to ensure the Groningen field delivers gas within agreed gas specifications (dew point, mercury content, glycol). For this reason, gas chromatographs have been installed at all of the Groningen Overslagen.

For Norg UGS the gas quality is highly important as the initial Hi-cal field is being used as UGS for LoCal gas (UGS Grijpskerk is HiCal gas). To ensure long-term delivery of the right gas quality, both injected and produced gas is continuously monitored for Wobbe Index. In 2008 gas chromatographs were installed on each well flowline to improve WI management with future increased working volumes. The system has been upgraded as part of Norg leaning well project to provide more comprehensive control of the WI, required for operation of NOR-416.

4.2 WRFM Data Acquisition Plan ('WRFS Plan')

The Groningen Asset Well, Reservoir and Facilities Data Acquisition plan is updated every year to provide an overview of the regular surveillance activities required to mitigate the potential risks to the optimal performance of the fields operated by the Groningen asset. This is done as part of the IAP process.

The formulation of the WRFS plan builds upon earlier work detailing the needs and frequency of surveillance for the Groningen asset. After the close out of the Groningen Field Review, the remaining risks and opportunities (see section 3.4) were categorized in an overview in the first Groningen field WRFS plan (2003) defining the strategy together with actions to be taken to mitigate the risk or enable the opportunity to be matured. Legal/regulatory requirements are elements also included in the overall data acquisition strategy. The WRFS activities considered in the plan have been grouped in three different categories related to *1.*

1185017 2555

Delivery of contractual Capacity & Volume, *2.* Well Integrity and Reservoir Integrity and *3.* Ultimate Recovery. *Table 4.2* shows an overview of the different Surveillance activities, their frequency and the accountable discipline within the Groningen Asset. *Table 8.1* shows the activities planned for 2013. *Table 8.2* shows the activities planned for 2014.

WRS Activities		Frequency			Accountable Discipline
		Groningen	UGS Grijpskerk	UGS Norg	
Delivery of Contractual Capacity & Volumes	Surface data monitoring				
	-production/injection data (quantities)	Continuous	Continuous	Continuous	PPr
	-water & condensate production	Continuous	Continuous	Continuous	PPr
	Wellmonitoring (FTHP, Q, in- and outflow parameters (A,F, B and C))	Continuous	Continuous	Continuous	PT
	Multi Rate Cluster Tests	1/cluster/3yrs	-	-	RE
	Capacity forecasting	Continous	Annual	Annual	RE/PE/PT
	Pressure monitoring				
	-SPTG	1 per cluster/5 yrs or per opportunity	1/yr	1/yr	RE
	-online surface pressure monitors	Continuous	Continuous	Continuous	PT
	Flowing Build Up (FBU) measurement	2 provisional/yr	after major alteratinos	after major alterations	RE
	Gas composition monitoring	Cluster dependant field wide, once/8 yrs	1/1-2yrs	1/1-2yrs	PT
	Gas Water Contact monitoring				
	-PNL	well dependant	after significant depletion	after significant depletion	PP
	-Cl content, water influx measurement	1/cluster/yr and more if required	-	-	PT
	Production Logging (PLT) measurement		opportunity based	opportunity based	PT
	Silica gel adsorber beds ageing	-	1/yr	1/yr	PE
Well Integrity	General integrity measurements & investigations				
	-wireline HUD, driftrun checks (apart from other well entries)	5 wells/yr or need based	opportunity/ need based	opportunity/ need based	PT
	-SC-SSV operability		1/yr	1/yr	PPr
	-leak investigation (annuli and/or tubing)	3/yr	need based	need based	PT
	-camera survey	2/yr	need based	need based	PT
	-caliper survey (deformation)	2/yr	need based	need based	PT
	Sand production	Continuous + conditioning 1/yr	Continuous	Continuous	PT
	Corrosion & annular pressures	Continuous	Continuous	Continuous	PPr
	Squeezing salts	Continuous	-	-	PG
	SET integrity monitoring	well dependant			PG
	Tubing corrosion monitoring	currently no schedule	currently no schedule	currently no schedule	PT
	Effects of cyclic pressure/temperature cariations on cement bonds	-	check as required	check as requried	PPr
Reservoir & Ultimate Recovery	Water influx	Well dependant			PP
	Criteria for updating reservoir models	1-2/yr	1-2/yr	1-2/yr	RE
	Subsidence monitoring and seismicity	1/5yrs	1/5yrs	1/5yrs	PG, PP
	Compartmentalisation	Study based	Study based	Study based	PG + RE
	Effects of cyclic loading	-	Study based	Study based	PT
	Injection gas quality	-	Continuous	Continuous	PE
	Maximum reservoir pressure	-	Continuous	Continuous	RE

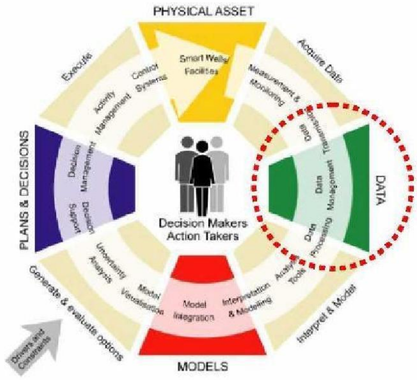
Table 4.2 – Overview of WRS activities

A more detailed description on the Groningen Asset Data Acquisition Strategy and W&RS yearly plan can be found in reference [2].

5 WRFM Data/Information Management

The amount of information that is available on a daily basis (and beyond) for the Groningen field is large, with each of the 25 clusters transmitting over a 1000 signals. The management of all this data is a challenge and a number of systems/computer-platforms are in place to facilitate this.

The strategy for the future, in line with the smart operation philosophy, is to further develop "smart" monitoring systems with SAS-Wikker.



5.1 Systems in place for Data/Information Management

As in the other assets within NAM, Groningen uses Discovery as an online platform to facilitate the retrieval of well-related data. Discovery.com is an UIO web application which provides a single point of access to much of UIO's Subsurface Data. Discovery.com is a web-based application integration platform aimed at contributing to strategic growth opportunities in the North Sea area of Upstream International Operated. Discovery.com is a read only portal that allows the user to perform powerful document, data and knowledge searches through multiple databases across UIO. The ability to perform these searches without the need for any specific database or application knowledge means that Discovery.com can be a core part of your workflows. In addition it plays an important role in assisting staff with data quality control (QC) and reporting.

In the future the plan is to replace Discovery.com with a new platform called DREAM which is part of the WFRM SS&W Portal.
Discovery.com obtains its data from different data storage systems; the most important sources for Discovery.com are:

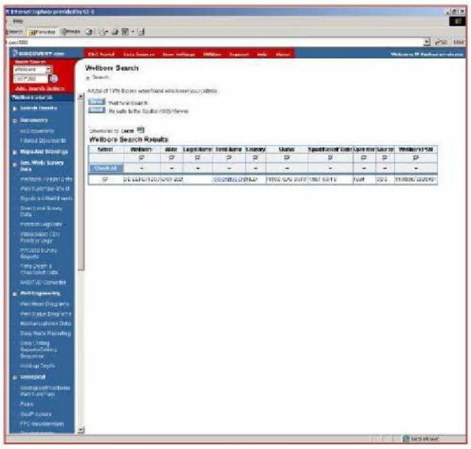


Figure 5.1 – Screenshot of Discovery

- CDS
- EP catalog
- EDM
- SAP
- SWED
- Siesta
- Energy Components
- Recall
- PVD
- Hydran

5.1.1 WRFM SS&W Portal

Currently incorporates DREAM (future replacement of Discovery.com) and eBook. It also has links to SWED, SIESTA & ERO Portal

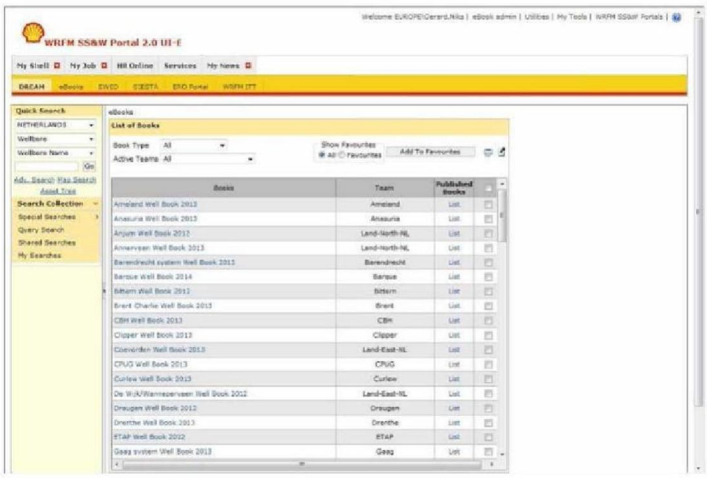


Figure 5.2 – Screenshot of WRFM SS&W portal

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5.1.2 Dream

Is the replacement of Discovery.com, will be rolled out in 2013/2014

5.1.3 eBooks

It is primarily an IMIT application that seeks to consolidate, improve, and streamline the production and delivery of well books. The presentations as used during Annual Wells and Facility Reviews (AWFR) are stored in an eWellBook. This can be structured by cluster as well as by well. In Groningen the AWFR's are done on a cluster basis.

5.1.4 SWED

In 2008-2009 a new database was introduced across UIE (now UIO), called Significant Well Events Database (SWED). As the name indicates, the objective of this database is to capture the most important well events in one place. Various reports from Subsurface Engineers describe which activities have been executed. As an addition SWED also includes the evaluation and results, e.g. actual gains after acid stimulation and/or re-perforation activities. SWED is used during well reviews to give an historical overview of the well and also to capture observations and recommendations for future actions.

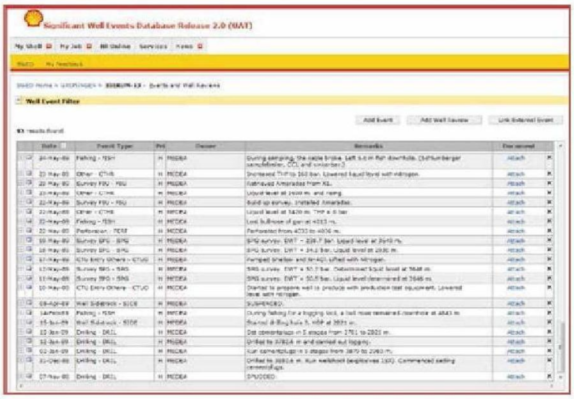


Figure 5.3 – Screenshot of SWED

5.1.5 ERO Portal

The Emergency Response Organisation (ERO) Portal is a one-stop-shop for Subsurface & Wells data & documents that are of immediate importance in a well site emergency situation. In an emergency the information retrieved from the ERO Portal would be provided to Wells by the Subsurface ER-teams as part of the Wells emergency response procedures. It also shows the available data.

