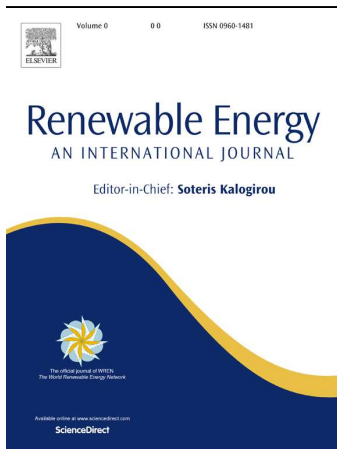


# Artificial Neural Networks for the Generation of Geothermal Maps of Cyprus

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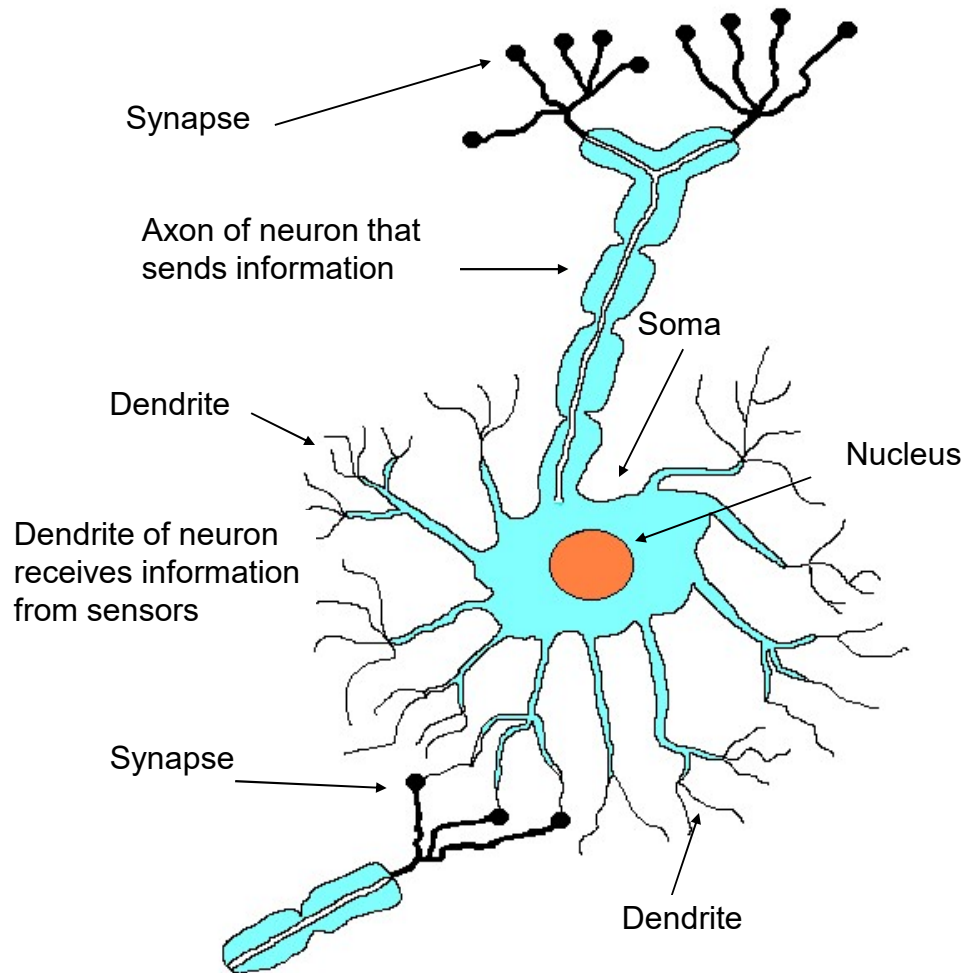


# Geothermal Maps

1. The purpose of the maps is to draw isothermal lines of temperature and conductivity at various depths in Cyprus so as to provide a valuable tool for engineers working in the area for the effective design of geothermal systems.
  2. For this purpose four maps were drawn:
    - i. Temperature at a depth of 20m
    - ii. Temperature at a depth of 50m
    - iii. Temperature at a depth of 100m
    - iv. Mean thermal conductivity of the ground
  3. As readings were not available in many places of the island Artificial Neural Networks (ANN) were used.
  4. These are special computer programs which once “trained”, using historic data, are able to predict data at other unknown cases..
    - They belong to the general area of Artificial Intelligence.
- More details in the next slides....

# Artificial Neural Networks (ANNs)

# A simplified model of biological neuron



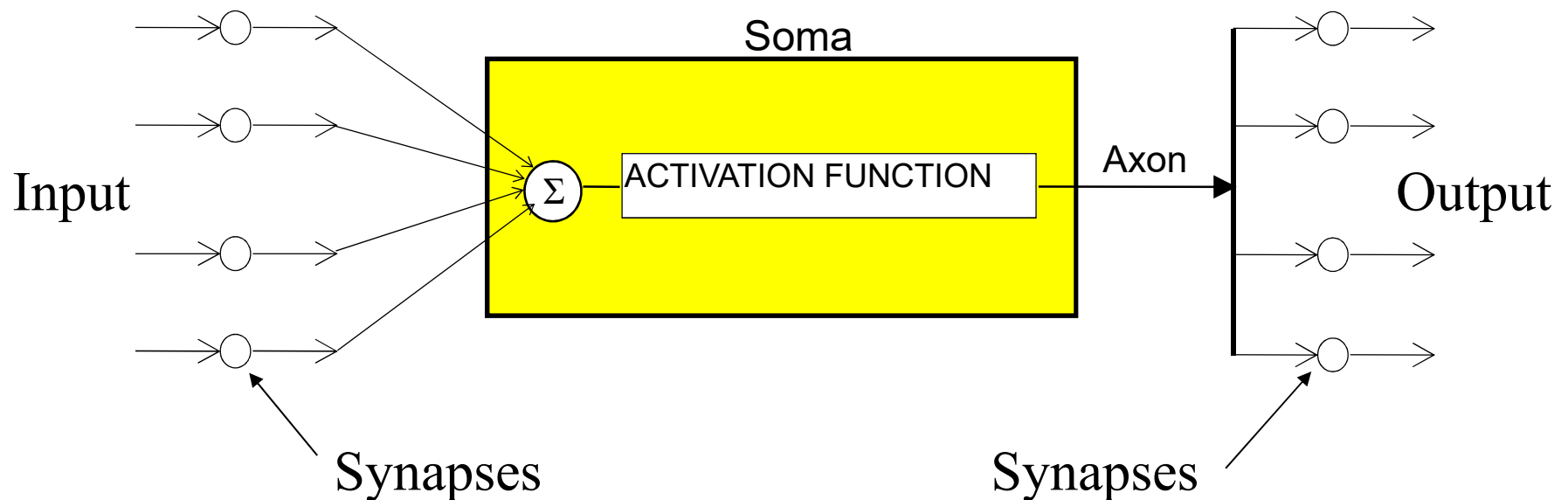
In brain there is a flow of coded information using electrochemical media, (called neurotransmitters), from the synapses towards the axon

