Pumping Optimization of Coastal Aquifers based on Evolutionary Annealing-Simplex Scheme and Artificial Neural Networks

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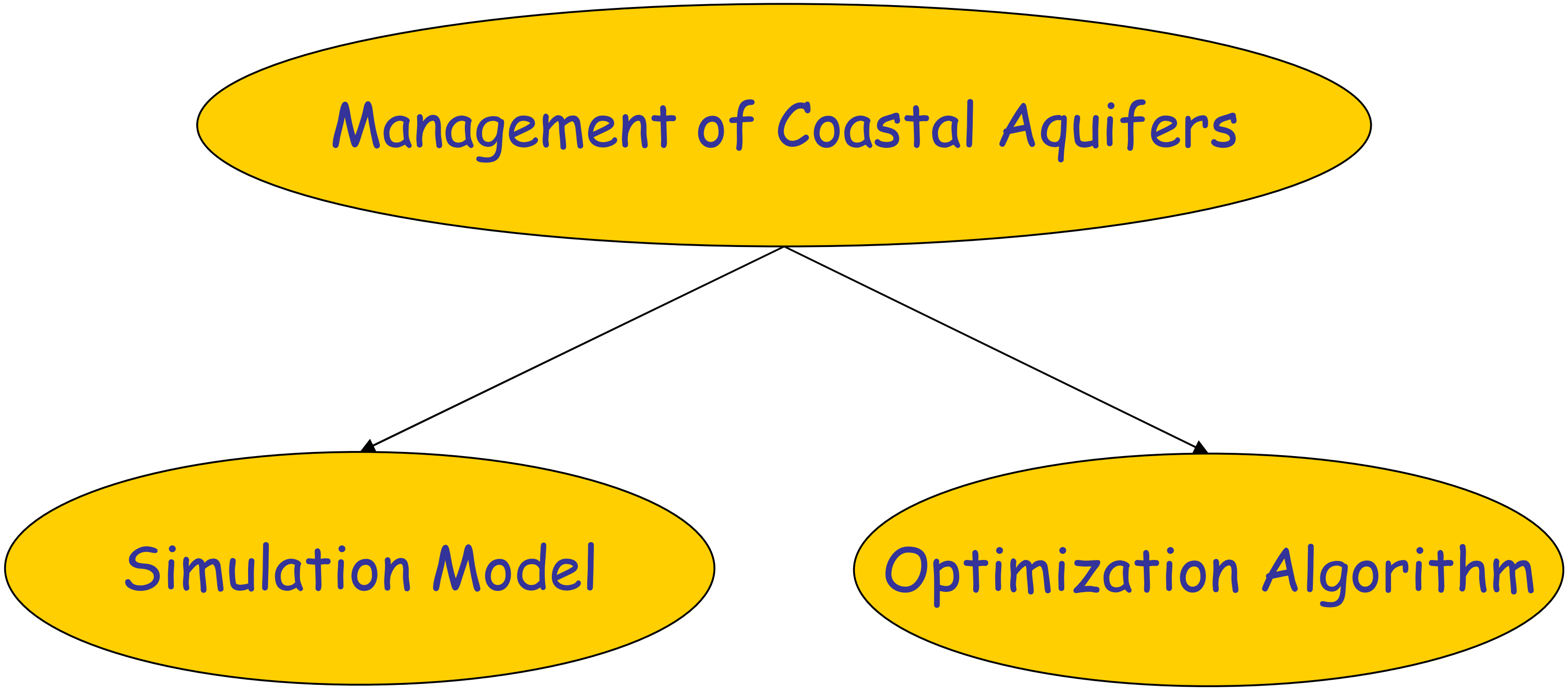
Introduction