Item	Presence (%)	Source		Discipline Responsible
Top Structure Maps	50	EP Catalog		PG
Composite Well Log	100	EP Catalog/Recall		PG
Formation Tops	100	CDS		PG
CBL/VDL	100	EP Catalog/Recall	Cement Bond Log / Variable Density Log	PG/PP
Petrophysical Miniplot	100	EP Catalog		PP
MAASP	99	EDM via eWIMS	Maximum Allowable Annulus Surface Pressure	Pprog
Reservoir Fluid Composition	50	EP Catalog	Pressure Volume Temperature (PVT) Composition Analysis Reports	RE
Reservoir Fluid Composition (NL)	50	RISRES		RE
Reservoir Pressure	100	CDS	CNNS ERO Pressure data	RE
Wellbore Header	100	CDS		PT
Key Well Events	100	SWED	Significant Well Events Database	PT
Perforation Data	100	EDM via CDS		PT
Well Head Diagrams	100	EP Catalog	CNNS & X-Border Wellhead Diagrams	PT
Well Barrier Diagrams (NO)	0	EP Catalog	Well Barrier Diagrams are a requirement in Norway only	PT
Well Status Diagrams	99	EP Catalog		PT
Well Status Diagrams (Dynamic)	100	EDM	Dynamic well status diagrams may take several minutes to load.	PT
Well Mechanical Data (Wellbore / Annuli [Fluids and Cements])	100	EDM via CDS		PT
Well Mechanical Data (String Components)	100	EDM via CDS		PT
Well Mechanical Data (Hole Sections)	100	EDM via CDS		PT
Well Mechanical Data (Contents)	10	EDM via CDS		PT

Figure 5.4 – Screenshot of ERO portal

5.1.6 Collaborative Wellfile Environment

All "work in progress" well related documents should be stored in the correct UIO Collaborative Wellfile (CWF) Environment. This ensures that key documents are easy to retrieve, which is especially important in ERO situations. It also allows Wells documents to be fully compliant with Group Records Management (GRM). Once documents are final they need to be published by contacting the publishing team (e-mail Epe-Wellfile EPT-IT-ED), so that a full close out of the CWF project structure can be executed.

5.1.7 Development Engineering Dropbox

The Development Engineering Dropbox contains a setup for the publishing process of subsurface field related documents and declaration of records –for Group Records Management compliancy- across Europe. These are used to move the final field related documents to the business records repository. From there the documents are made available via the Discovery.com document field search for re-use and knowledge sharing. The Asset-field setup should be used for specific field related records; for multiple fields related records the Pan Asset area should be used.

5.1.8 Reservoir Pressure Data Management (SIESTA)

The Groningen Asset has incorporated a new Global Reservoir Pressure Data Management Tool as an integral part of its WRFM process; SIESTA, released in June 2010. It is a web based application that takes advantage of the best practices found in the WTIS (system formerly used by NAM) workflows and data storage. SIESTA has been designed to QA/QC newly acquired reservoir pressure data and to update and audit data during the entire life span of the data and data management process. The quality controlled data will be stored in, and accessed from CDS.

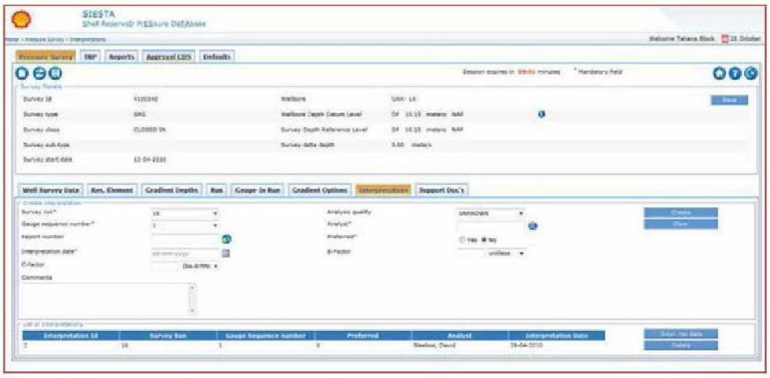


Figure 5.5 – Screenshot of SIESTA

5.1.9 PI Process Book

All critical WRFM data such as pressure, rates and temperatures, both at well level and throughout the process flow, is available for online monitoring via PI. Via PI-Process Books all relevant well/process data can be visualized, as standard screens or customized to fit the specific user requirements. It is therefore possible to monitor a single well, a whole cluster or an entire production system. The program is used as a data historian as well as a real time tool. Examples of monitoring are: well/cluster performance after a re-perforation job; CITHP's which are being converted to BHP for reservoir modeling.

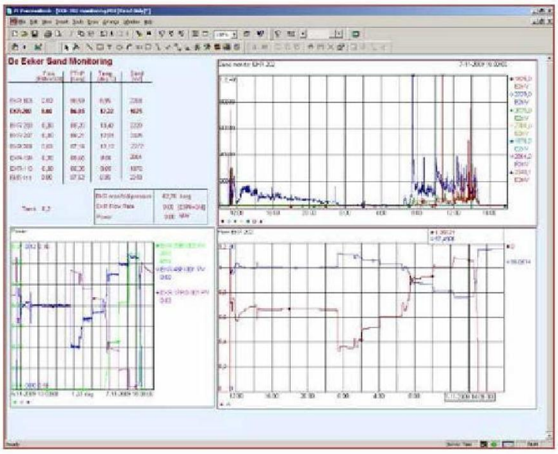


Figure 5.6 – Screenshot of PI Processbook

5.1.10 Well Performance monitoring

In 2005, the program WellMon was introduced for monitoring well performance. It was the first generation online well and cluster performance-monitoring program developed for the Groningen Field. The later version includes a surveillance dashboard.

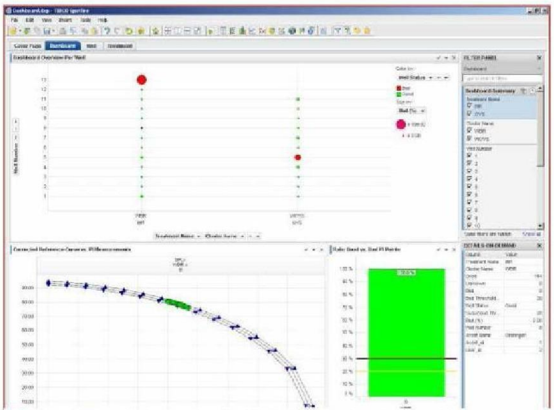


Figure 5.7 – Screenshot of Wellmon dashboard

The program uses cluster and well data from PI-Process Book and is based on the principle of testing wells "as you produce". This is done by sophisticated filtering of data in order to find representative production periods with which performance curves can be generated. The software can also provide the user with an indication of real vs. ideal flow. Yearly performance curves are normalized for declining reservoir pressures. Current production can be plotted against reference curves and subsequently, performance trends can be generated over time.

WellMon results are being used during the AWFR sessions; both to monitor individual well performance over time as well as to compare performance of various cluster wells, by comparing wells with similar well completion. WellMon has not been implemented on Norg and Grijpskerk UGS's due to the complications created by the cyclic production mode. In Q3 2013 a review of the feasibility and value of implementation of WellMon on the UGS's will be carried out.

5.1.11 Surface Equipment Capacity Monitoring and Calibration

Since 2010 SAS Wikker is used for monitoring surface equipment capacity. Steady state (PI) data is determined and capacity performance parameters are calculated on a continuous basis. Models are in use to monitor the pressure drop over main equipment, thermal performance of heat exchangers and head and efficiency of compressors. Examples are given in the graphs below.

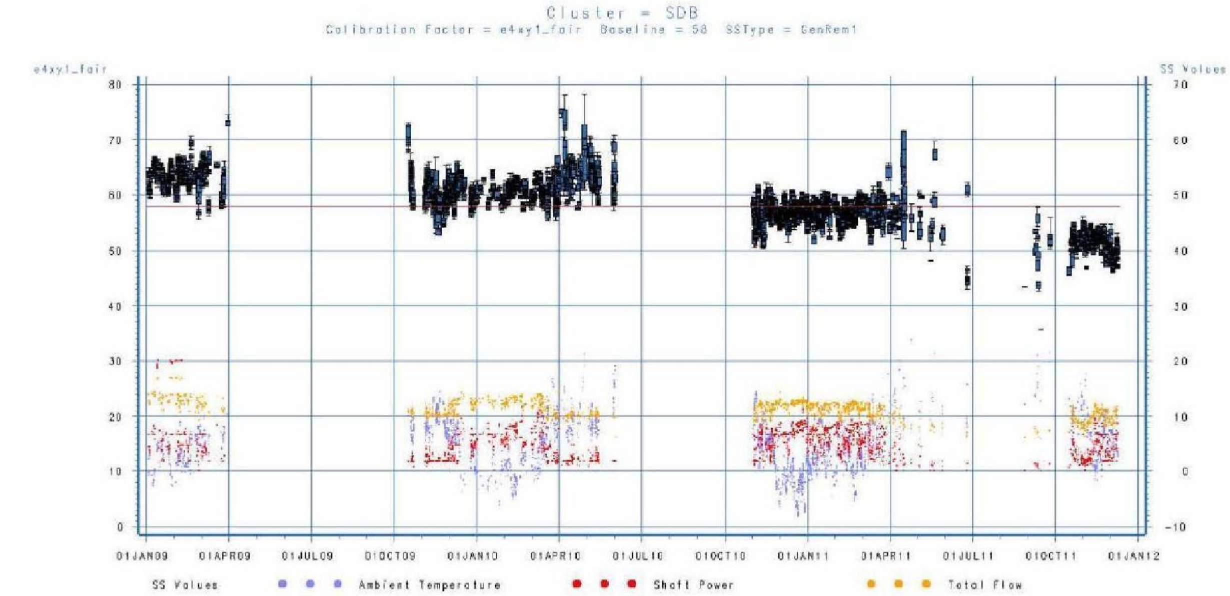


Figure 5.8 – Capacity performance parameter of air cooled heat exchanger

The graph shows the thermal performance of the compressor suction cooler on the Siddeburen cluster. As can be seen the performance gradually drops over the years. This is most likely due to (outside) fouling, which is a normal phenomenon for air cooled heat exchangers. A program is in place to clean these coolers during maintenance stops.