Each neuron receives info at the synapses from about 10,000 other neurons

It is estimated that human brain has got around 100 billion interconnected neurons

# Simplified model of artificial neuron

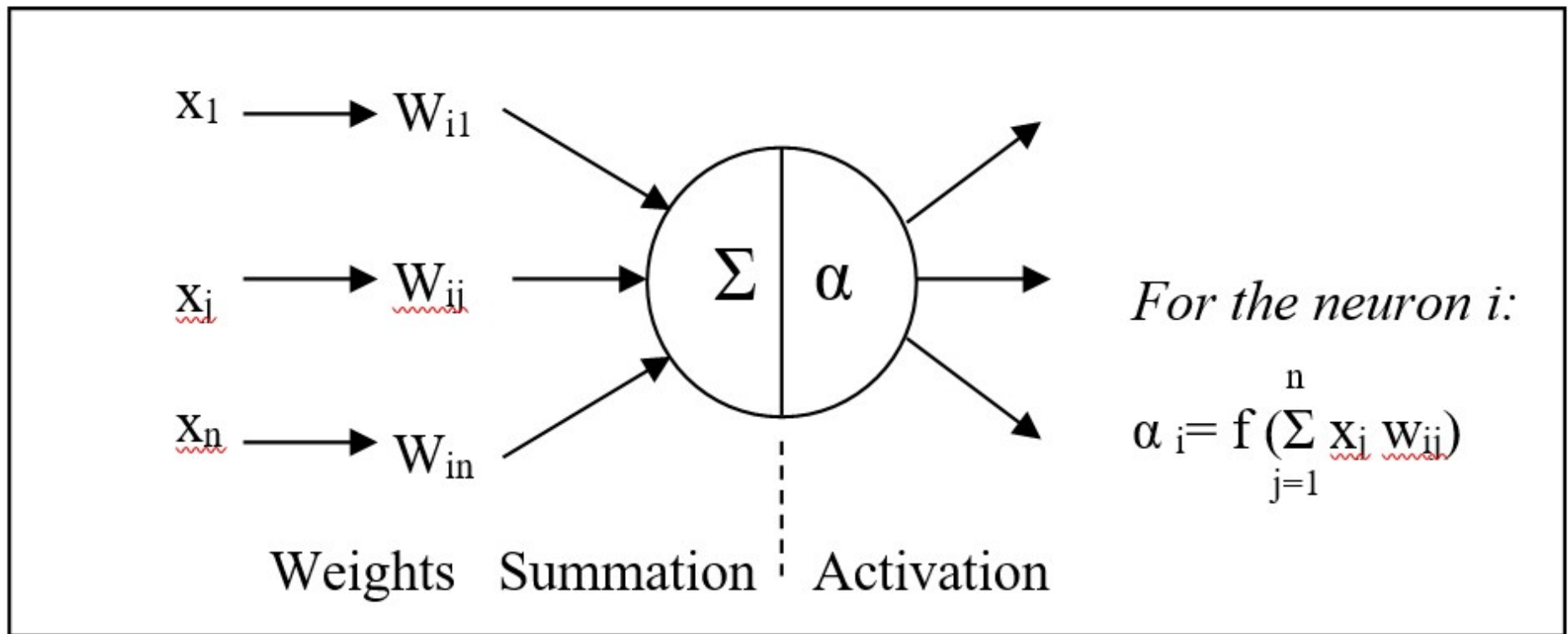
This is a highly simplified model of an artificial neuron, which may be used to stimulate some important aspects of the real biological neuron