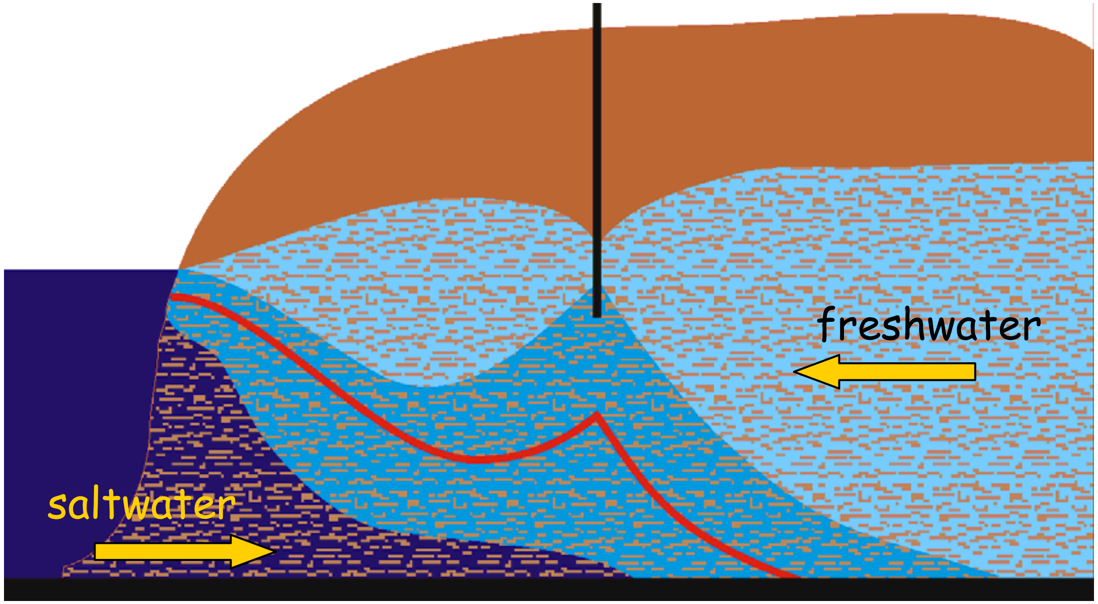
Management of Coastal Aquifers

Simulation Model

Optimization Algorithm

Simulation Model

- Variable Density models



- Accurate Solution
- CPU time intensive
- Difficulty in estimating dispersivity parameters

Simulation Model

- Equation of mass balance
- Equation of solute transport
- Darcy law for variable density flow
- Equation that relates fluid density to concentration

Numerical models

FDM:
SEAWAT

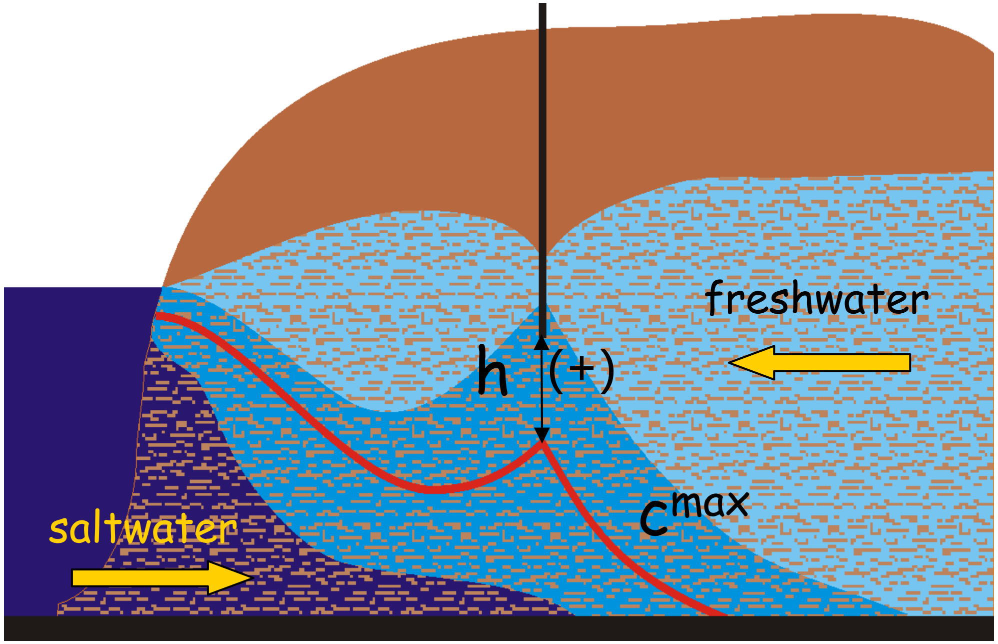
FEM:
FEFLOW
HYDROGEOSPHERE
SUTRA
etc.