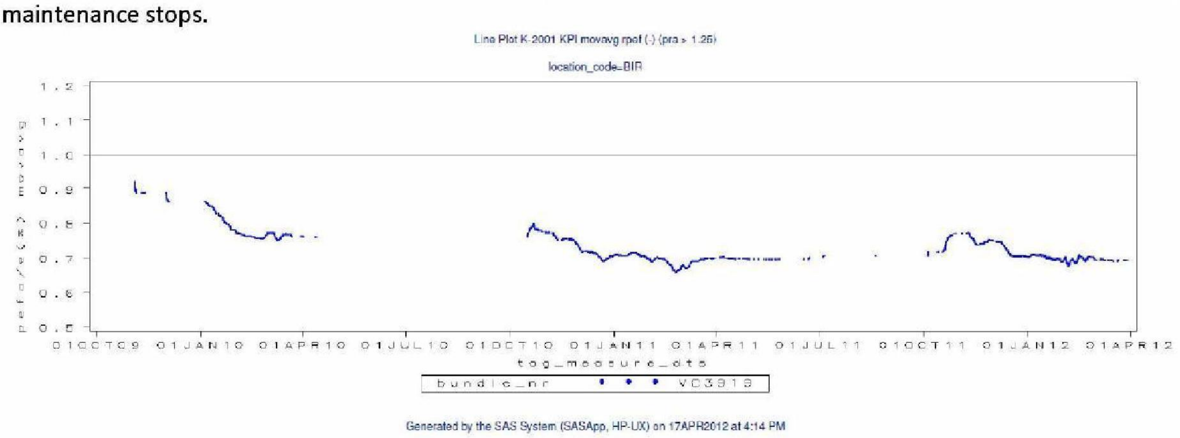


Figure 5.9 – Relative polytrophic efficiency of compressor

Figure 5.9 shows the polytrophic efficiency of the compressor on the Bierum cluster, relative to the design data. This compressor shows some 30% loss in efficiency and is scheduled for replacement of internals.
The monitoring data is also used for calibration of GenRem (see section 6.1). The capacity performance parameters are input values in GenRem, so changes in these parameters are reflected in changes in system capacity as determined by GenRem.

5.1.12 Production Optimization System (POS)

POS is a very useful tool used extensively by the control room (PCC) and production programming to keep track of actual production/ injection, capacities and down time registration. The system shows the capacity per cluster and signals temporary unavailability's for the whole Groningen system; Groningen and Norg- and Grijpskerk UGS's.

Figure 5.10 – Screenshot of POS

5.1.13 LIP-T

The Locked-In Potential and Threats (LIP-T) Database has been in use across UIO since 2003. It is an MS Access repository used for the tracking, ranking and visualization (in conjunction with the LIP-T Visualizer tool) of well intervention and surface activities associated with the preservation or re-instatement of existing production, generation of further "Build-up" or "Locked in Potential" production, and of surveillance activities targeted at opportunity identification, HSE, and reservoir management. Though not presently used as a tool for management of threats to production, LIP-T also has the capability to act as repository for these threats at a UIO or Asset level.

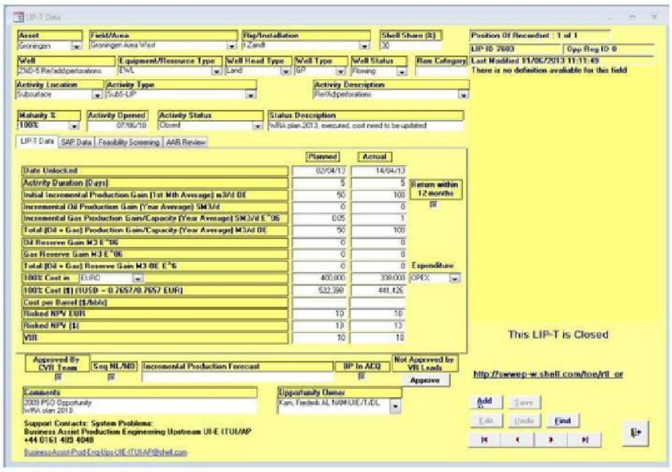


Figure 5.11 – Screenshot of LIP-T

5.1.14 WRS tracker sheet

Surveillance activities are being tracked in the WRS tracker sheet. This sheet is updated regularly by the Reservoir Engineering focal point for WRFM. Costs are updated by the WRFM development Technician. With the WRS tracker sheet, an overview of planned versus executed activities can easily be generated.

Last Update: 23-Jul-13 — Asset 2013 Well and Reservoir Surveillance Tracker

General | ıned

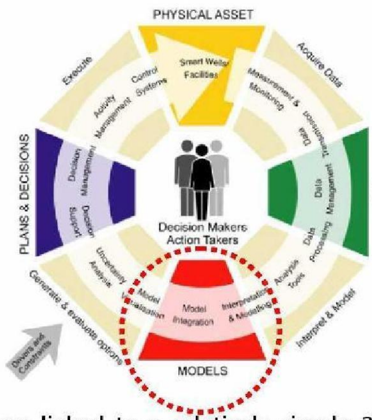
Country	Area	System	Field	Shell Share %	Location/Cluster/Platform	Well Number	Activity/Survey Type	Main Justification	Timing	Deferment in m³	Default Cost 100% in I (from fixed data sheet)	Budget Planned Cost 100% in I	Budget Planned Cost 100% in I	Original Status	Current status	Actual Cost 100% in I	Activity Coordinator	Scheduled Date	Execution Date
NL	GRO		Groningen	30	HGL	1	SPTG	Support proved reserves booking			15,500		15,500	Planned	Cancelled			15-Jan-2013	
NL	GRO		Groningen	30	ZRP	1	SPTG in combi PNL	Support proved reserves booking			45,000		45,000	Planned	Executed	48,000		23-Jan-2013	05-Feb-2013
NL	GRO		Groningen	30	HGL	1	FBU/ Downhole Pressure	Other			26,000		26,000	Planned	Executed	26,000		01-Feb-2013	01-Feb-2013
NL	GRO		Groningen	30	SWO	1	SPTG	Support proved reserves booking			15,500		15,500	Planned	Executed	2,000		21-Feb-2013	16-May-2013
NL	GRO		Groningen	30	BRH	1	PNL	Support proved reserves booking			40,000		40,000	Planned	Executed	42,000		04-Mar-2013	06-Mar-2013
NL	GRO		Groningen	30	OOP	1	PNL	Support proved reserves booking			40,000		40,000	Planned	Executed	35,000		05-Mar-2013	08-Mar-2013
NL	GRO		Groningen	30	ZVN	4	Surface Multi Rate Cluster	Support capacity generation			6,250		6,250	Planned	Executed	30,000		08-Mar-2013	20-Mar-2013
NL	GRO		Groningen	30	OWG	2	Surface Multi Rate Cluster	Support capacity generation			6,250		6,250	Planned	Executed	44,000		15-Mar-2013	27-Mar-2013
NL	GRO		Groningen	30	TUS	ALL	Surface Gas Sampling	Support capacity generation			2,500		2,500	Planned	Executed			18-Mar-2013	26-Apr-2013
NL	GRO		Norg	30	NOR	ALL	Surface Multi Rate Wells	Support capacity generation			?		?	Planned	Cancelled			18-Mar-2013	
NL	GRO		Groningen	30	POS	4	Surface Multi Rate Cluster	Support capacity generation			6,250		6,250	Planned	Cancelled			22-Mar-2013	
NL	GRO		Groningen	30	BOL	1	SPTG	Support proved reserves booking			15,500		15,500	Planned	Executed	7,000		25-Mar-2013	28-Mar-2013
NL	GRO		Grijpskerk	30	GRK	ALL	Surface Multi Rate Wells	Support development activity			?		?	Planned	Cancelled			25-Mar-2013	
NL	GRO		Groningen	30	UHZ	1	SPTG	Support proved reserves booking			15,500		15,500	Planned	Executed	16,000		08-Apr-2013	09-Apr-2013
NL	GRO		Groningen	30	EKL	ALL	Surface Gas Sampling	Support capacity generation			2,500		2,500	Planned	Executed			08-Apr-2013	19-Mar-2013

Figure 5.12 – Screenshot of the WRS tracker sheet

5.2 Data Quality

In order to ensure correct data in Discovery, there is a monthly data quality check called the Information Quality Matrix (IQM). The different data sources have the following data readily available from the resources mentioned above (and more) and contribute to the data management of well status and performance, reservoir performance and facilities performance:

- Drilling/ Well Services History
- Well Completion Schematic
- Well Mechanical Data
- Directional Data
- Perforated Intervals
- Petrophysical logs
- Reservoir Fluid Compositional Data
- Well sample and Production Chemistry data
- Well test data
- SPTG/FBU data
- Allocated Production/Injection volumes and rates (HCA)
- ERO portal
- Published documents, indexed by well/field



6 Models Supporting WRFM

Over the past years, modeling has played an increasingly important role in the Groningen field and its UGS's. This chapter describes the current modeling platforms and goes into future plans to improve these.

6.1 Models in Use

The Asset Groningen uses two modeling systems:

- ***GenRem/ResMod:***
  GenRem is a detailed surface network simulator, which has been linked to a relatively simple 2-dimensional, single phase reservoir simulation model (called ResMod). The main objective of this model is to perform short to medium term forecasting and production/injection capacity nomination. ResMod is currently being phased out and will be replaced by MoReS;
- ***HFPT/MoReS:***
  MoReS is a 3-dimensional, multi-phase reservoir simulation model. It uses a simplified representation of the surface facilities (HFPT). The main objective of this model is to perform medium to long term forecasting. It is used as the main input for the ARPR and for development planning;

MoReS is history matched with gas production data and pressure data obtained from regular static downhole pressure measurements (Static Pressure Temperature Gradients, SPTG). It is also updated to match the inflow performance of the individual production clusters to multi-rate cluster tests that are performed in the field periodically. Finally, the results from the SPTG's are used to validate the THP-BHP correlations that exist for the Groningen field and the UGS's.

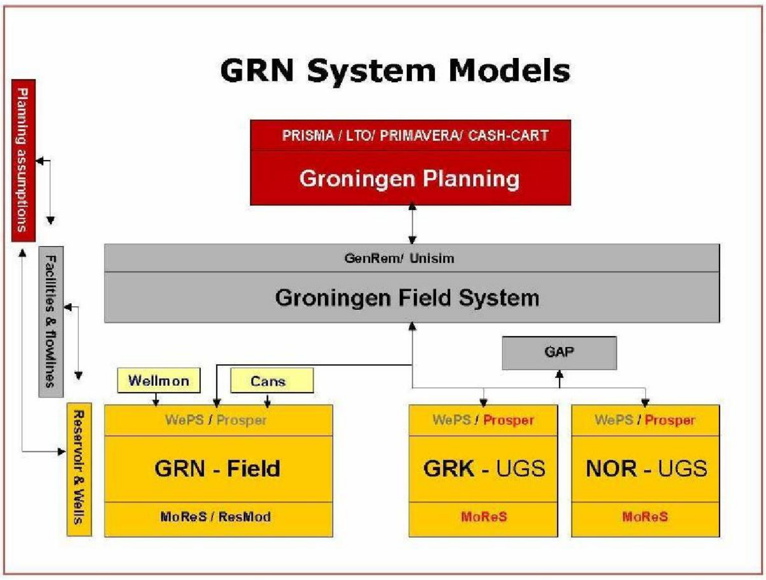


Figure 6.1 – Groningen system models

GenRem is embedded within the Groningen Asset business process and its ultimate objective is to model and optimize the Groningen System (see *Figure 6.1*), which includes the Groningen field and the UGS's Grijpskerk and Norg. Currently, both ResMod and MoReS can be used to model the Groningen reservoir. (ResMod is being phased out).