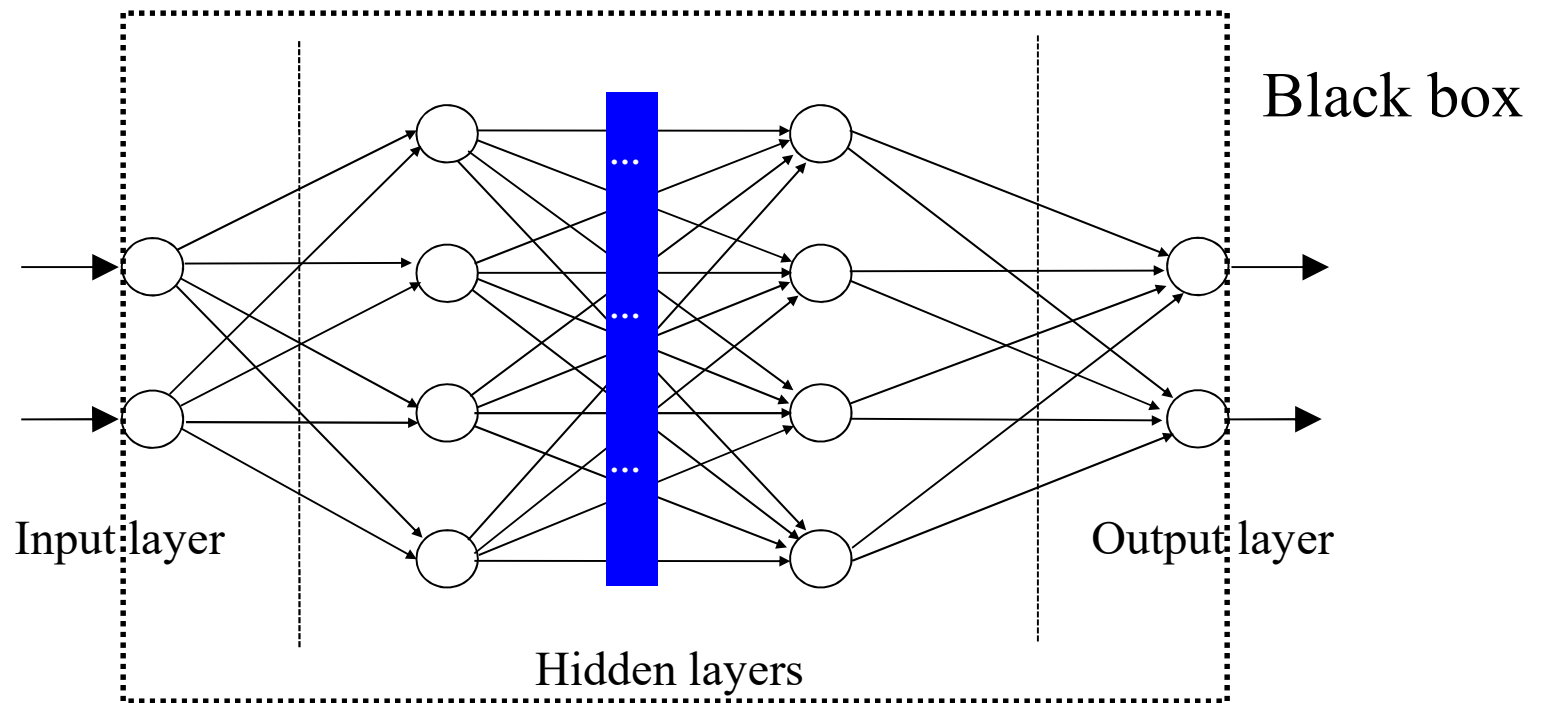
At the synapses, there is an accumulation of some potential, which in the case of the artificial neurons is modelled as a connection weight

These weights are continuously modified during training, based on suitable learning rules

# Information processing in a neuron



# Artificial Neural Network



An ANN is a group of interconnected artificial neurons, interacting with one another in a concerted manner

Excitation is applied to the input of the network. Following some suitable operation, it results in a desired output

Operate like a **black box** model and no detailed info about the system is required

# Artificial Neural Networks

- An ANN is in fact a massively parallel distributed processor that has a natural propensity for storing experiential knowledge, making it available for use.
- It resembles the human brain in two respects;
  - the knowledge is acquired by the network through a learning process, and
  - inter-neuron connection strengths known as synaptic weights are used to store the knowledge.
- In fact ANNs learn the relationship between the input parameters and the controlled and uncontrolled variables by studying previously recorded data.

# Properties of ANNs

- ANN models may be used as an alternative method in engineering analysis and prediction.
- ANNs are particularly good for tasks involving:
  - incomplete data sets,
  - fuzzy or incomplete information and
  - for highly complex and ill-defined problems, where humans usually decide on an intuitional basis.
- Additionally, they can learn from examples, and are able to deal with non-linear problems.
- Furthermore they exhibit robustness and fault tolerance.