Optimization problem

Objective: Maximize withdrawals of water

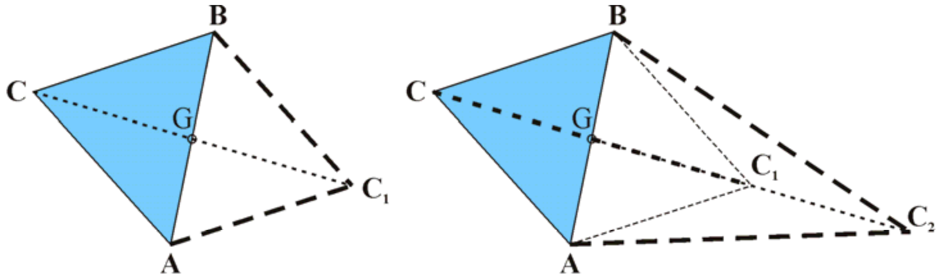
Constrains: Protect aquifer from seawater intrusion

$\mathrm{Max}(\Sigma Q_i)$
st.
$h_i > 0$ or $c_i < c^{max}$



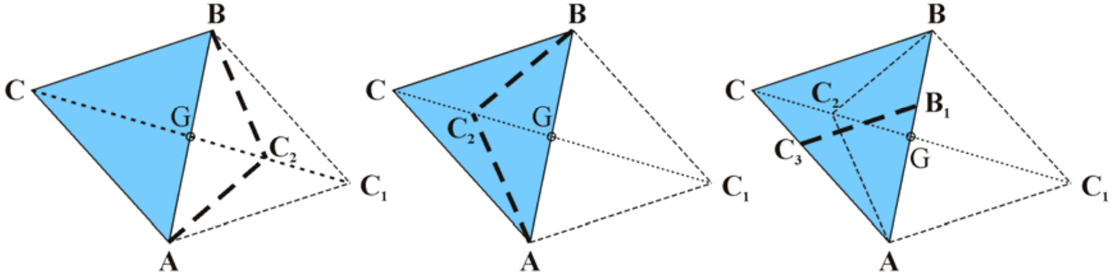
Optimization Algorithm (Evolutionary Annealing Simplex Scheme - EASS)

- Introduced by Eustratiades & Koutsogiannis [2002]
- Follows the main steps of Simulated Annealing
- New points are generated through downhill simplex evolution
- Requires fewer function evaluations compared to Genetic Algorithms, Simulated Annealing etc



Reflection (a)

Expansion (b)



Outer contraction (c)

Inner contraction (d)

Shrinkage (e)

Computational requirements

When…

- Model based evaluation of objective function is CPU time intensive
- Number of decision variables is large

Global optimization techniques require excessive CPU time

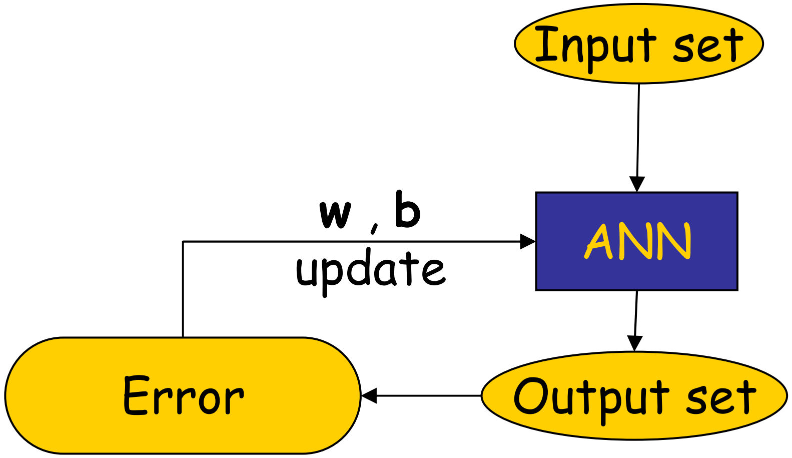
Idea:

It is proposed to substitute the CPU intensive numerical model with fast Artificial Neural Networks (ANN)

Artificial Neural Networks (General)

