Testing requirements for Geothermal exploration in RSM

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Steps in geothermal exploration

1. Review and study of existing data
2. Studies of surface manifestations and Geochemical studies
3. Geological Exploration
4. Geophysical Exploration
5. **Exploration Drilling and flow testing**
6. Preliminary Resources Estimate

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Four aspects will be looked at during proposal evaluation of drilling programs and well designs

Drilling programs and well designs (15%)

No.	Items to be evaluated	Points
1	Well design and applicability of the design	30
2	Rig requirements based on the well design	10
3	Drilling program (including estimated drilling time and drilling fluid program)	30
4	Well-testing design and well testing program (to determine success)	30

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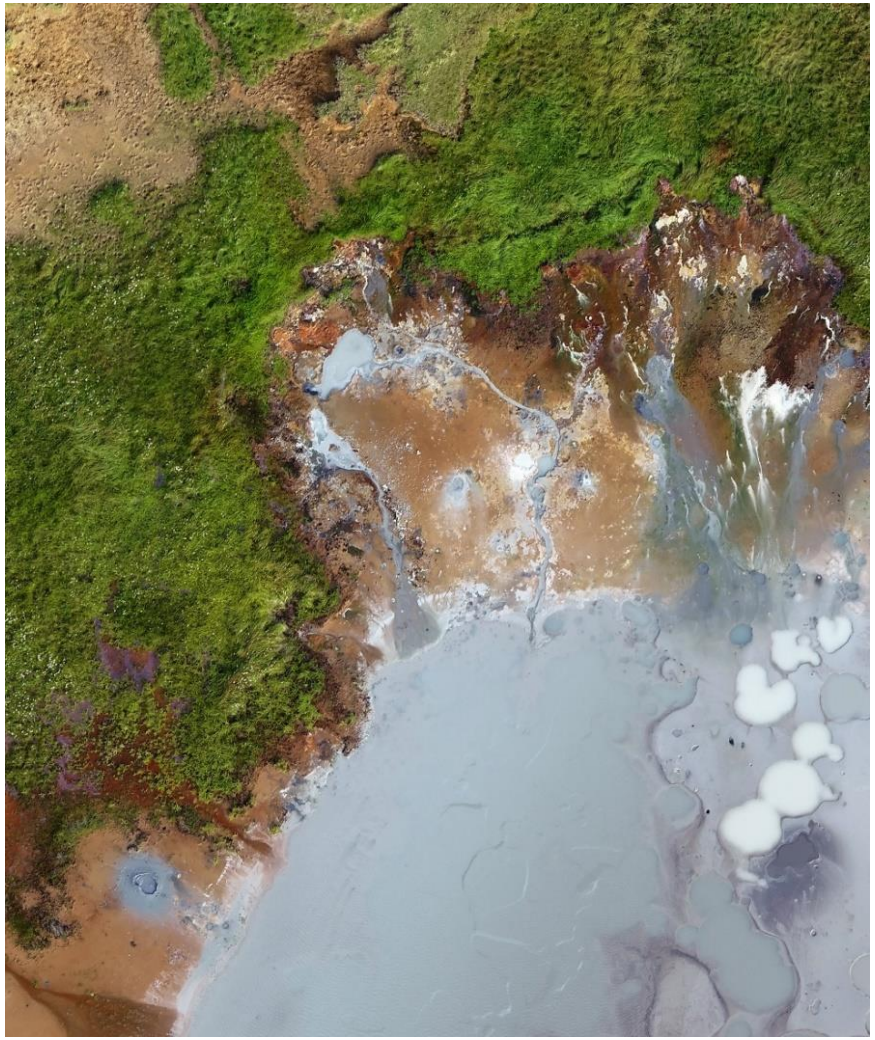
Key requirements for drilling programs and well designs

- Mud logging and wireline logging.
- Well completion test.
  - Injectivity and/or short discharge testing of wells.
  - Feed zone location and quantitative estimates.
- Discharge testing for estimating success. If not reached via artesian flow, the use of airlifting and/or downhole pumps may be needed to reach conclusion.



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Well testing procedures requirements

- Each application shall include a well testing program relevant to the reservoir temperature and well types.
  - In the case where wells are artesian, or gas drives flow from wells, airlifting or pumping may not be required.
  - Where the temperature is above approximately 200 °C “flashing” may facilitate discharge from well.
  - In the case of deep slim wells, flow testing may not be possible.
- In the case where deep slim wells are drilled for temperature estimation only, flow testing is not required.