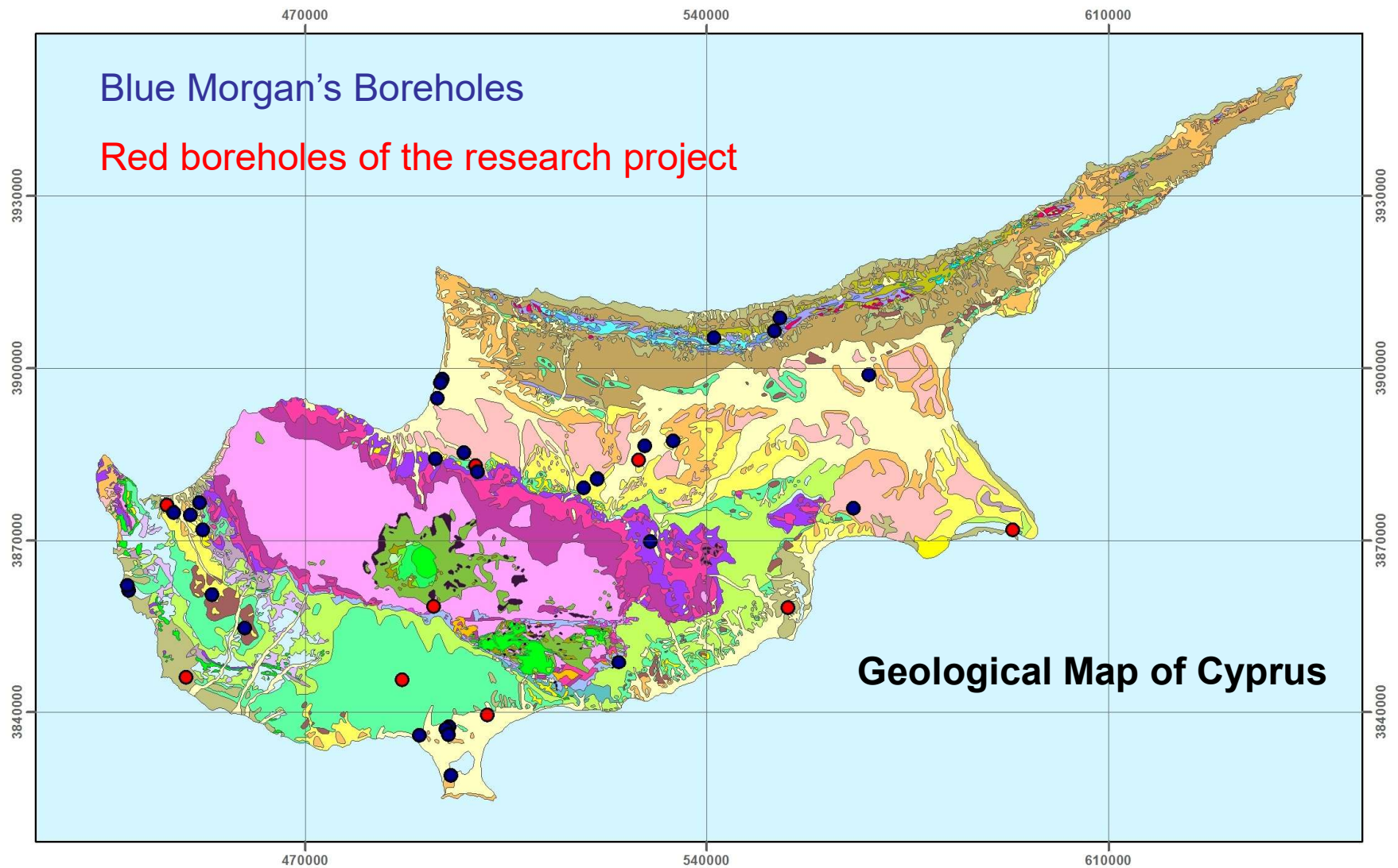
# Geothermal Maps

## **Available information**

The input data that were available are:

1. Data from 8 boreholes that were drilled under a research funded project.
  2. Data from 33 boreholes that were drilled in the 70's by Morgan.
  3. Geologic maps of the Department of Geological Survey Department
  4. Temperature and rainfall at the area of the boreholes from the Meteorological Service of Cyprus.
- Data were not available for all depths.

# Location of the 41 boreholes



## **Total number of data available:**

Subtracting the cases where data were missing, we have:

**90 cases** with recorded temperature – which were divided into :

- 81 cases for the training of the ANN
- 9 cases for the model validation

**41 cases** with recorded thermal conductivity – which were divided into:

- 37 cases for the training of the ANN
  - 4 cases for the model validation
- The selection of the ANN model is done by using trial and error method – There is still no science for this selection.
- After the selection of the suitable model and the proof of accuracy using the validation data sets, all cases were used for the retraining of the model for better learning/accuracy.

## **Basic input data for the training of the ANN:**

These data are the ones which could be recorded for each case, and they are related to the objective of prediction we wish to make:

### **Input parameters:**

1. Geologic glass at the area of the borehole
2. The elevation at the area of the borehole
- 3,4,5. The mean, minimum and maximum temperature at the area of the borehole.
6. The rainfall at the area of the borehole.
- 7,8. The x- and y-coordinates of the place of the borehole (all measured from a common random point.
9. The depth at which the temperature is measured (20, 50 or 100m)

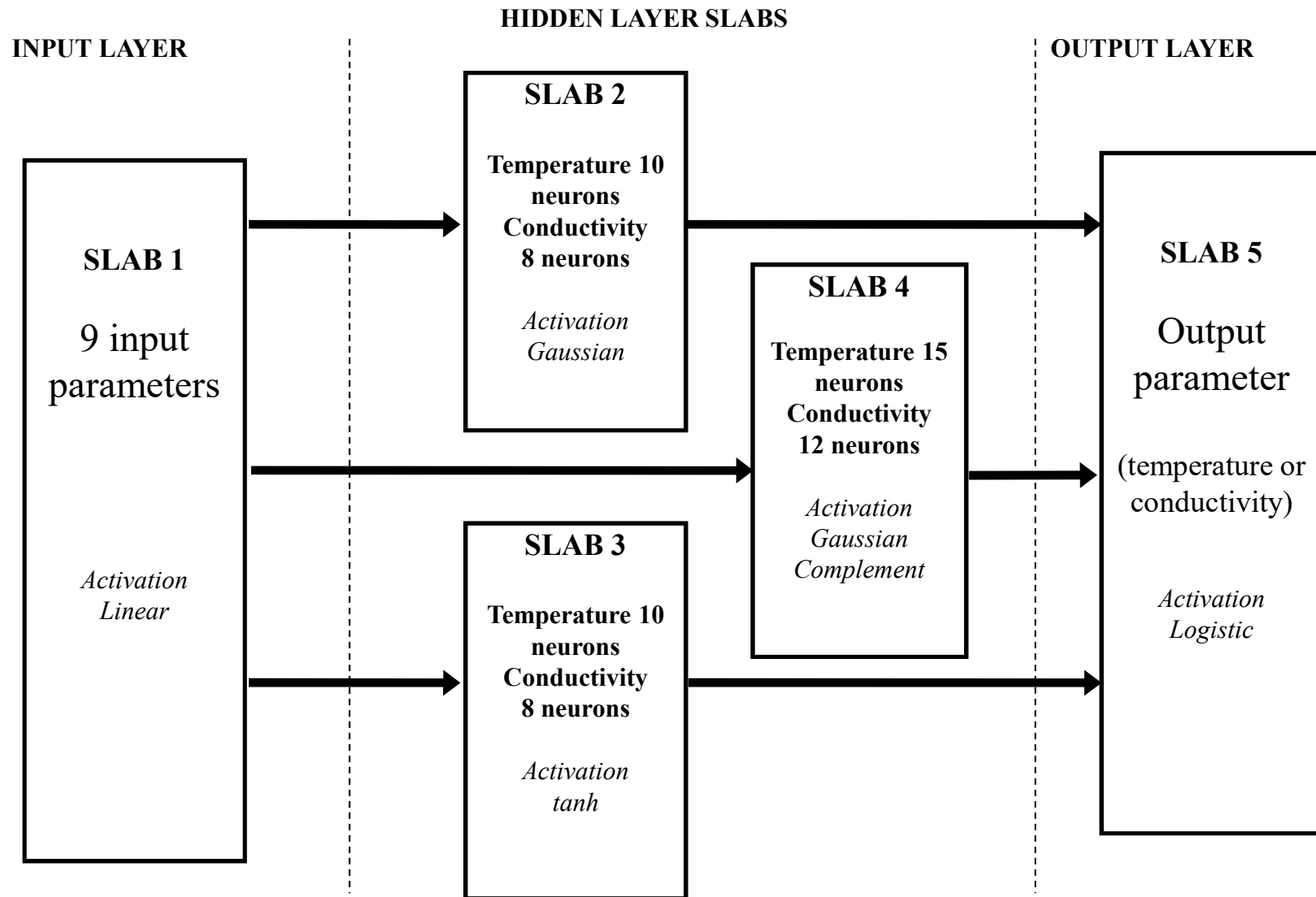
**Output:** The temperature or thermal conductivity at the respective depth.