For the UGS's mostly MoReS is used as it has a more detailed reservoir description. This enables modeling of localized pressure effects due to high production and injection rates, which play an important role for the UGS short-term planning process. For this reason GenRem and MoReS have been linked and are used for short-term planning for the Grijpskerk and Norg UGS's.

Figure 6.2 gives an overview of how different applications are being used by a multidisciplinary team for Production System Optimization, Integrated Activity Planning and Production Forecasting Processes for the Groningen field.

- Short term capacity forecasting is done using CaSH/CaRT. Forecasts are based on GenRem (either linked to MoReS or ResMod) and monthly updated;
- Long-term capacity planning is done through the joint GasTerra/NAM Prisma study;

As mentioned, both models are calibrated with cluster multi-rate surface tests, these tests are used to calibrate cluster AFBC-factors (indicators of inflow/outflow performance). The Groningen asset uses Wellmon and CAnS/Wikker (see chapters 0 and 10) applications to supplement GenRem calibration and support well and facilities surveillance. See detailed list of all Groningen and UGS applications in *Figure 6.3*.

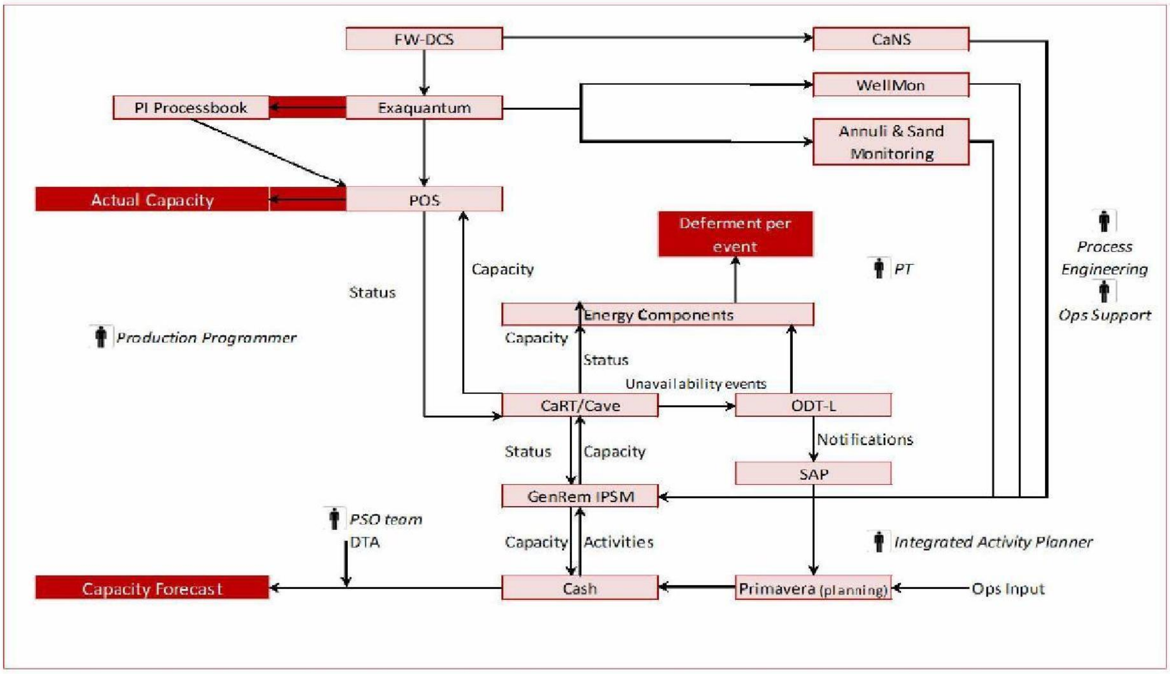


Figure 6.2 – Use of Groningen applications

Groningen Applications	GenRem-ResMod	MoReS	Others
GRN Planning	Primavera / LTO / Primavera / Cash CaRT	Primavera / LTO / Primavera / Cash CaRT	
GRN System	GenRem/ LTO / Cash CaRT	GenRem/ LTO / Cash CaRT	
Compressor Facilities	GenRem	HFPT	Unisim / CaNS / PI / Exaquantum
Cluster	PQ Super Well	PQ Super Well	WellMon / CaNS / PI / Exaquantum
Wells Outflow	Modelled through B&C factors	Prosper lift table	PI / Exaquantum DCS Start-up functionality WellMon
Wells Inflow	Modelled through A&F factors	Peaceman Model	
Reservoir	ResMod*(1-phase, 2D)	MoReS (2-phase, 3D)	
*being replaced by MoReS	Planning, Short term forecasting, Capacity Nomination, RTO	GFR, ARPR	Surveillance

UGS Appliations	GenRem-ResMod	GenRem-MoReS (GRK)	IPM & MoReS (NOR)
GRN Planning	n.a	Primavera / LTO / Primavera / Cash CaRT	Not in Scope
GRN System	n.a	GenRem/ LTO / Cash CaRT	Not in Scope
Compressor Facilities	n.a	GenRem	GenRem
Facilities dP/dT	n.a	GenRem	GenRem
Wells Outflow	n.a	VLP, Prosper	VLP, Prosper
Wells Inflow	n.a	MoReS	MoReS
Reservoir	n.a	MoReS	MoReS
		Planning, Short term forecasting, RTO, FDP	FDP, Well Surveillance, ARPR Annual Capacity Nomination

Figure 6.3 – Overview of Groningen and UGS applications

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Individual well models exist for the UGS's and all the Groningen wells, providing opportunities for individual well surveillance.
For the UGS expansion studies, the IPM suite was chosen since it provides the desired accuracy and represents a good platform for integration between disciplines. The Grijpskerk model was completed during 2008 which has proven to be suitable for the FDP and has been successfully used for capacity nomination and injection planning. However, currently short term capacity prediction is done more effectively by GenRem/MoRes (see below).

6.2 Modeling Strategy

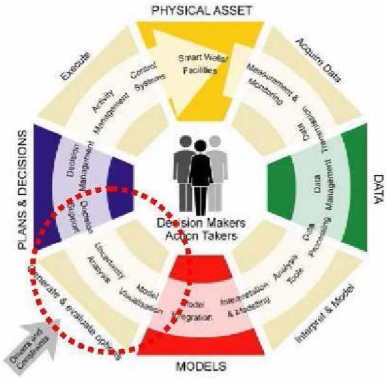
The declining reservoir pressure of the Groningen field will push it into a different role: from a swing producer to a high load factor producer. This change will take place gradually over the course of the next ±20 years and during that time modeling requirements will change.

Short term (2-5 years)
With a declining Groningen field reservoir pressure, it is expected that the need for short-term capacity measures will increase. Ideally, a single system model should be in place in the near future to provide both sufficient detail and desired running times. For Grijpskerk this is already in place as a link has been made between GenRem and MoReS for this UGS. The same has been done for Norg. As part of Groningen field review 2012 a GenRem/MoRes link has been developed also for the Groningen field.

Long term (5-20 years)
As mentioned earlier, the role of the Groningen field will change to a high load factor producer. At that point in time the requirements for fit-for purpose scripting of capacity and injection nominations will disappear opening the window for using standard global applications.
Current expectation is that three years before the base-load production era a change process needs to be kicked-off (current estimate is 2015).

7 WRFM Performance Reviews

Regular performance reviews are core to the WRFM Process. For the Groningen Asset, the different types of reviews are shown in the practice *Table 7.1* below



WRFM Practice Table - Groningen 2013

Key Events	Steer	Attendance	Daily	Weekly	Bi-weekly	Monthly	Quarterly	Yearly
Production review (EBS)	PP	PP	x					
Business Improvement meeting	PP	Ops, E&M (FST), PCC	x					
Weekly Production Review	PP	PP, PT, PE, RE		x				
Production System review	PT	PT, PP, PE, RE				x		
Well, Reservoir & Facility review	PT	PT, PP, PE, all subs. disc.						x
Field Performance review	RE	PT, PP, PE, all subs. disc.						x
Well activity review and planning	PP	PP, PT, RE, CWI			x			
OPEX Budget review	Fin	Finance, PT, CWI				x		
Surveillance review and Plan	RE	RE, PT, PP, PE				x		x
WRFM meeting	PT	PT, PP, PE, RE, Ops			x			

Table 7.1 – Overview of WRFM reviews (practice table) for the Groningen Asset

Daily production monitoring/review is the responsibility of Production Programming; done with EBS (Exception Based Surveillance) systems as described in chapter 0. When follow-up is required, contact is made with production technologists and/or process engineers to discuss and solve problems with a multi-discipline team. The daily BIM (Business Improvement Meetings) gives input to the Daily Dashboard meetings which are being held with operations and E&M in Hoogezand. Production programming attends these meeting on an ad hoc basis and the minutes of meetings are being shared with Production Programming.

The Minimum Standard prescribes yearly well reviews, See *Table 7.2* for an overview of the review schedule. Well reviews are being executed per Cluster, starting with the subsurface (reservoir review) and closing off with the facilities. The performance of the production system is also reviewed as part of the yearly capacity nomination process for the UGS's. Changes to the GenRem model (Reference Deck) for Groningen are reviewed and documented twice a year.

All production/injection wells are reviewed annually. Opportunities identified during the reviews are captured in one common opportunity register for surface and subsurface opportunities, LIP-T. The output from LIP-T is used to monitor capacity gains and costs; compare for both actual vs. plan. Execution of surveillance activities is being tracked with the WRS Tracker sheet and the progress is discussed monthly on WRFM meetings.

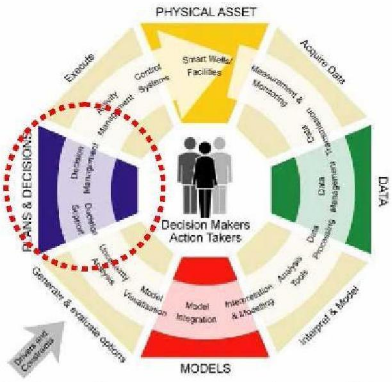
The WRFM activities are included in the IAP and once every 2 weeks, the WRFM team discusses upcoming activities with the C&WI asset focal point and the IAP-planner.

Well integrity is monitored by the production programmers with eWIMS; EBS's are in place to ensure effective daily monitoring of annular pressures and sand alarms. The asset well integrity status is being reviewed monthly and shared with the asset leader during monthly BPR sessions. On a regular (bi-weekly) basis, high priority well integrity issues are being reviewed and discussed with the TA/2 and TA/3 for well integrity. In addition, problem wells are reviewed annually with the TA1/2's. Routine wellhead maintenance and the testing of both surface and sub-surface safety valves are incorporated in the well-related activity year-plan.