Input **p** → f(**w**,**b**,**p**) → Output **t**

ANN parameters **w**,**b** are calculated by training



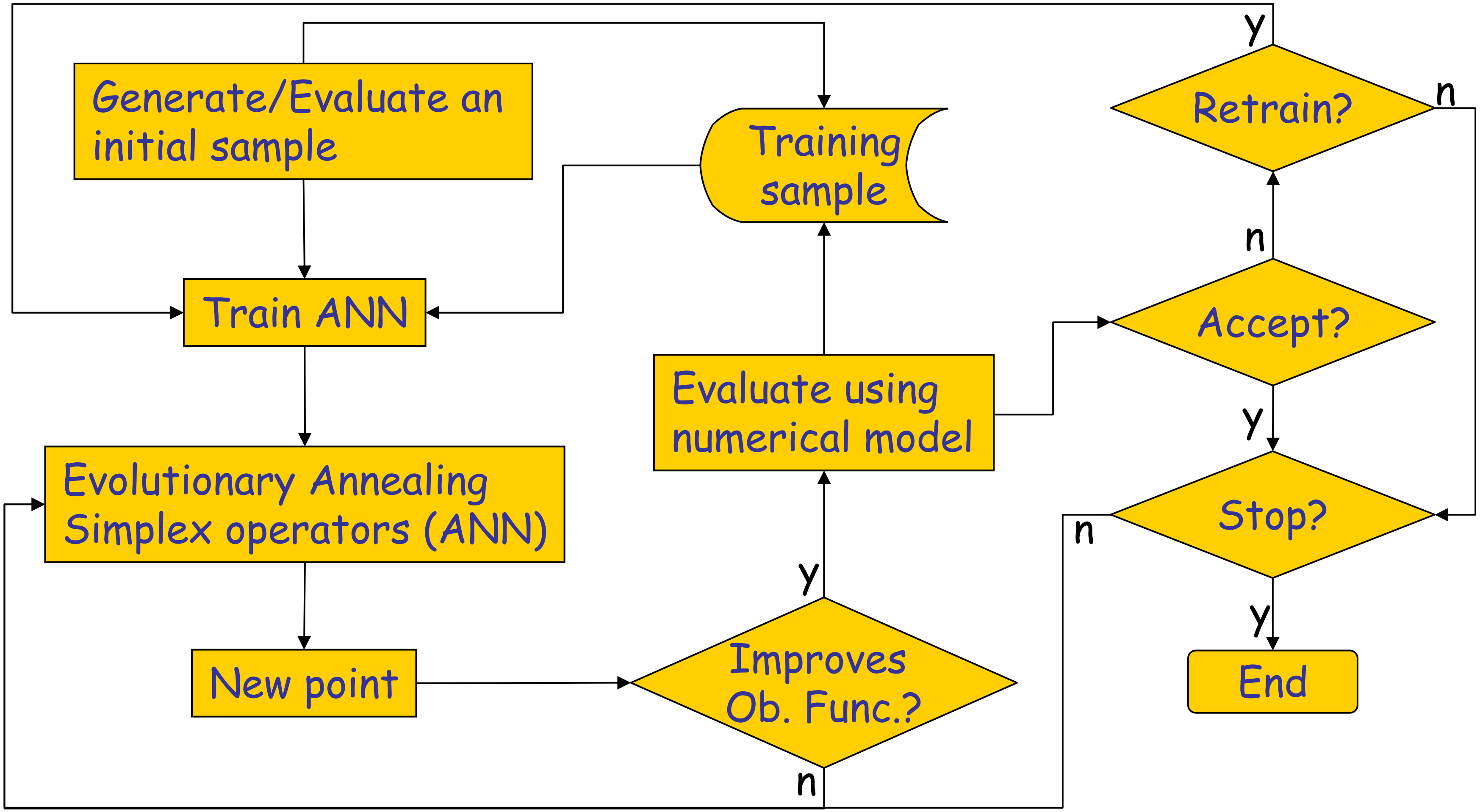
Adaptive Training

Promising when ANN are used in optimization

1. Initialization: Generate a small training sample
2. Train ANN with this small sample (ANN is not expected to perform well)
3. Optimize system using ANN. Obtain new sets of decision variables.
4. These values are evaluated based on the numerical model and join the training sample
5. Repeat steps 2-5 until convergence.

Adaptive training has been used in various studies (Arndt et al., 2005; Yan and Minsker, 2006)

Evolutionary Annealing Simplex scheme with Artificial Neural Networks (EASS-ANN)



Evolutionary Annealing Simplex scheme with Artificial Neural Networks (EASS-ANN)

EASS fits better to adaptive training than other algorithms because…

- EASS search the space in a smoother fashion than GA, SA
- New sets of decision variables may assist the algorithm to follow the right direction even before retraining

Sub – Network implementation

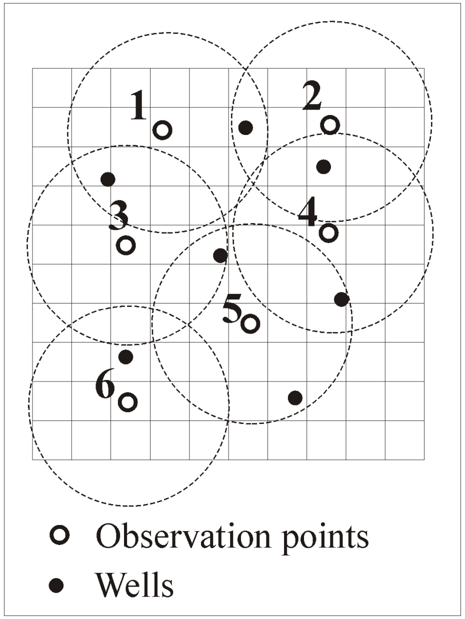
Inputs correspond to pumping rates, and outputs to hydraulic heads, concentration etc.