# Lithology class

→ Note that numbers are used to identify the various classes.

| Lithology                                   | Lithology Class |
|---|-----------------|
| Clay  | 1               |
| Silts and clays                             | 2               |
| Sand  | 3               |
| Sands and gravels                           | 4               |
| Gravels                                     | 5               |
| Calcarenite                                 | 6               |
| Sandstone                                   | 7               |
| Sandstones and marls                        | 8               |
| Gypsum                                      | 9               |
| Marl over gypsum                            | 10              |
| Marl  | 11              |
| Chalk and Marl                              | 12              |
| Chalk                                       | 13              |
| Limestones and chalks over clay lithologies | 14              |
| Limestone over chalk                        | 15              |
| Limestone                                   | 16              |
| Basalt                                      | 17              |
| Basalt and Diabase                          | 18              |
| Diabase                                     | 19              |
| Gabbro                                      | 20              |
| Serpentinite                                | 21              |
| Hurzburgite                                 | 22              |

# Artificial Neural Network architecture selected



# Results:

The training of the ANNs (one for temperature and one for thermal conductivity) was done with high accuracy:

## 1. Temperature

Correlation coefficient = 0.9889 (training)

Coefficient for the unknown validation data = 0.9818

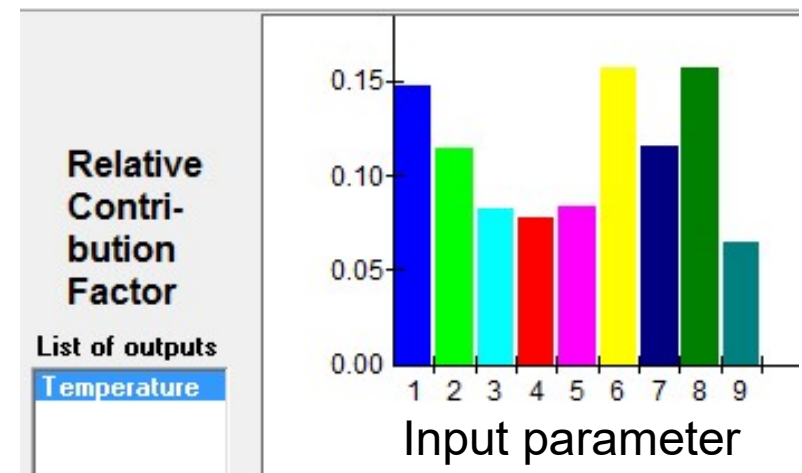
Maximum deviation = 1.74°C

## 2. Thermal conductivity

Correlation coefficient = 0.9220 (training)

Coefficient for the unknown validation data = 0.9178

Maximum deviation = 0.344 W/mK



- The results are considered very satisfactory
- The results show that the most important inputs are the geology class, rainfall and the coordinates (contribution factors)

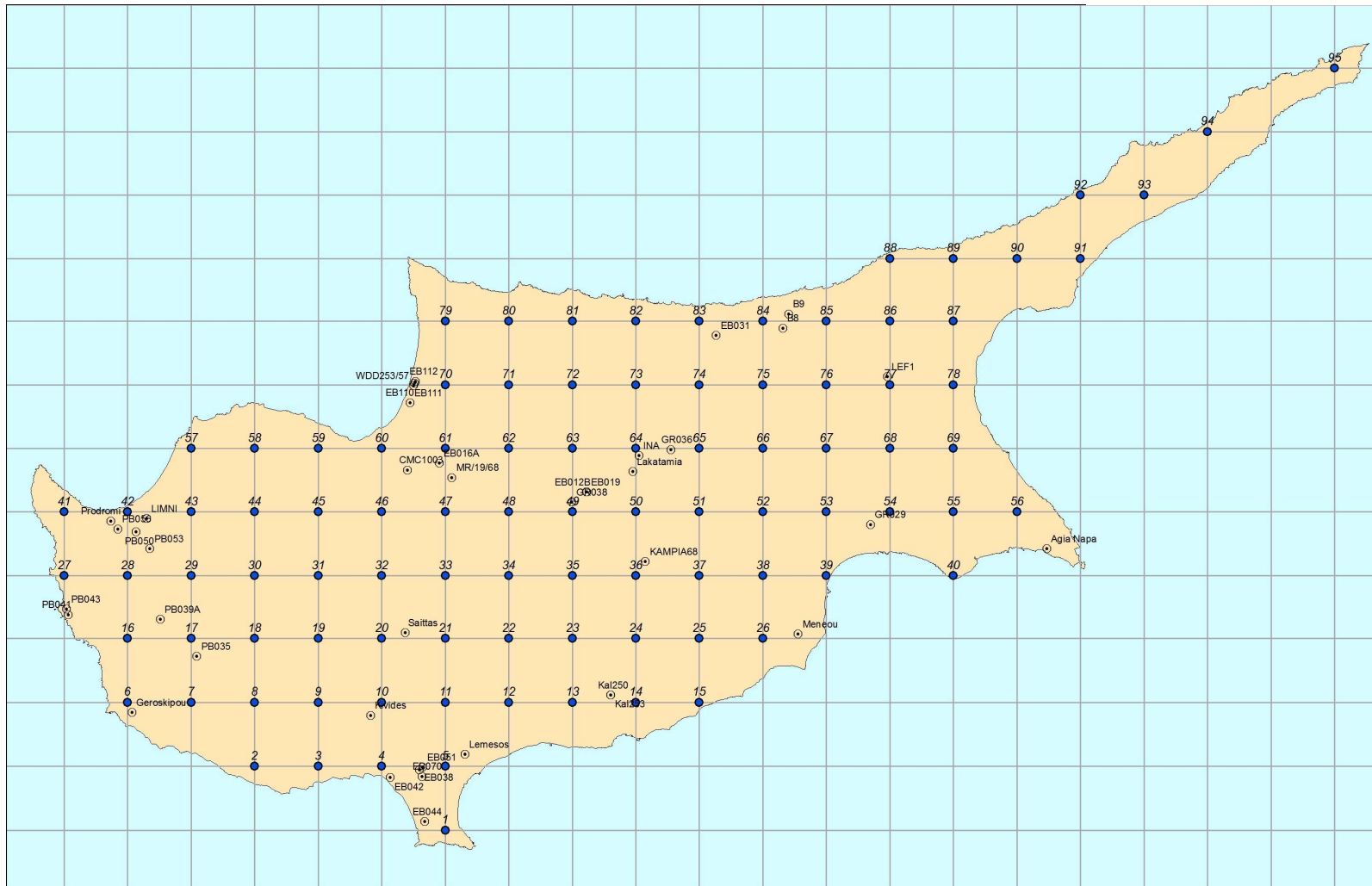
# The use of ANNs:

