# PROPOSED METHODOLOGY FOR ASSESSMENT AND RANKING OF GEOTHERMAL SYSTEMS

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**ABSTRACT**

Geothermal resources most suited for large-scale electricity generation are those with high temperature (commonly >250°C) reservoirs, yet small power and direct use schemes may be possible using low-moderate temperature (<150-220°C) resources. The nature of thermal springs in Thailand, India, Malaysia, Vietnam or elsewhere in Asia differ to active geothermal systems elsewhere, and any methodology for their assessment must be robust and consistently applied. We employ a two-stage approach that sets a minimum temperature to identify areas with potential, followed by a second-stage assessment (based on a numerical scoring) to evaluate a range of resource characteristics, that help identify and prioritise areas with potential for utilisation.

Our Stage One Assessment identifies sites that discharge water (or steam) of ≥60°C. By setting a minimum discharge (surface) temperature, we endeavor no area with potential for power generation is overlooked. Sites that meet the Stage One Assessment Criteria are then evaluated using a Stage Two Assessment, incorporating indicators of resource temperature, permeability, fluid flow, geological structure, heat source, reservoir characteristics, extent and type of surface thermal activity, proximity to other thermal areas, insight from previous geoscientific surveys and the history of drilling in the area. Arbitrary 'high', 'intermediate' and 'low' scores are attributed to each Stage Two Criteria. No area is excessively "penalised" if it scores lowly in regard to one parameter, but displays other positive attributes. By utilising a scoring system, thermal areas that meet the Stage One Criteria can be ranked for development or prioritisation for detailed (potentially expensive) exploration (i.e., geophysical surveys, exploration drilling etc.), at reduced financial risk.

**Keywords**: Resource assessment, exploration, development, ranking methodology, risk management

## 1. INTRODUCTION

Geothermal developments require tapping of hot fluids, typically by drilling, with fluid extraction managed to avoid resource depletion, impact on surface features or other users. Geothermal aquifers best suited for power generation, using proven technologies, occur in areas with high crustal heat flow, where heat is carried to the surface by fluid circulation in connected fractures, faults and permeable formations. However, systems need not be associated with magmatic heat, and development of binary-type technologies mean the temperature of the hot water / steam need only be 120°C, although ideally >150°C.
Insight a thermal area has potential for power or industrial direct use, prior to confirmation drilling, can be attained by examining its surface manifestations and chemistry of discharge fluids. The occurrence of near-boiling springs, unaffected by near surface processes (e.g., dilution by groundwater), with large flows

and high calculated geothermometry temperatures, are positive resource indicators and may point to an aquifer with well-connected permeability. In our experience, the absence of such surface manifestations does not preclude the possibility of a thermal area being able to support power generation or direct use, but may result in a lower prioritisation ranking for investigation, compared to more prospective areas.

In prioritising a geothermal resource for detailed exploration, positive and negative factors are evaluated in regard to the overall prospectivity. The following factors can be regarded as "positive attributes":

a. Large size
b. Good Permeability
c. High temperature
d. Presence of vapour zones
e. Nearby thermal activity
f. Accessibility / easy terrain
g. Shallow reservoir (to minimize drilling cost)
h. Proximity to market

There are also factors that may be sufficiently serious to preclude development, and may include:

a. Presence of acid fluids
b. High gas content
c. Hydrothermal eruptions
d. Tendency to deposit scale
e. Geotechnical hazards
f. Volcanic or seismic risk

The initial resource assessment is typically undertaken with sparse data. As an investigation proceeds, more reliable information becomes available, and a refinement of resource potential becomes possible.

## 2. RESOURCE EVALUATION METHODOLOGY

There are many regions in Asia that are prospective for geothermal energy and/or direct use developments, not only in established areas of SE Asia (e.g. Java and Sumatra in Indonesia; Philippines) and NE Asia (e.g. Kyushu and Tohoku regions of Japan). In any geothermal project, risk must be assessed and steps taken to mitigate those that could threaten development. To minimise financial risk, geothermal development is best promoted via a staged exploration strategy. As the cost of each stage increases, it is essential reliable geoscientific investigations are undertaken as the basis for sound decision-making.

Scientific investigations cover a range of techniques, and are aimed at characterising the geothermal system and quantifying its resource potential. The approach is to collate all scientific data, and develop a conceptual model of the geothermal system. The significance of risks is assessed by considering their likelihood and consequence, leading to ways of mitigating each risk.