Outputs are affected mostly by inputs located nearby

It is proposed to split the network into smaller sub-networks

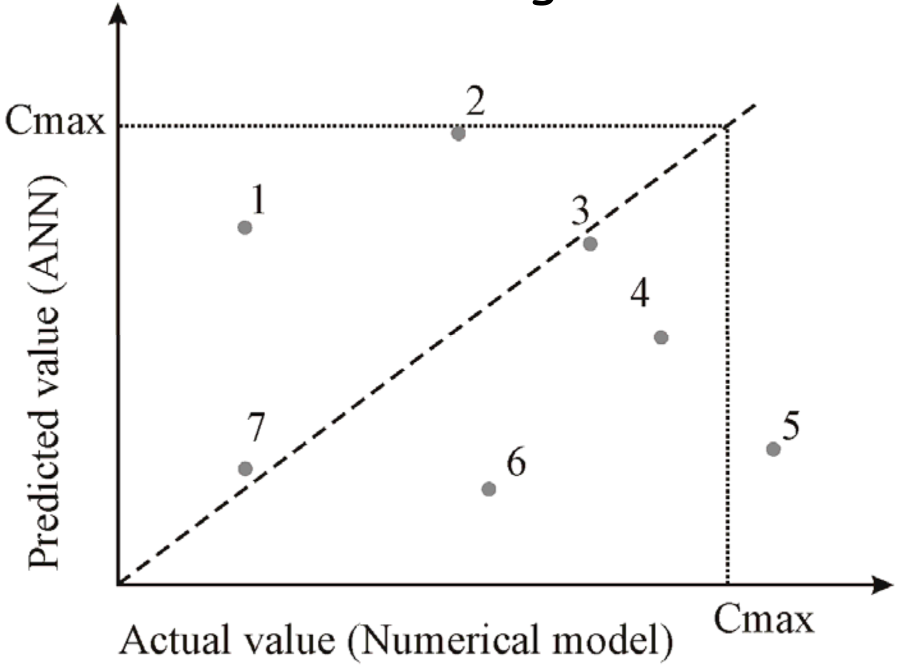
Direct approach
7-N_h-6 (N_h>≈6)

Sub-Network:
1-4: 2-N_h-1
5: 3-N_h-1
6: 1-N_h-1



Sub – Network implementation

Not all sub – networks need retraining



Networks 3,7 are well correlated, therefore do not need training

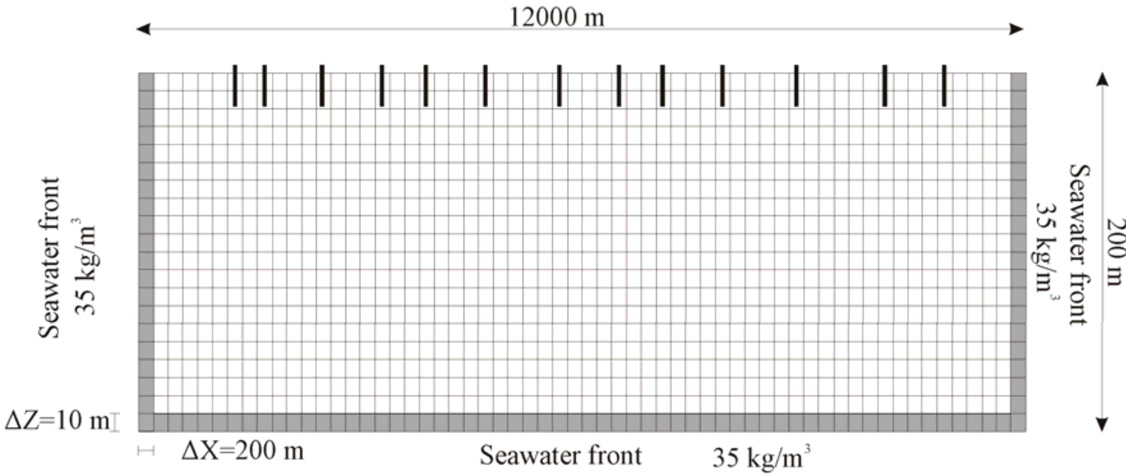
Application 1.
Hypothetical orthogonal aquifer