After the ANN training, the island of Cyprus was divided into a 10x10km grid (total 95 points).

## At every grid-point:

- The same input parameters used for the training of the ANNs were recorded/collected/estimated.
- These data were used on the trained ANN to predict the same output parameters (temperature at the three depths and mean thermal conductivity of the ground) at the different grid-points.
- The estimation time was under 1 second → very fast.

# Grid points used in the study

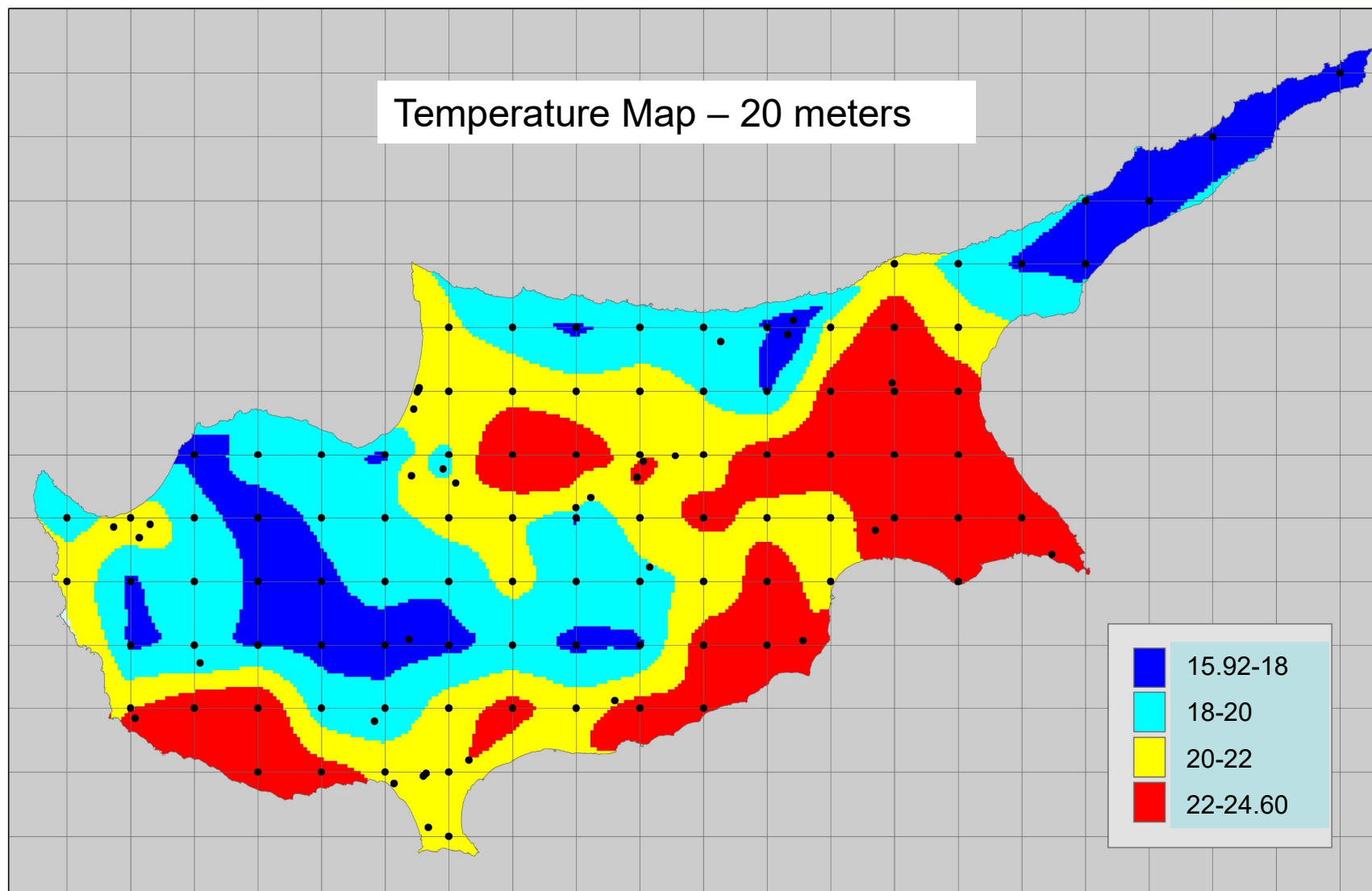