## 3. RESOURCE PARAMETERS

Information concerning a thermal area can vary in reliability and content. There are numerous approaches to ranking geothermal resource potential, with a view to prioritising two or more thermal areas for exploration or development. However, approaches can be impacted by assessor bias. Although available information is initially insufficient to make a detailed resource capacity assessment, a range of resource characteristics are identified, in order to establish a preliminary assessment of potential, or to prioritise areas for further investigation. Commonly, the following parameters are considered:

**Areal Extent (Resource Size) :** The areal extent of a resource is typically estimated from geophysical surveys, with assessment of an prospect is based on inferences of resource temperature, and the nature and chemistry of surface manifestations, etc.

**Reservoir Depth – Thickness – Volume :** "Depth" is typically defined as mean depth from the ground surface to the top of the reservoir. "Thickness" is the mean thickness of the reservoir, with the upper surface corresponding to a minimum temperature, and the bottom to a maximum practical vertical drilling depth. Reservoir volume is the resource area multiplied by reservoir thickness.

**Temperature (Enthalpy) :** Information may exist under one or more of the following categories:
a. *Measured:* maximum measured temperature of surface thermal features, or bores ;
b. *Water Geothermometry:* reservoir temperature estimated from solute geothermometry ;
c. *Gas Geothermometry:* reservoir temperature estimated on the basis of reliable gas analyses.
"Enthalpy" is the thermodynamic quantity equivalent to the total heat content of a system, and is based on the best available temperature estimate (typically with a distinction between vapour and liquid zones).

**Acidity – Gas Content – Scaling :** Fluid acidity, gas content and scaling may have a detrimental impact on resource utilisation. These issues can impose constraints that may result in a prospective geothermal area receiving a low exploration ranking, or impact on future ranking and prioritisation for development.

**Reservoir-Related Effects :** Potential effects include subsidence, ingress of groundwater (e.g., response to pressure drawdown) and injection returns (c.f. reservoirs with fracture-dominated permeability). Whilst these effects can result from exploitation, it is possible to make predictions of their likelihood.

**Geological Hazards :** Geological hazards have potential to impact development. Volcanic risk may be a low probability event, but a region could still be seismically active. Assessing risk involves identifying site-specific geotechnical factors and avoiding siting facilities on at-risk locations.

## 4. RANKING OF HOT SPRING AREAS

How should a prospective developer prioritise / rank thermal systems for further investigation and/or development? The character of the hot springs, their surface manifestations and hydrology in Thailand, for example, differ to most majority of systems developed for power generation in New Zealand, Japan, Indonesia etc. Consequently, a methodology applied to geothermal prospectivity in New Zealand, is quite different to what is appropriate for Thailand or elsewhere.

A reasonable “first step” might be to obtain spring temperatures, and prioritise on a basis an area with “highest surface discharge temperature has greatest development potential”. The problem with this approach is that a high-temperature, low-flow seep might rank “higher” than an area with numerous high-flow springs, but lower measured discharge temperature. Obtaining samples from surface manifestations and using geothermometry may provide further indication of resource potential, although there must be confidence in a rigorous field sampling methodology and analysis is conducted by a reputable laboratory.

Ranking prospectivity on the basis of measured surface temperatures or calculated geothermometry alone has potential to exclude areas with characteristics that might otherwise justify further investigation. Consequently GNS promote a two-stage assessment that is “more inclusive”, by setting a minimum temperature requirement to identify areas with potential, followed by a comprehensive assessment involving a numerical scoring system that evaluates a wider range of resource criteria.

Our **Stage One Assessment Criteria** for prioritising areas for further consideration is the requirement that the thermal area discharges water of ≥60°C (or steam, in the situation there is only fumarolic activity). In New Zealand, prospective systems typically have surface manifestations that discharge waters of >75°C, and it may be inferred any area with surface discharges of <75°C has little power generation potential. A temperature of 60°C should ensure no area with good potential for power generation is overlooked.