Cross-section of aquifer

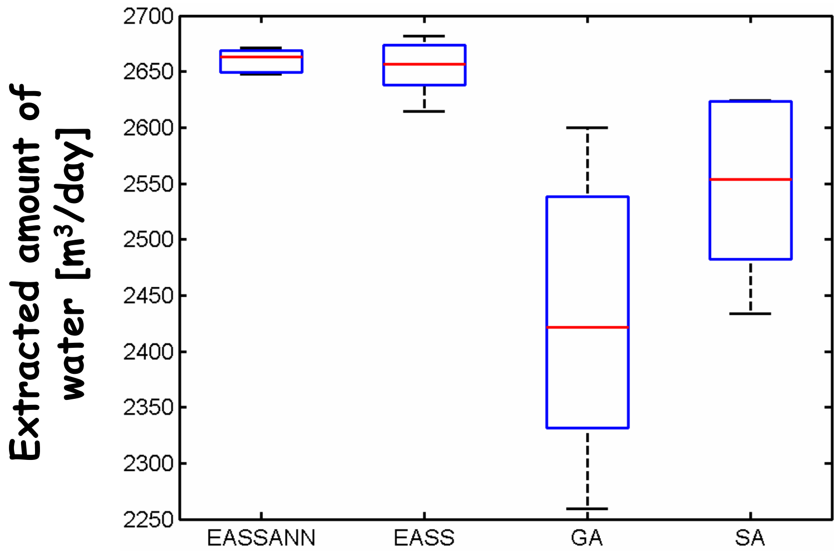
Objective: maximize pumping rates of 13 wells