Annual Wells & Facilities Review			
Field	**Cluster**	**AWFR 2012**	**AWFR 2013**
Groningen	Amsweer	24-1-2012	29-1-2013
	Bierum	26-6-2012	25-6-2013
	Borgsweer Water Disp.	-	5-11-2013
	De Eeker	25-9-2012	24-9-2013
	De Paauwen	18-12-2012	13-12-2013
	Eemskanaal	22-5-2012	28-5-2013
	Froombosch	28-2-2012	26-2-2013
	Kooipolder	23-10-2012	29-10-2013
	Leermens	24-11-2012	26-11-2013
	Oudeweg	23-10-2012	29-10-2013
	Overschild	24-11-2012	26-11-2013
	Sappemeer	27-3-2012	26-3-2013
	Schaapbulten	24-1-2012	29-1-2013
	Scheemderzwaag	22-5-2012	28-5-2013
	Slochteren	28-2-2012	26-2-2013
	Siddeburen	28-8-2012	3-9-2013
	Spitsbergen	25-9-2012	24-9-2013
	't Zandt	26-6-2012	25-6-2013
	Ten Post	18-12-2012	13-12-2013
	Tjuchem	28-8-2012	3-9-2013
	Tussenklappen	27-3-2012	26-3-2013
	Zuiderpolder	24-4-2012	23-4-2013
	Zuiderveen	24-4-2012	23-4-2013
Norg well review		16-3-2012	Q3 2013
Norg facilities review		-	Q3 2013
Grijpskerk well review		6-4-2012	Q3 2013
Grijpskerk facilities review		-	Q3 2013

Table 7.2 – Overview of AWFR sessions in 2012 and 2013

8 Decision Making and Planning



All WRFM activities are planned in the asset IAP (Integrated Activity Plan) and budgeted and approved as part of the Business Plan (Well OPEX). Major activities as the planned workovers on AMR-4 and -11 (tubing – A-annulus communication), are discussed and approved by the Asset Leader and the Asset Development leader. Approval of Opex activities, including workovers are given by the partners through the WP&B cycle (Work Program and Budget). Input to the IAP is requested around 3rd quarter of the previous year; for 2014 by July 2013. Activities which have not been included in yearly IAP plan can only be included in the short term plan after it has been justified and approved by the Change panel.

WRFM activities include routine wellhead maintenance and testing for both surface and subsurface safety valves (planned and scheduled by the C&WI-team), well and reservoir surveillance activities and capacity generating activities (incl. workovers). The planning for the well and reservoir surveillance activities for 2013 is summarized below in *Table 8.1*. A planning for the well and reservoir surveillance activities for 2014 is given in *Table 8.2*

Well & Reservoir Surveillance Activities						
	Groningen		UGS Grijpskerk		UGS Norg	
Activity	#		#		#	
FBU	2	2 ad-hoc measurements provisionally scheduled per year TBD	1	Ad-Hoc	1	Ad-Hoc
SPTG/SPG	12	Producers: LRM-2, FRB-3, SZW-2, SZW-204; Injectors/Observation: HGL-1, ZRP-1, SWO-1, BOL-1, UHZ-1, UHM-1a, MWD-1, OLD-1	2	Ad-Hoc	2	1 Ad-Hoc + NOR-2 (in case PNL taken, combined)
PNL	6	ZRP-1, BRH-1, ODP-1, SCB-1, EKL-13, PAU-2	0		1	NOR-2 if production > 3 bcm
PLT	0	none	0		0	
Multi-Rate Surface Clusters Test (Well test for U	7	OWG, ZVN, LRM, EKL, SZW1, SZW2, AMR	20	2/well at beginning and end of winter season	12	2/well at beginning and end of winter season, plus NOR-3-L1
Calliper	2	ad-hoc	0		0	
Video Survey	2	ad-hoc	0		1	
Gas Sampling Observation wells			0		0	
Gas Sampling Production wells	5	2xEKL,KPD,PAU,TUS	5	Ad-Hoc	4	Ad-hoc
Surface Water Sampling	152	Monthly sampling for chlorides content monitoring on 6 clusters: BIR/ZND/PAU/OWG/SCB/POS - Quarterly water composition monitoring for all clusters	n.a.		0	
Subsidence Monitoring	0		0		0	
RFT	0	none	0		0	
Downhole Gas Sampling (PTE)	0	none	0		0	
Subsurface Water Sampling	0		0		0	
extended FBU's (reservoir characterization)	1	LRM-7	0		1	NOR-3
Total activities	37		28		24	

Table 8.1 – Overview of surveillance activities for the Groningen asset in the year 2013

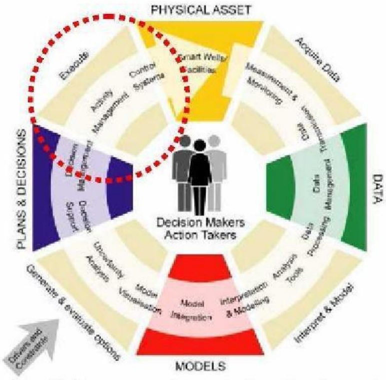
Well & Reservoir Surveillance Activities						
	Groningen		UGS Grijpskerk		UGS Norg	
Activity	#		#		#	
FBU	2	2 ad-hoc measurements provisionally scheduled per year TBD	1	Ad-Hoc	1	Ad-Hoc
SPTG/SPG	10	Producers: EKR-1, EKR-209, SDB-2, TJM-6, ZND-9, POS-4 Injectors/Observation: HND-1, KHM-1, ODP-1, ZWD-2a	2	Ad-Hoc	2	1 Ad-Hoc + NOR-2 (in case PNL taken, combined)
PNL	4	HND-1, ZWD-2a, SDB-7, EKL-13*	0		0	
PLT	3	EKL-13*, BIR-5*, BIR-12*	0		0	
Multi-Rate Surface Clusters Test (Well test for U	8	KPD, OVS, POS, SCB, SDB, TJM, ZND, ZPD	20	2/well at beginning and end of winter season	12	2/well at beginning and end of winter season, plus NOR-3-L1
Calliper	2	ad-hoc	0		0	
Video Survey	2	ad-hoc	0		1	
Gas Sampling Observation wells			0		0	
Gas Sampling Production wells	5	2xEKL,KPD,PAU,TUS	5	Ad-Hoc	4	Ad-hoc
Surface Water Sampling	152	Monthly sampling for chlorides content monitoring on 6 clusters: BIR/ZND/PAU/OWG/SCB/POS - Quarterly water composition monitoring for all clusters	n.a.		0	
Subsidence Monitoring	1	HND-1	0		0	
RFT	0	none	0		0	
Downhole Gas Sampling (PTE)	0	none	0		0	
Subsurface Water Sampling	0		0		0	
extended FBU's (reservoir characterization)	1	POS	0		0	
Total activities	38		28		24	

* depending on 2013 results

Table 8.2 – Overview of surveillance activities for the Groningen asset in the year 2014. Surveillance activities as part of the earthquake investigation program are not included.

As a yearly process, based on the WRFS strategy, the well and reservoir (and facilities) surveillance plan is being generated by the multi-discipline WRFM team. During the AWFR's, surface and subsurface WRFM opportunities are being identified by a multi-disciplinary team and these are captured in one opportunity register, LIP-T. As part of the yearly BP and PRISMA cycles, the capacity demands are being quantified. Depending on the capacity demands and the attractiveness of the identified opportunities, these are being executed as soon as possible or delayed to later years. The execution priority is optimized based on estimated cost of capacity; estimated cost per capacity gain. In this process the opportunities are checked against actual limits of the production system; i.e. checked against surface facilities limits and depletion priorities (by PT, RE, PP and PE).

9 Execution



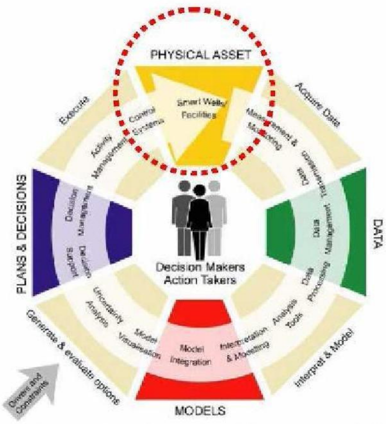
In the Integrated Activity Planning (IAP) process the functional plans are combined in a total integrated and rationalized plan to achieve the most efficient use of resources, to avoid clashes and ensure attainment of company objectives. GLTplus is using the same tools (SAP Blueprint connected to Primavera) as the NAM planners, which enables a very efficient and clear process.

The capacity and production plans are derived from the IAP plan. The impact of all capacity deferring activities is calculated with the integrated reservoir simulator (GenRem/CaSHCaRT) and the results are evaluated against commitments to GasTerra.

Execution of all WRFM activities is monitored in LIP-T; for costs, capacity gains (other assets: production) and reserves. Besides WRFS activities are being monitored in a WRFS Tracking sheet (used across UIO). Since 2010, execution of WRFM activities are also tracked with the WRFM KPI's. New global KPI's have been implemented in 2013, with main focus on NFA production, Annual Field performance reviews, production gains from WRFM activities and UTC. Generally, the execution of subsurface surveillance activities are executed as planned.

As the C&WI is executing activities for all the NL assets: Groningen, Land and ONEgas (NL and UK), these are scheduled in a C&WI plan and priorities have to be set for sharing common resources. When necessary, conflicts are being solved in bi-weekly meetings with the Production Services Manager and WRFM process owner for NAM, the three WRFM leads and head of C&WI.

10 Physical Assets



The modern process instrumentation installed on the renovated Groningen production locations, in combination with online storage of the measured data in PI, offers more than just process control. In this way, key WRFM parameters (flows, pressure and temperatures on well level and through the process, cluster level) are easily available for all the users. After the GLT compression and renovation campaign, the different pieces of equipment (all new) of each cluster were tested to determine their fully functioning operating envelope. The registration of this performance served as a basis for the cluster Capacity Analysis System (CAnS). The last years CAnS has been replaced by SAS/Wikker, the key system that in the future will be used to identify underperformance in the production system; it combines data from various sources and it also has predictive capabilities. Monitors for this are being developed with support of the Groningen Support Centre in co-operation with the future users; the disciplines which will make use of the monitors. Everyday monitoring tools like PI Processbook also remain a source to analyze and determine the status of the performance of physical assets; such as the facilities and wells.

Operating Envelopes

The well integrity is management with eWIMS (Well Integrity Management System); with operating envelopes specified for the wells with respect to annulus pressures etc. Besides, annual maintenance and testing is managed through this system. When action is requested the responsible production programmer gets alerted by e-mail.

The Risico Beheers Plans for the UGS Norg and Grijpskerk are yearly updated documents that outline the potential risks during the production/injection periods of the UGS. These documents (ref.[3]) are updated and issued each year, before the start of the winter, and typically discuss the following topics:

- Operational limits for each well
- Production priority
- Managing 'Wobbe Index' specs for production (Norg specific)
- Sand management issues

For the Groningen clusters the operating procedures are described in the yearly updated "Inset volgorde". The main focus in this document is production priorities between stronger and weaker clusters as pressure support is critical to for end of winter capacities. Since 2011 a "Risico Beheers Plan" has been prepared also for Groningen.