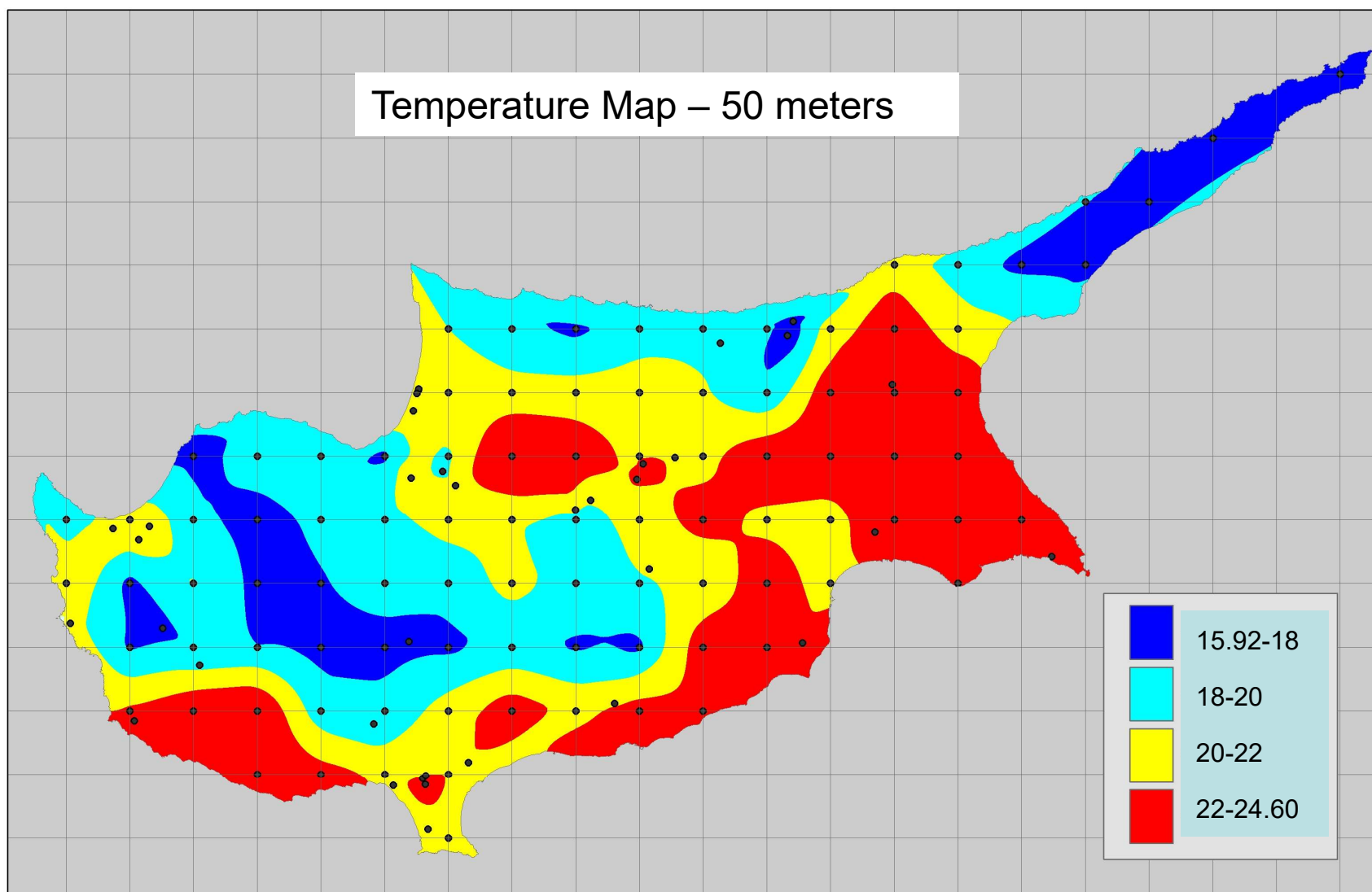
Random reference point

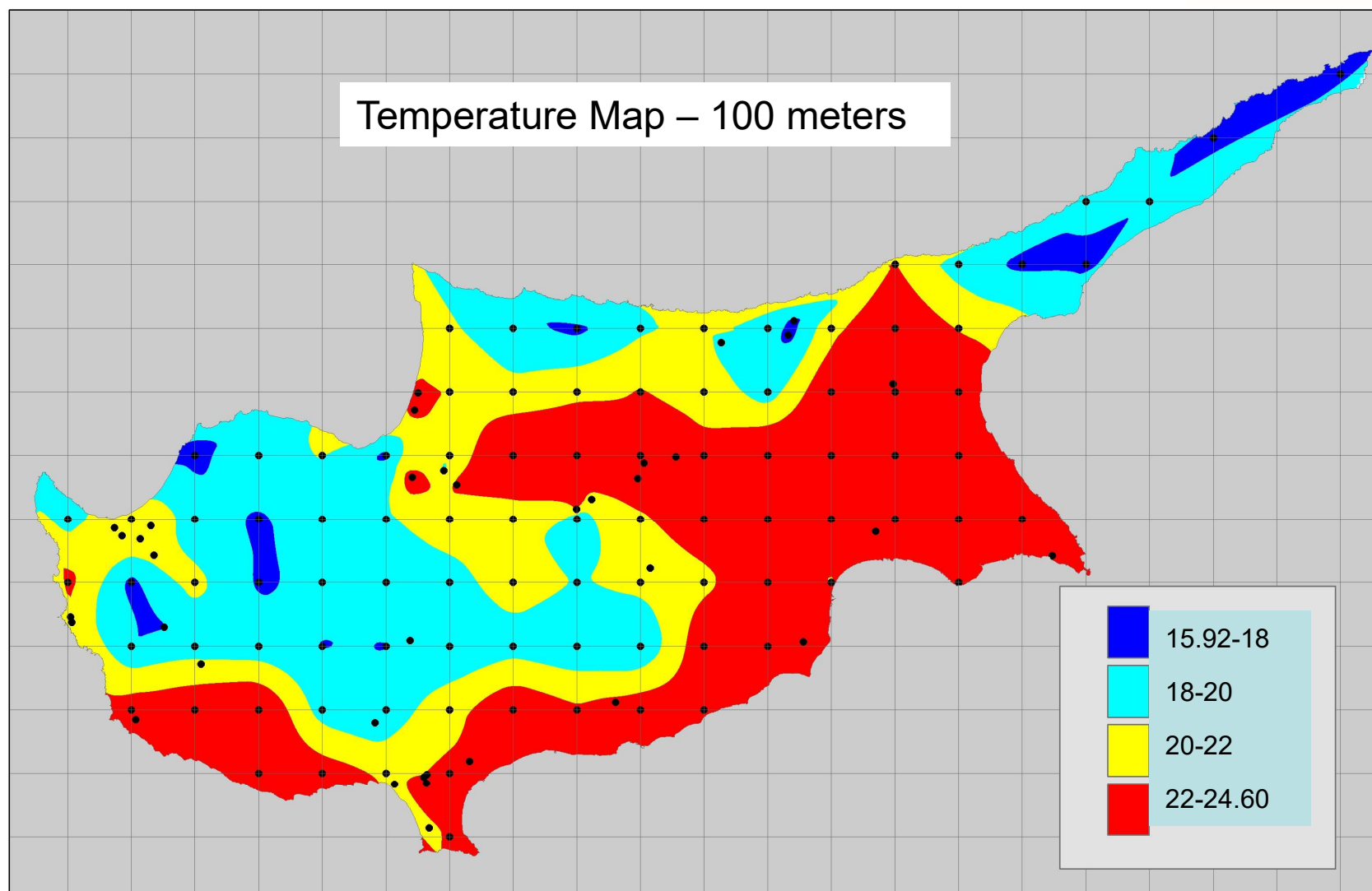
# Results

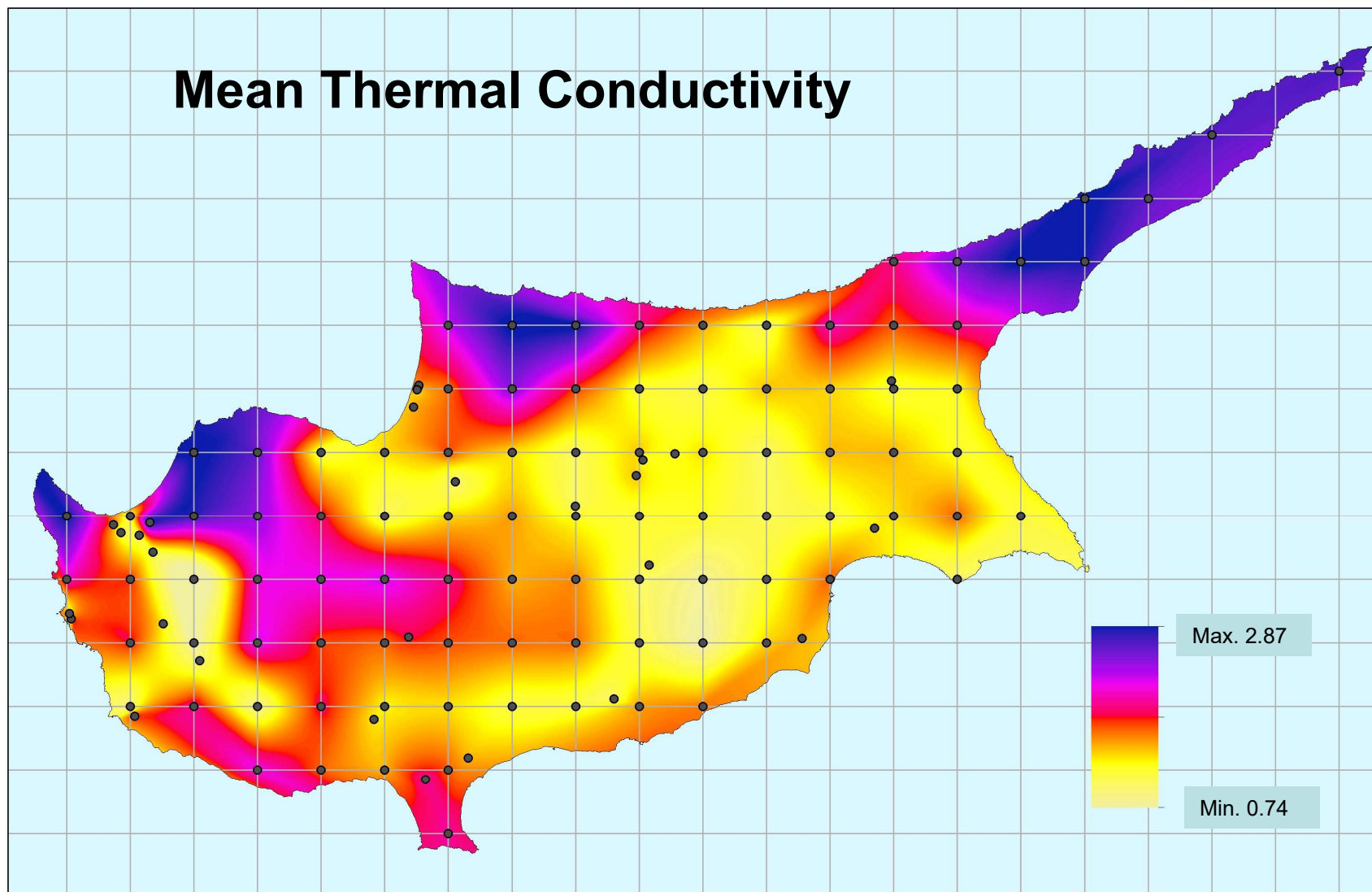
- For the construction of the geothermal maps temperatures at the three depths (20, 50 and 100m) and the mean ground thermal conductivity were used, from:
  - The real data from the 41 boreholes that were available
  - The ANN predictions at the 95 grid-points
- The maps were constructed with the use of ArcGIS 3D Analyst software using the Natural Neighbor algorithm.
- The actual maps are.....

Temperature Map – 20 meters









# Conclusions:

- The maps were successfully constructed.
- The maps are very useful for the application of geothermal energy in Cyprus and are considered as a very useful tool for the Cypriot engineers working in this area.
- More improved maps can be constructed in the future as more actual data are available.

Thank you for your attention.

Glad to answer any questions.....

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