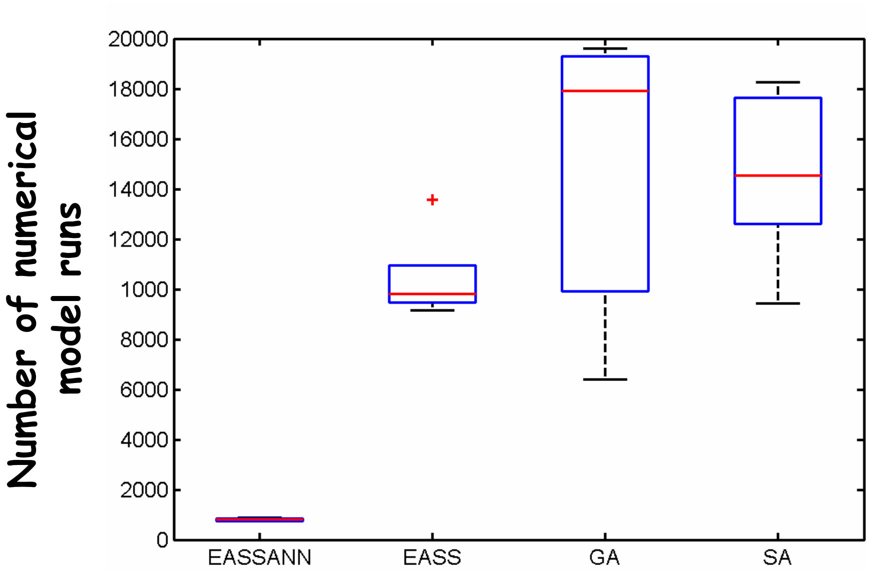
Constrain: $c_i < 0.5 \text{ kg/m}^3$

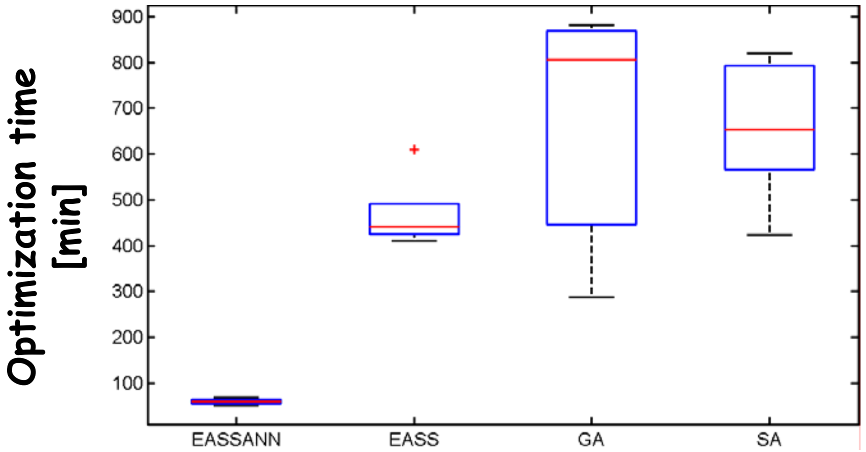
CPU time of numerical model 2.7 sec



Application 1.
Comparisons with other methods





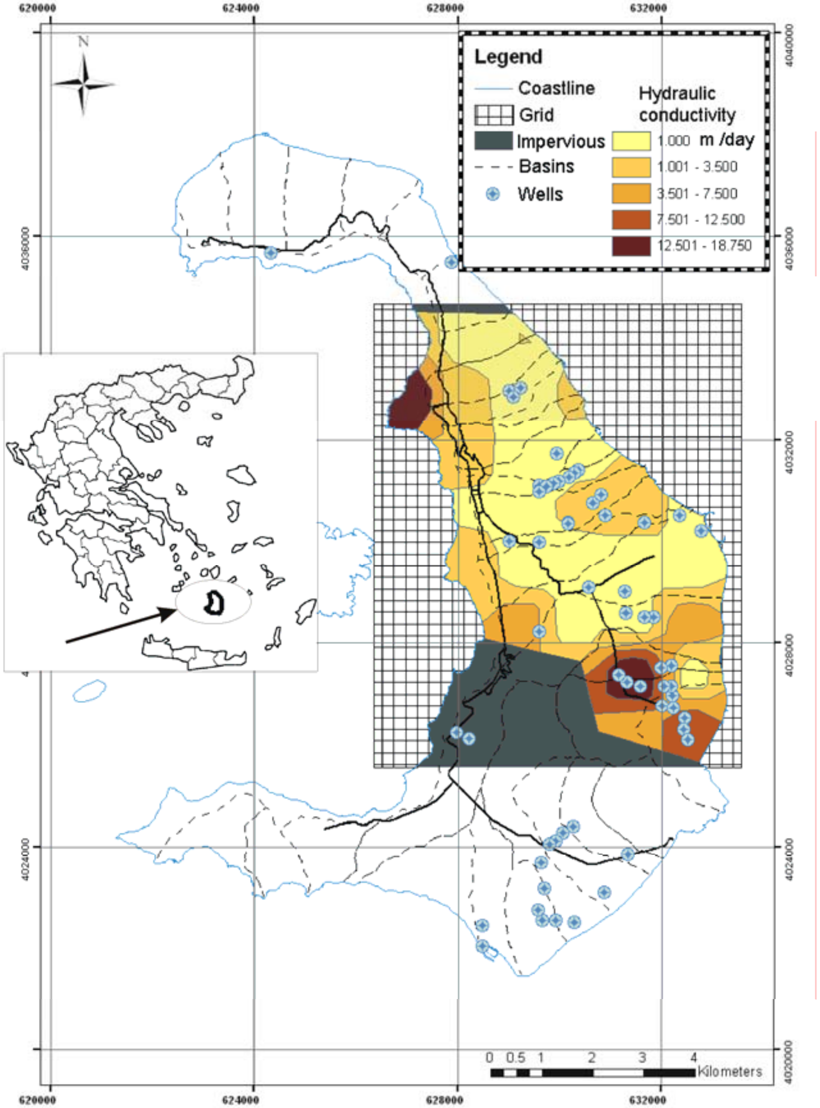


Application 2.
Santorini island aquifer

Objective:
maximize pumping rates of 41 wells which correspond to 34 source/sink cells