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11 WRFM Resources

The main objective of the Well, Reservoir and Facility Management (WRFM) Plan is to maximize the asset lifecycle value; to reduce future development uncertainties and to meet or exceed production, reserves and cost forecasts. This is illustrated in *Figure 11.1*. Effective WRFM includes all disciplines, from subsurface to surface and operations. Hence, the WRFM plan must be fully supported by the entire Asset.

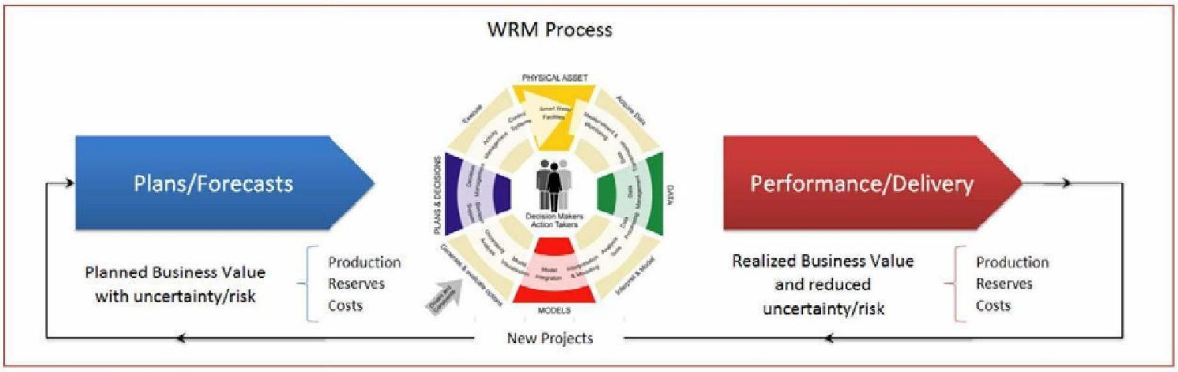

***Figure 11.1** – WRFM Process*

11.1 Groningen Operations

Production Operations manages the producing assets (i.e. wells, clusters, gas pipelines, custody transfer stations, WaCo System, RBI, Delfzijl, Borgsweer and the UGS) and the activities required to sustain the operations of the Groningen field (e.g. pigging operations in gas pipelines for integrity monitoring).

The Production Control Centre (PCC) is situated in a secure room in Hoogezand and is responsible for matching the actual production volumes to the actual demand of our customer GasTerra. This is done by controlling production of the clusters (using the DCS) and throughput at the transfer stations. All facilities have been designed to allow unmanned production, and theoretically only the PCC is needed to control the entire Groningen system. The Groningen Support Centre (GSC) is available to support PCC for data trending, analysis and alarm management.

The Production Programmers, including the Well Integrity focal point and the Integrated Activity Planner are all sitting in Assen, co-located in the WRFM team (i.e. next to the Production Technologists and the Process Engineers).

11.2 Development Engineering

The role of Development Engineering (DE) is to identify, mature and optimize the field development and production opportunities in order to maximize the ultimate recovery of hydrocarbons and meet the contractual capacity given the relevant technical and economic constraints.

From the 1st of February 2010 there is a common development team for the Onshore assets (Land and Groningen), with one ADL for both assets, a CDL (Cluster Development Lead) for each asset/area (as Groningen) and shared Subsurface Discipline leads, except for production technology and process engineering; To ensure maintained high focus of WRFM, there are two WRFM teams, one for asset Groningen and one for the Land asset, both headed by a WRFM Lead. Since January 2013, to increase focus on the WRFM, the WRFM leads are reporting to the Asset leader. The current WRFM lead for Groningen is PT and therefore also TA/2 for the WRFM PT work and TA/3 for well integrity. The VC PT's are no longer reporting to the asset WRFM/PT lead but to an all-NAM VC PT lead who is reporting to NAM Development manager (reporting to NAM DIR).

11.3 Business Delivery

Business delivery in the Groningen Development Team is via an Integrated Delivery / Discipline matrix organization. The Discipline aspect of the organizational matrix provides technical excellence: tools, standards, processes, assurance, and manpower resourcing, reporting and development. These aspects are addressed in the Onshore Development Leadership Team. The disciplines represented in our core team are geology, geophysics, petrophysics, reservoir engineering, production technology, business planning, process engineering, and appraisal engineering. Well engineering, production chemistry, and commercial are part of our extended team.

11.4 Staffing and competence levels are defined

This WRFM plan is owned by the AL and is developed with input and help from all surface and sub-surface disciplines. The other parties involved are:

• WRFM lead	→ Accountable for the WRFM plan; → Drives implementation of WRFM plan throughout the year; → Sets priorities across fields/wells;
• Discipline leads	→ Provide integrated assurance of the WRFM plan;
• WRFM focal points	→ Ensure plan is up to date and obtain input from disciplines; → WFRM focal point coordinates plans and timing and monitors implementation; → WRFM focal point maintains and updates WRS tracking tool;

Table 11.1 – Overview of staff involved in WRFM

A key part of the team involved with the WRFM process has attended an advanced WRFM course; next course is planned for October 2013, with support of the global WRFM team. For the rest of the team, an in-house awareness training will be given at the end of the year.

11.5 The technical/operational resources and capabilities required to carry out the WRFM Plan (incl. Well Services, Production Operations)

All well related activities are planned and executed by the C&WI team, supported by production operations. As a single C&WI team executes activities for the NL-Assets it is important to maintain an integrated plan. When the C&WI team is limited with its resources, constant priorities have to be set between the assets, supported by C&WI and the WRFM/PT Leads. Priorities are discussed and agreed during bi-weekly meetings attended by the Production Services Manager, the WRFM leads and head of C&WI.

Appendix A: Background Groningen field and UGS's

Groningen

The Groningen field, discovered by the well SLO-1 in 1959, is the largest gas accumulation in Western Europe.

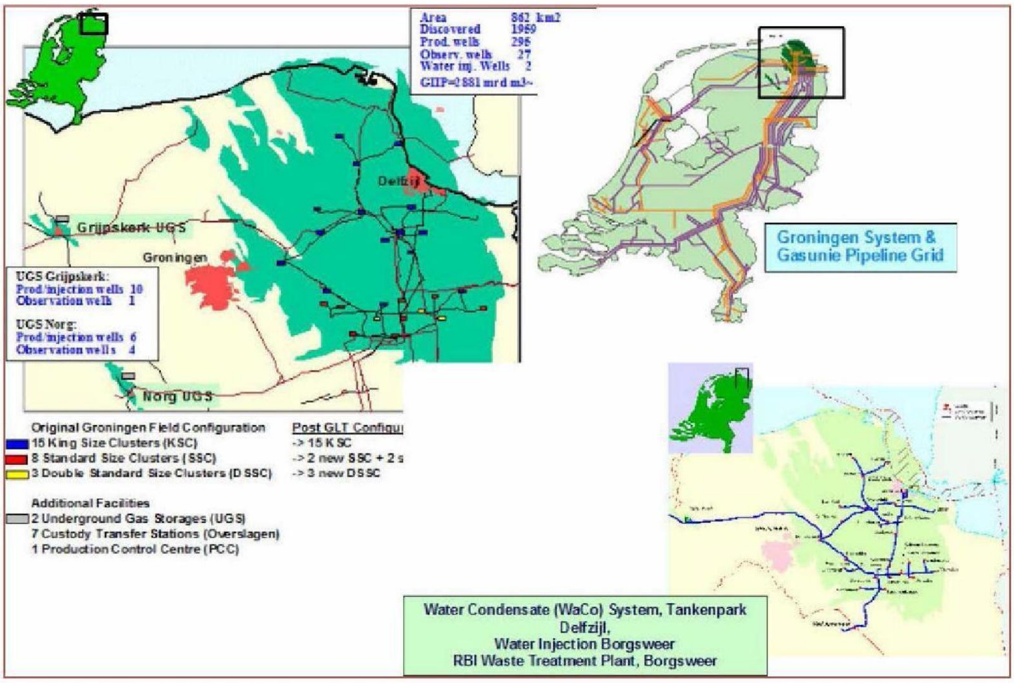

Figure A.1 – The Groningen system

Reservoir Description

The main reservoir comprises fluvial and aeolian sands of the Slochteren Formation (ROSL), which is part of the Permian Rotliegend Group. The gross reservoir thickness increases from some 70 m in the SE part of the field to 240 m in the NW. The ROSL comprises a fairly homogeneous mixture of fluvial and aeolian sandstones. The average porosity ranges from 10% to 25%, with the highest values in the central part of the field. The average permeability is 200 mD. Maximum porosity measured on cores is as high as 33% and permeability 6300 mD.

A continuous shale barrier, the so-called Ten Boer Claystone member (ROCLT), overlies the ROSL. In the northern part of the field, the Ameland Claystone member (ROCLA), intersects the Slochteren and acts locally as a flow barrier. Both the ROCLT and ROCLA members contain thin, intercalated gas bearing sand/silt beds. Primarily in the South of the field, these beds are depleted by production from the ROSL. However, pressure measurements indicate that some of those sand interbeds have a pressure lag with ROSL.

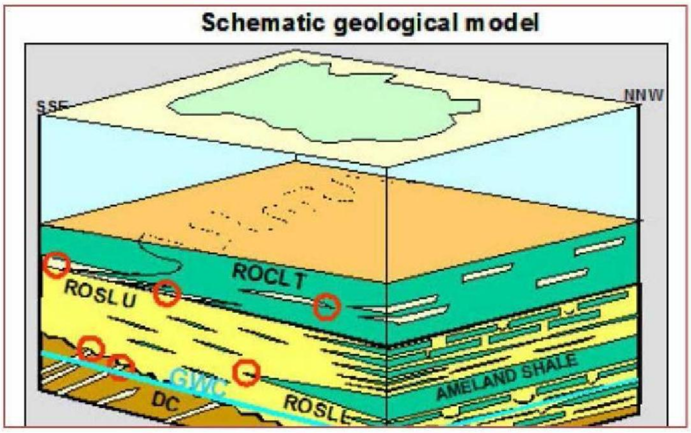

Figure A.2 – Groningen field geological model

The production mechanism of Groningen is gas-depletion drive. The Groningen Rotliegend field has been subdivided in a number of compartments based on interpretation of faults (offsets), GWC, reservoir pressures and gas composition. The GWC has been interpreted from logs at depths ranging from 2971 to 3017m TVNAP, with a definite trend of deepening from NE to SW. Periodic monitoring of the GWC shows that it remains stable in some areas (e.g. HND, KHM, LRM, SDM, UHM, UHZ), and has moved upwards in others (e.g. t'Zand 26m, Bierum 29m, Oldorp 24m, Harkstede 9m, Zuidwending 56m).

The Slochteren reservoir unconformity overlies Carboniferous Limburg Group (Westphalian), which consists of sands, shales and coals of fluvio-deltaic origin. The coals are the main source of the Groningen gas.