The rationale for a **Stage Two Assessment** is to consider criteria (i.e. field observations, measurements and calculated data) that facilitate unbiased comparison assessment, so no area is excessively "penalised" if it scores lowly in regard to one criteria, but has other positive attributes. For example, it allows unbiased assessment of an area that might have a small number of high temperature features, and a second area characterised by a large number of warm, widely distributed manifestations, or associated geological features (e.g., possible heat sources or potential structurally-controlled fluid pathways). The rationale for our Stage Two Assessment scoring system is:

**Resource Temperature Indicators**

- *Measured surface discharge temperature*: Where thermal areas have springs with discharge waters of ≥80°C, these areas "score" highly, while springs of >60 - <80°C prompt an intermediate score. Sites with 30-<60°C and <30°C <60°C features are deemed low and zero score, respectively.
- *Estimated reservoir temperature*: the calculated $SiO_2$ geothermometry temperature, if the analytical data is reliable, may provide the best (pre-drilling) indication of reservoir temperature, and can guide exploration. Scores are awarded for a range of reservoir temperatures, e.g., a high score for areas with inferred reservoir fluids of >200°C, and a negative score where the inferred fluid source is <100°C, and hence unlikely to be suitable for power generation or large direct use applications.
- *Measured subsurface temperature*: information from previous well drilling that provides insight into the reservoir temperature is invaluable. Scores reflect measured reservoir conditions (ranging from a high score for springs with a reservoir of ≥200°C, and negative score where the fluid is <80°C and unlikely to be suitable for power generation or large industrial uses.

**Permeability Indicators**

- *Surface Fluid Flow*: a high combined fluid flow is deemed a positive resource attribute (i.e., well-connected fluid pathways in the near surface) whereas areas with low combined flow may be indicative of poor recharge or limited permeability. Scores range correspondingly. It is assumed that scores given represent combined fluid flow rates.
- *Structural Control*: Faults identified by geological mapping, stratigraphic offsets (variable depth to formation contacts) in wells, alignment of surface features, etc., may point to a structural control on fluid pathways, and possible enhanced vertically-connected permeability that could be a target for drilling. Scores are based on the proximity of the thermal area to mapped fault structures.

**Heat Source Indicator**

- *Heat source*: Scores are awarded according to the likelihood that encountered geology proffers potential for a heat source (e.g. evidence for an igneous intrusion or tectonic influences) conducive for resource development.

**Reservoir Characteristics**

- *Surface Feature Type*: surface manifestations provide insight into the hydrology of a thermal area (e.g., indicative of upflow or outflow). The "best" type of feature is awarded to areas with near boiling springs, pools or fumaroles, whilst areas with mud pots or seeps score lower.
- *Areal extent*: if known, a large inferred areal extent for the surface expression of the hot spring system (i.e., surface manifestation occurring over several $km^2$) is a positive resource attribute.
- *Proximity to other thermal areas*: the occurrence of nearby thermal areas, even if hydrological links are unknown, is a positive resource attribute, as it may point to a large heat source.
- *Geology data type*: insight into the stratigraphy of an area may be important, e.g., igneous rocks may point to a potential heat source, occurrence of limestone or evaporates might be implicated in an increased likelihood of scaling, unconsolidated units that might prove problematic during drilling should be identified. Scores are allocated to reflect the degree / type of information available.
- *Chemical data type*: availability of analytical data of surface features, springs etc, and confidence in the reliability of the data, provides important information to assess resource characteristics, i.e., inferred reservoir temperature from application of geothermometry, potential of scaling or corrosion, high gas content that might impact sustainable plant performance. Scores are awarded to recognise the level of chemical information available for the hot spring system.
- *Past geophysical surveys*: knowledge geophysical surveys have been conducted, and availability of results, is a positive exploration attribute. Geophysical survey data guide exploration, with insight into the extent and hydrology of the hydrothermal system, and insight into any fault structures that might focus fluid flow. Scores are allocated to reflect the degree of information available.

**Geothermal Drilling**

- The occurrence of past geothermal well drilling (any depth and purpose, e.g. shallow thermal gradient wells) in a prospect area is deemed a positive attribute. It shows past developers had confidence (and relevant information) to drill, and because information obtained from the borehole adds to the understanding of the reservoir and is scored accordingly.

Stage Two Assessment is applied to areas that meet Stage One criteria. A total numerical score is obtained for each site, collated, and placed in order from highest to lowest total assessment score. Sites can then be ranked according to their total assessment scores to determine those with the greatest resource potential.

## 6. CONCLUSIONS

Any process for assessing geothermal resource potential must be robust and consistently applied. We recommend a two-stage approach that sets a minimum temperature to identify potential, followed by a second-stage numerical scoring assessment (incorporating reservoir characteristics, temperature, permeability, geological structure and heat source, nature of surface thermal activity, insight from previous geoscientific surveys and drilling). No area is excessively "penalised" if it scores lowly in regard to one parameter, but displays other positive attributes. By utilising a scoring system, hot spring areas can be ranked for development or prioritisation for detailed exploration, at reduced financial risk