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Logging at well completion

A detailed plan for logging at well completion is required, including a schedule for logging and interpretation as well as information on instrumentation to be used. The following information is required:

- Proposed schedule (timing of logs, well section to be logged, staff involved and expertise)
- Required measurements (Temperature, Pressure vs. depth)
- Instrumentation (logging unit, slick-line or wireline, logging tools, etc.)
- Interpretation (incl. feed-zone depth and first estimate of reservoir temperature and initial pressure)

Well completion testing - 1

The main results of well completion testing (at end of drilling):

- first indications of reservoir temperature and
- initial pressure, as well as
- feed-zone information,

This may give early indication if the well is a failure or how the final flow testing should be carried out for estimating success.

Well Completion Testing - 2

- Short-term step-rate testing at the end of drilling is required.
- Injection testing is usually only done for high-temperature wells
- Airlifting is generally more common for lower temperature wells.
- Preliminary plan for the testing should include:
  - Proposed schedule:
  - Number and length of steps.
  - Pressure recovery (decline/loss for injection).
  - Staff involved and expertise.

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Well Completion Testing - 3

Required interpretation, as far as data allows:

- Well injectivity/yield.
- Transmissivity, permeability-thickness, and skin (from pressure transient analysis).
- Feed-zone depth and their relative contribution.
- Estimates of formation temperature (specifically at feed-zone depth).

The main results of this phase will provide early indications relevant for the estimation of success.

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Warm-up phase

- Often a specific warm-up phase after drilling is required, especially in high temperature wells.
  - The reference length for warm-up is about two months, while a shorter period is acceptable in some cases, especially when pumping or airlifting is used.*
- The preferred number of warm-up temperature logs is four with increasing time between them.
  - Short term (a few hours) continuous recording downhole may reduce the number of logs.
- This will be used for formation temperature estimations (Horner plot)

* Specifying a universal length of the warm-up period is not possible due to variable well conditions, as well as constraints related to logistics and time.

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Flow or output testing for geothermal wells – 1*

- High-temperature wells are tested through spontaneous discharge driven by boiling in the wellbore.
- Low- to intermediate temperature wells are either tested by down-hole pumps (preferable) or airlifting, if artesian flow is not sufficient.
- A detailed plan for the testing is required, including a schedule for the testing, measurement, and interpretation as well as information on instrumentation to be used.

* For details, see chapter 6 in Beneficiary Manual.

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Flow or output testing for wells - 2

<u>An example of a possible testing schedule is as follows:</u>

- Initiation of flow; method to be used.
- Method to be used to measure flow and enthalpy:
  - water-flow and reservoir enthalpy (liquid dominated reservoir).
  - lip-pressure (Russel James) and water-flow (high temperature).
  - TFT measurements of liquid and steam flowrate (optional).
- Monitoring (parameters, mode, frequency, etc.).
- Length of test and need for variable opening (steps).
- Logs, especially temperature and pressure.
- Down-hole measurements with time (pressure&temperature).
- Down-hole pressure recovery after flow-test.
- Gas content and composition in fluid.
- Staff involved and expertise.

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Flow or output testing - 3

Interpretation:

- Water-flow, steam-flow, and fluid enthalpy.
- Productivity-index, i.e. total flow per unit change in reservoir pressure.
- Production characteristics (simple plot of flowrate vs. pressure, either well-head pressure or down-hole pressure).
- Output capacity as total flowrate and enthalpy, or steam-flow and water-flow, at a given well-head pressures.
- Transmissivity (permeability-thickness) and skin.
- Further improvement of formation temperature profiles and feed-zone locations.
- Indication on long term pressure and temperature response.

Flow or output testing

- A key element in flow-testing of geothermal wells is the length of the test.
- Ideally, such a test should last long enough for the well to have reached stable flow-conditions (well-head pressure, flowrate, and enthalpy), which may often take a few weeks or up to 2-3 months.
- Reaching fully stable conditions may often not be realistic, so semi-state stability may be used for long term estimations.
- If local conditions and/or local regulations and permits involved do not allow testing long enough for stable or semi-stable conditions to be reached, a short-term test may have to be implemented. That means that if the well has not reached stable or semi-stable conditions during the short-term testing, the **success or failure decisions(sc)** needs to be postponed until the conditions for long enough testing has been met and a long-term flow-testing has been carried out.


Thank you