Groningen Wells and Facilities

With the completion of the GLT project in 2009 there are roughly 260 producing wells located on 25 Clusters; there are 15 KSC (with compression), 2 new Central Clusters (with compression), 2 satellites (connected via wet gas pipelines) and 3 new double standard size clusters (DSSC) (with compression) with integral satellites. Batch #8 of the GLT project has been cancelled; the facilities at locations Uiterburen, Noordbroek, Nieuw Scheemda and Midwolda has been abandoned and the wells mothballed (dependent on PRISMA / GasTerra's gas demands, these clusters will be renovated in 2018 or later).

The gas is treated at the cluster facilities and fed into a ring pipeline, which is connected via 6 NAM and 1 GTS custody transfer points (Overslagen) to GTS' main pipeline system for distribution to the customers. Produced liquids are routed by the WaCo pipeline to Delfzijl where water and condensate are separated. Condensate is shipped to refineries in Rotterdam, whilst water is re-injected into the formation at a location near Borgsweer. The WaCo system and RBI are also used by other NAM assets, particularly Land North. Costs are allocated on the basis of throughput.
The earlier standard size clusters (SSC), situated in the south of the field, have wells with predominantly 7" production casings. These were originally completed with 5" tubing, but during later workovers some wells have installed 5"x5½" special clearance (SC) tubing.
The later king size clusters (KSC), located mostly in the centre and north of the field where the average reservoir porosity is generally higher and inflow performance better, have 7⅝" production casing and were originally completed with 5½" and during later workover 5½"x6" SC tubing were installed. In the 80-ies infill wells were drilled with 9⅝" production casing and 7⅝" tubing. One well, PAU-6, drilled in the 90-ies, have 9⅝" completion.

Many of the wells have either internal plastic coating or a machined internal wall to improve tubing roughness and vertical flow. SET workovers took place in 2002 (EKL-2) and 2004 (ZVN-12 & ZVN-5) to replace 5½" tubing with 6" expandable and 7⅝" tubing.

Most clusters are well-constrained, rather than facilities constrained.

UGS Grijpskerk

The Grijpskerk field was discovered by well GRK-1A in 1990 and was further delineated by GRK-2 (1992) and GRK-3 (1994). The field straddles the Groningen/ Tietjerksteradeel concession boundary. Developed reserves estimates are based on an equity freeze between Groningen (97%) and Tietjerksteradeel (3%). Originally, the Grijpskerk Main reservoir was operated as a conventional depletion field under the Groningen-Drenthe HiCal contract. Grijpskerk South (GRK-2) was never conventionally produced. Subsequently, the field was shut-in for conversion to an underground gas storage (UGS) and a total of six additional wells were drilled in Blocks 1 and 2 during 1995 – 1996. To increase working volume-capacity two more wells were drilled in Block 1. Those eight wells together with the existing GRK-1A and GRK-2 wells are currently used in UGS operation.

The gas quality of the Grijpskerk UGS is HiCal, similar to the indigenous field gas. GTS can blend produced gas to pseudo G-gas with nitrogen. In this way the Grijpskerk UGS is able to contribute to the total balance market of the Groningen system. The injected gas originates partly from the Asset Land Small Fields and partly from Norway (pipeline via Emden). In the future GTS may extend its pipeline network to allow HiCal gas transport from Russia via Germany and The Netherlands to Great Britain.
If a shortage of HiCal gas occurs, Grijpskerk can be used as back up but also to create additional sales. This flexibility is unique for Grijpskerk, as the other elements in the Groningen system cannot contribute to the HiCal balance.

Reservoir Description

The Grijpskerk field is recognized to comprise two separate reservoirs: Grijpskerk Main (Blocks 1 and 2) and Grijpskerk South (Block 3). Grijpskerk South is penetrated by GRK-2 only, see *Figure A.3*.

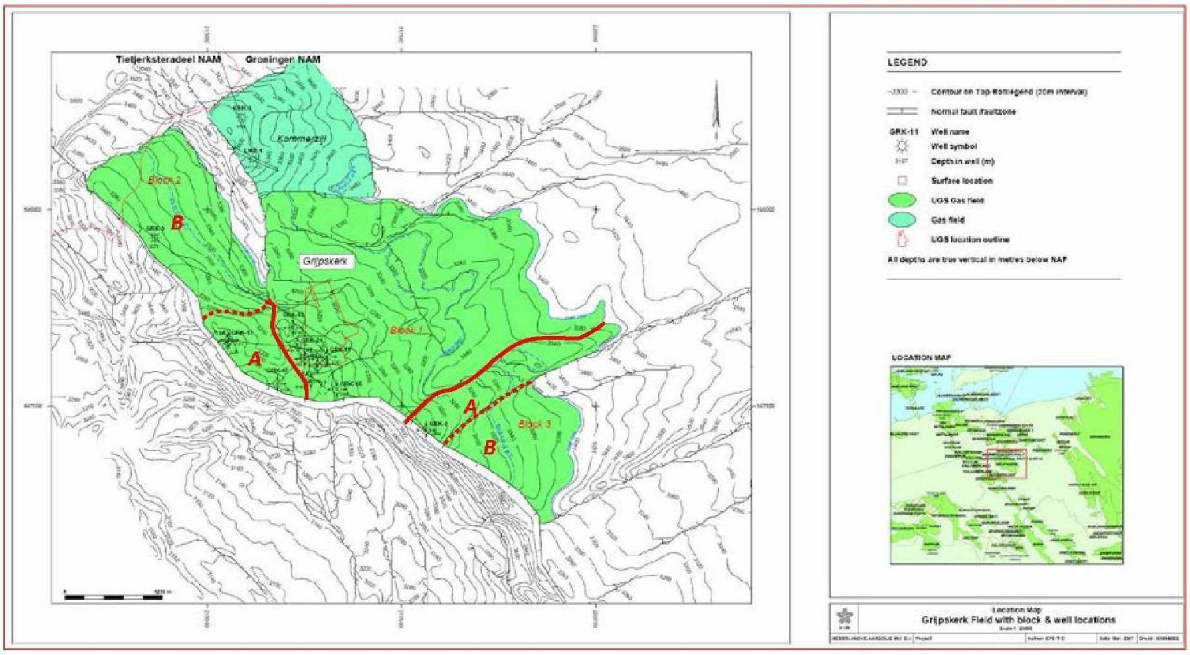

***Figure A.3** – Map of the Grijpskerk field*

The Grijpskerk field is located on the western margin of the Lauwerszee Trough, a distinct tectonically low area between the Friesland and Groningen Highs. In the centre of the trough, a thick Rotliegend sequence is encountered (up to 420m in well SSM-1), whereas in Grijpskerk, 260-290m of Rotliegend is encountered. Seismic facies and isopach mapping across the area indicate that the Lower Slochteren Sandstone Member (ROSLL) shows the greatest variation in thickness, indicating existing palaeo-relief at the Saalian unconformity and/or syn-depositional subsidence across the trough. In contrast, the overlying Ameland Claystone Member (ROCLA) and Upper Slochteren Sandstone Member (ROSLU) do not vary greatly. The Ten Boer Claystone Member (ROCLT) also shows thickness variation related to proximal to distal position, although this is relatively minor across the Grijpskerk field itself.

Diagenesis exerts the major control on reservoir quality and overprints less significant facies-related variations. A 3-fold subdivision of the field was therefore made into an upper kaolinite zone (high permeability), a lower illite zone (low permeability) and an intervening transition zone. In the illite zone the combined effects of grain rim illite overgrowths and fibrous illite are at a maximum for all wells.
In the recently drilled GRK-43 a dedicated test carried out on the Illite Zone (which contains the bulk of the field's GIIP) demonstrated significant production capacity, with a flow rate of 1.13 mln m3/d recorded from a perforated interval of 36m. Subsequent production testing and PLT logging of the entire reservoir section (Kaolin, Transition and Illite Zones) also indicated significant Illite Zone productivity, with around 25% of the wells total inflow originating from the illitised reservoir. These results w.r.t. the contribution of the Illite Zone have been used to update the reservoir model and the expansion plans.

The testing of GRK-43 also revealed unexpected results regarding the productivity of the Kaolinite Zone (the high quality reservoir interval that is the focus of the current Grijpskerk Field development). PLT results suggest that the basal 15m of the Kaolinite Zone has a relatively low productivity, not dissimilar from that of the underlying Transition and Illite Zones, with the vast majority of Kaolinite Zone inflow originating from its uppermost 32m. More specifically, the basal third of the Kaolinite Zone is responsible for only around 10% of the zone's inflow, with the remaining upper two-thirds of the zone responsible for 90% of the zones inflow. These results contrast with the general perception that the Kaolinite Zone is relatively homogeneous and that permeability is uniformly distributed through this interval.

PLT logging during a shut-in period indicated that there is cross-flow from the Illite Zone to the Kaolinite Zone. Again the recorded inflow was primarily focused on the highly productive uppermost 32m of the Kaolinite Zone indicating that the permeability of this zone is not homogeneous. It is notable that cursory inspection of PLT data from other wells suggests that GRK-43 is not atypical.

Grijpskerk Wells and Facilities
The facilities at Grijpskerk consist of ten producing wells and one observation well, a 80 mln Nm3/d production facility with two silica gel drying units and one 38 MW injection compressor installation. Four manifolds, each with a maximum capacity of 24 mln Nm3/day (whereby the HIPPS systems are the limiting factor). Fiscal metering for up to 84 mln Nm3/d has been installed. Additional metering is needed for expansion beyond this capacity.

The wells within a cluster are connected to a cluster manifold. This means that all wells in a cluster are in the same operating mode (i.e. either injection or production). Each cluster is connected to the production and injection manifolds and has links to other clusters. An exception to this is GRK-11, which part of a debottlenecking exercise has been re-routed from cluster 1 to cluster 2 manifold.

The gas is cooled in air coolers (down to 23 Deg. C) and led to a high-pressure separator (with Gasunie Cyclones). The separator design minimizes the risks of liquid carry-over that would cause damage to the adsorbent beds. The gas from the four HP (high pressure) separators is fed into two parallel adsorber trains consisting of three vessels. Water and hydrocarbons are removed from the gas in the spare production mode of the adsorption trains.

Dew Point Specification is obtained with the silica gel adsorption process. The desiccant adsorbs water and heavy hydrocarbons from the gas. The adsorbent bed gradually becomes saturated with adsorbed fluid. As the cycle proceeds, water displaces hydrocarbons and heavier hydro-carbons displace lighter hydrocarbons from the bed so that progressively heavier components appear in the processed gas and the outlet approaches specification. The bed is then taken off-line and regenerated by passing a slipstream of hot gas over the adsorbent. The saturated bed is regenerated by hot gas to adsorb the water and hydrocarbons. Thereafter the hot, dry regenerated bed is cooled by a cold gas flow prior to being brought back on-line to replace a saturated bed. Regeneration gas is taken from upstream of the adsorption train and passed through a furnace (18 MW) that heats the gas to 275 Deg C. The regeneration gas containing water and hydrocarbons is then led to the regeneration condenser and cooled to 23 Deg C and thereafter to the gas/liquid separator.