Constrain:
Maintain 0.5 kg/m^3 iso surface 10 m below m.s.l

CPU time of numerical model 38 sec
For 10000 days simulation



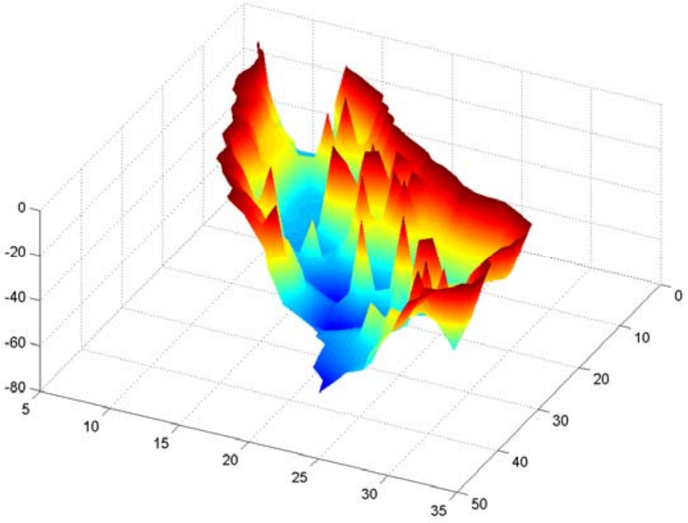
Application 2.
Santorini island aquifer

- EASS

Total extracted amount of water
2066.88 m^3/day

Number of function evaluations
27300

Optimization time
12 days



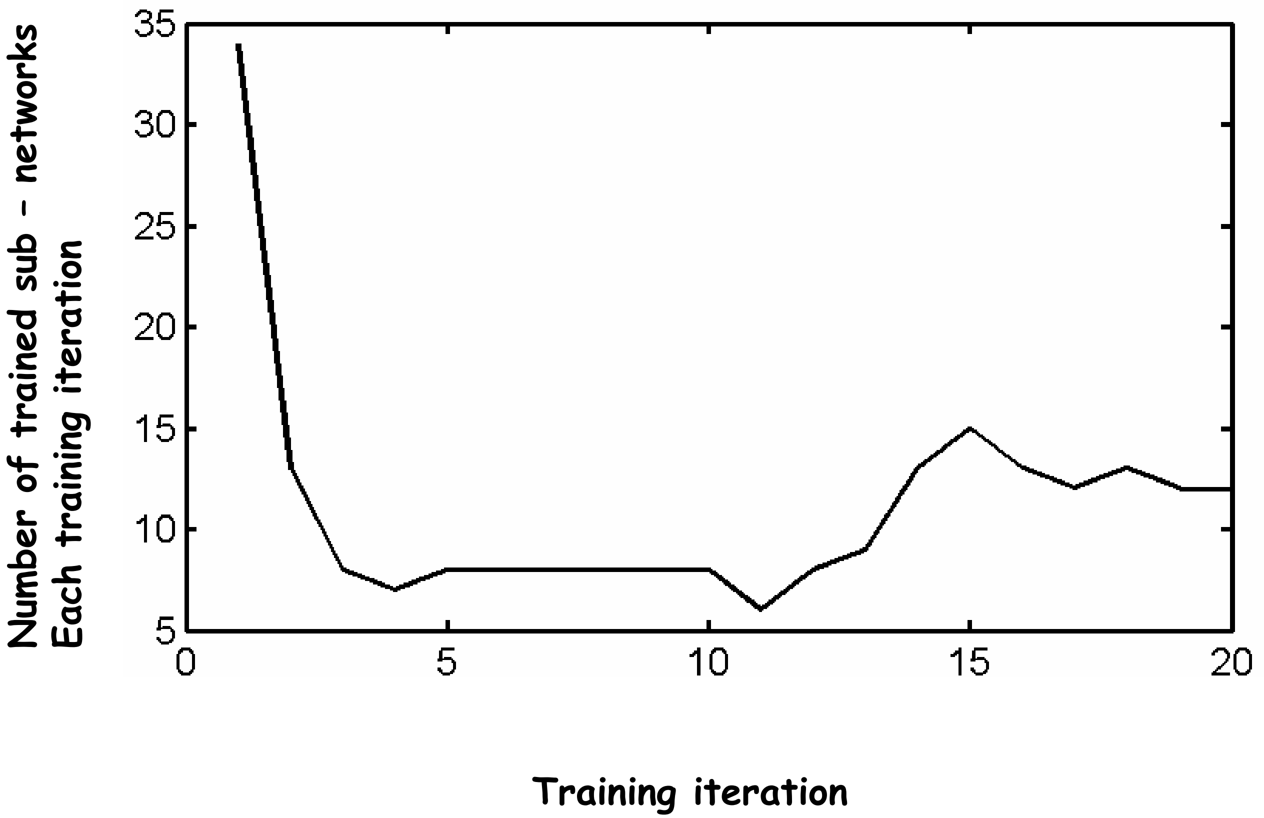
- EASS-ANN

Total extracted amount of water
2096.53 m^3/day

Number of function evaluations
101703 using ANN, 1347 using numerical model

Optimization time
18 hours

Application 2.
Santorini island aquifer



Conclusions

- The proposed algorithm EASS-ANN appears more efficient than other known global optimizations techniques
- EASS-ANN is significantly faster
- The sub-network implementation improves the performance of the algorithm in terms of optimal value and computer time

Thank you for your attention!!!!