After cooling to the dew point the gas is fed to a mercury removal/filtration section. Entrained solids are removed from the gas, which is then mixed with gas from the other processing train. Currently the mercury removal vessels are by-passed. The gas then flows to the metering station, which has five meter-runs in parallel (one group of three and one group of two) for flexibility and turndown reasons. Metered gas passes to the import/export header for custody transfer to Gasunie.

Grijpskerk completions consist of a 7-5/8" Cr13 tubing with SSSV at +/- 100 m, inside a 9-5/8" production casing. Above the SSSV the tubing size is 7". Most wells have been completed with a 7-in cemented liner across the reservoir. GRK-45 and -47 have 300 □m Baker Slimp
GRK-13/15/17a/43 have 7" pre-packed WWS installed below the packer, as part of the tail pipe as a contingency for sand control. In case of unacceptable high levels of sand production, a wireline retrievable WWS can be installed to plug off and actuate the 7" WWS, as done in GRK-13 and GRK-15. In wells GRK-17a and -43 the WWS have been left open. It should be noted that this contingency measure is no longer recommended since it has been found difficult to remove the wireline retrievable WWS- plug again from the screen because of fines blocking the lock-mandrel (NOR-5 and GRK-15).

UGS Norg

The Norg field is located in the northern part of the Drenthe Concession. Originally, the field was operated as a conventional depletion field under the Groningen-Drenthe HiCal contract. In total, 10.310 mrd Nm3 gas was produced between 1983 and 1995. Subsequently, the field was shut-in for conversion to an Underground Gas Storage (UGS) and a total of five additional wells were drilled.

Reservoir Description

The Norg field consists of four fault blocks, see *Figure A.4*.

- Block 1: NOR-1 (observation well, exploration well never used for production)
- Block 2: NOR-2, -4, -5, -21, -23, -31, -33, -35 (of the old production wells NOR-2, -4 and -5 only NOR-5 is being used for UGS operations, other two as observation wells. NOR-21, -23, -31, -33, -35 have been drilled as UGS wells)
- Block 3: NOR-3 (old production well, used as observation well)
- Block 4: NRD-1 (exploration well, abandoned)

The structure of Block 2 is complicated further by faulting which has led to a narrow pop-up block along the western flank. Gas was originally found in both the Ten Boer Claystone and Slochteren Sandstone reservoirs. Additional Carboniferous gas-bearing sands were encountered during drilling of the UGS wells.

Faults over the Norg field are mainly normal and steeply dipping. From production behavior it is clear that fault Blocks 1, 2 and 3 are in pressure communication via their gas columns. Pressure communication between the main field and Block 4 was proven by well NRD-1 which was found with almost 90 bar pressure depletion, identical GWC and a similar gas composition.

Following uplift and erosion of the region, during the late Carboniferous and early Permian, the Slochteren was deposited in an aeolian environment (dunes and dry sandflats) while the Ten Boer Claystone was deposited in a mixture of alluvial, aeolian and playa mudflats environments. Differential subsidence of the basin resulted in the development of a wedge of Rotliegend sediments. Over the Norg field the Rotliegend thickness varies from some 150 m in the south to over 200 m in the north. The Carboniferous was deposited in a fluvial "channel facies" environment.

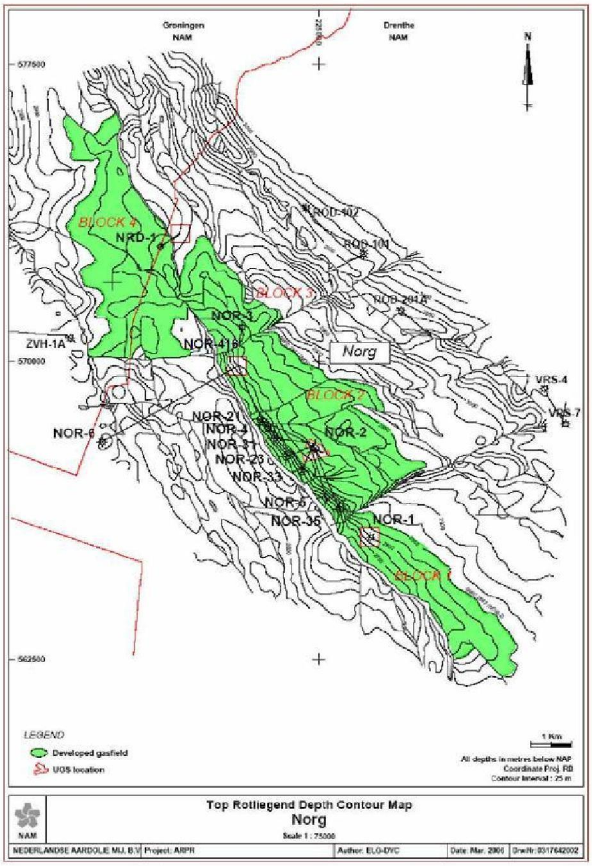

Figure A.4 – Map of the Norg field

In the Norg field the reservoir is subdivided into 8 main units (see *Figure A.5*). The lowest reservoir unit (RESU8) is part of the Lower Slochteren and comprises basal fluvial and/or fan conglomerate deposits. The overlying unit RESU7 is dominated by aeolian sand deposits (dunes and dry sandflats). The Ameland Claystone above (RESU6) is developed as a lacustrine deposit in the north and grades into a fluvial pebbly/conglomeratic sand unit towards the south. Reservoir units 3, 4 and 5 form the Upper Slochteren and comprise a high net-to-gross dune-dominated sand sequence. RESU4 is a relatively thin fluvial unit and can be recognized throughout the field. A sequence of fluvial pebbly sands and lacustrine/pond claystone beds characterize the basal part of the Ten Boer Claystone (RESU2). The overlying RESU1 is dominated by lacustrine clay stones with fluvial, thinly bedded intercalations of pebbly sands.

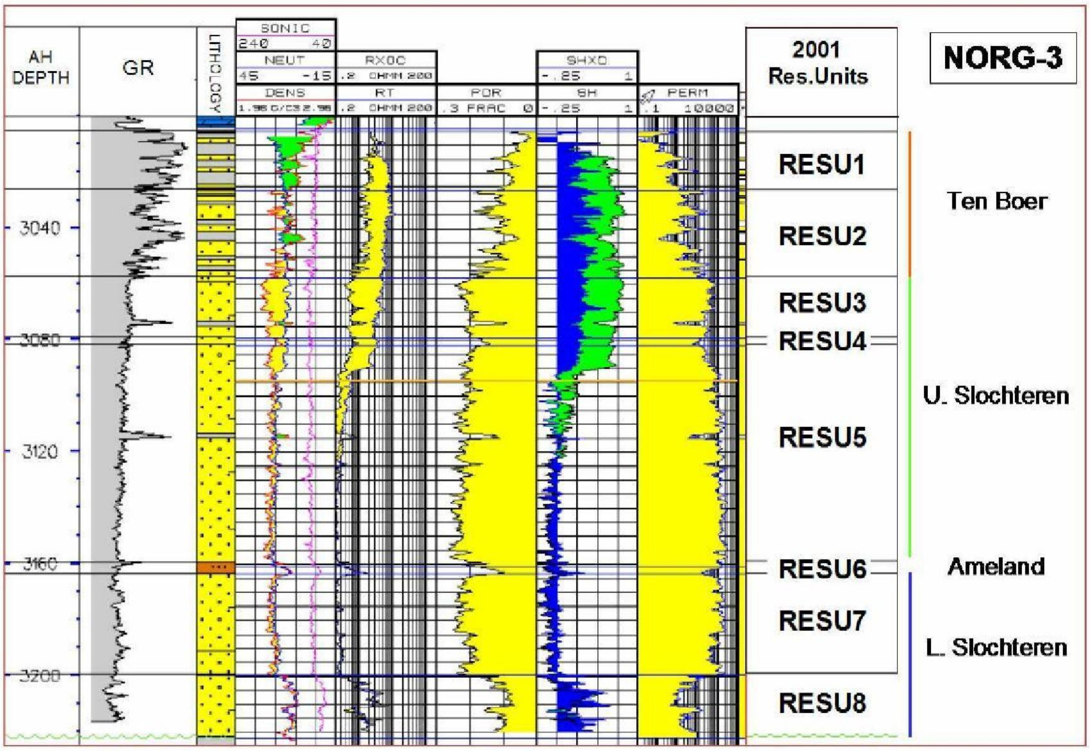

Figure A.5 –Norg field main reservoir units

Norg Wells and Facilities
The Norg UGS has seven producing/injection wells, two 38 MW injection compressors and two production trains. Gas treatment is based on the silica gel bed adsorption process.

Currently Norg has eleven wells. Seven UGS wells (7 5/8") have been drilled from three well clusters (i.e. Cluster-2, Cluster-3 and Cluster-4). In addition to these production/injection wells, there are four observation wells: two on the Norg-3 location (NOR-3 and -4), one on the UGS location (NOR-2) and one on the Norg 1 location (NOR-1).

Each cluster is provided with an inlet manifold and is hooked up to inlet separators and production coolers, which are in turn connected to two processing trains. These inlet facilities can accommodate the flow of five wells per cluster, with a maximum capacity of 24 mln m3/d. The plant has space for two additional well clusters with corresponding production manifolds.

The maximum capacity of the manifolds and the HIPPS valves is limited 15 mln Nm3/d because of erosional velocity constraints. With the double valve arrangement, the manifold capacity is 30 mln Nm3/d. The two existing clusters can handle up to 60 mln Nm3/d capacity provided well capacity is properly distributed between the clusters. A well capacity increase beyond 60 mln Nm3/d requires a new well cluster. Recent studies and tests show that the cooling capacity of the production coolers is limited to 24 mln Nm3/day per train at an ambient temperature of 5 Deg C. During the construction of the plant only the bare minimum on production coolers were installed for cost saving reasons.

Gas treatment is based on the process of silica gel adsorption. An adsorber needs to be regenerated after producing 3.3 mln Nm3 of gas, which takes ca. 2 hr using the full heating capacity of the furnaces. The production capacity of each adsorber is 24 mln Nm3/d. The nameplate plant capacity is 80 mln Nm3/d. Due to limited production cooler capacity the actual capacity is only 48 mln Nm3/d (2 * 24) at a design ambient temperature of 5 Deg. C.

The UGS has two 38 MW injection compressors. Norg is connected to the G-gas pipeline from OV Sappemeer to the West. In this pipeline configuration the production of Norg is limited to 59 mln Nm3/d. A study together with GTS has been initiated to investigate any back-out effects in the GTS pipeline system, originally designed for 55 mln Nm3/d. To expand Norg to bigger capacities a new pipeline is required from Norg to Groningen/Sappermeer (NorGron), planned for operations in 2013.