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DETERMINING OPTIMAL CANAL DIMENSIONS USING GENETIC OPTIMIZATION ALGORITHMS

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The Dutch Waterboards are mandatory to establish the 'Legger', a register describing the design dimensions as well as the maintenance and management of the main canals. As a consequence of changes in the water system, such as subsiding, urbanization and increased discharge capacity, the criteria for the design of the canals become more demanding. The current register is therefore often out of date. In order to conform the register to today's demanding criteria the Dutch Waterboard of Rijnland decided to update the design dimensions of the canals. Because of the complexity of the water system, it is very difficult and timeconsuming to translate these criteria to the required optimal dimensions using traditional methods. However, it appears to be feasible to determine the required optimal dimensions in an effective way by using mathematical optimization techniques, supported by the increase of processing power of computers and the availability of advanced hydraulic computer programs.

REGISTERED DIMENSIONS

The 'Legger' is a register in which the dimensions of all canals in a water system are described in detail. The following specifications are documented:

- The minimal dimensions required for the canals (bottom level, bottom width and slope);
- The person or authority that is responsible for the maintenance of the canals;
- The contents and requirements of the maintenance of the canals.

As a result of silting and growth of water plants and reed the water flow can be obstructed, resulting in inundation or flooding. To let the canals fulfil its function frequent maintenance has to be carried out. Based on the register maintenance is carefully regulated. The Waterboards are responsible for the maintenance of the majority of the main canals. Maintenance expenses are considerable due to extensive dredging programs and processing of polluted dredge. By determining the minimal required canal dimensions the expenses can be decreased.

The current dimensions of the canals have mostly been determined at the end of the nineteenth century. It's not possible to trace the origin of the criteria used at that time. Probably shipping interests were very important. However, these criteria have changed: nowadays it is much more important that the discharge is transported without obstruction. To be able to verify whether the canals fulfil their function, specific criteria for flow velocity and hydraulic grade have been quantified.

DETERMINING OPTIMAL DIMENSIONS

The optimal canal dimensions are defined as being the minimal canal dimensions (cross sections) for which the criteria are precisely met. It is possible to define these cross sections 'by hand' to fulfil all the criteria. However, because of the complexity of most of the water systems, the odds of finding the optimal dimensions this way are very small. The complex flow pattern in the water system is often caused by the interconnected pattern of canals. This is expressed in the changes of flow velocity and flow direction when altering the dimensions of the canals.

By changing the dimensions of one of the canals, the discharge through the other canals and therefore the flow velocity is influenced. In some occurrences the flow in a canal can even change direction. Therefore it is necessary to review the criteria for the water system after every alteration in the dimensions of the canals. By quantifying the criteria for flow velocity and hydraulic grade it is possible to determine the optimal dimensions, using a hydraulic model of the water system and mathematical optimization techniques. The optimal dimensions can then be determined systematically and automatically.

A suitable, and for this type of problem often applied optimization technique is based on genetic algorithms. Because of the structure of the genetic optimization algorithms it can solve complicated optimization problems in a robust and reliable way. The working of genetic algorithms is explained in de following section.

Genetic algorithms

A genetic algorithm is an optimization technique based on the mechanics of natural selection and genetics according to the Darwinistic principle of evolution. According to this theory three factors (genetic operators) influence the genetic material of a population (Baoding Liu, [1]). These genetic operators are:

1. Selection: Individuals that fit best in their environment have the largest probability of surviving. Only the surviving individuals pass their genetic material onto their offspring.
2. Crossover: Two individuals are involved in the crossover operation. Both of them pass a part of their genetic material onto their offspring.
3. Mutation: Some individuals are prone to unexpected changes in the genetic material. These so-called mutations sometimes make the individual better fit for its environment.

The genetic algorithm starts with an initial set of random-generated individuals called a population. For every individual in this generation the fitness values for solving the problem are determined using the object function (evaluation). A new population will be formed by a selection process using a sampling mechanism based on the fitness values (selection). The individuals with the better fitness have a larger probability of selection. Individuals can be selected more than once in order to keep the population the same size for every generation. After this, several individuals are chosen to combine and form altered individuals (crossover). Some individuals will be randomly changed (mutation).

After these operations a new population with adjusted individuals has been created. This new generation on its turn will be evaluated after which the genetic operators selection, crossover and mutation are applied.

CASE STUDY

The Waterboard of Rijnland is situated in the western part of the Netherlands. The catchment area is about 1000 km^2, mainly consisting of low-lying polder areas. These polders drain their discharge to the main storage basin. The main storage basin consists of 270 kilometers of interconnected canals and lakes (figure 1). By way of four pumping stations the excess water in the storage basin is discharged.

To verify whether the dimensions of the main canals fulfil the criteria, the hydrologic SOBEK model of the Waterboard of Rijnland is used. In this model the main canals in the storage basin, the polder areas and the pumping stations are schematised. With this model the flow velocity and water levels that occur in the main canals are determined. The dimensions of the canals in the model are described by 427 cross sections. Because only dredging problems are considered in this paper, only the bottom levels of these cross-sections are assumed variable in this optimisation.

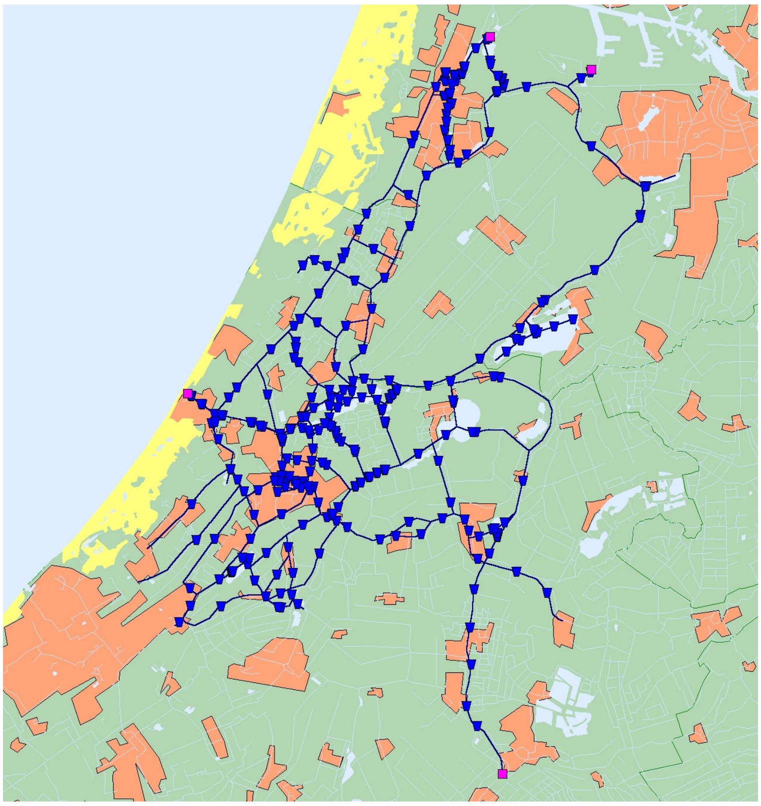

Figure 1. Layout of the main canals in the water system of Rijnland.

The criteria for the water system that have to be fulfilled are expressed in water levels and flow velocity. The water levels at the suction side of the pumping stations may not be too low because this can lead to negative results for the installations in the pumping stations, foundations in the surroundings of the pumping stations as well as the stability of the embankments. Also a maximum water level is defined which may not be exceeded due to safety problems in extreme situations. Because of the water level criteria the hydraulic grade in the water system will not become unacceptable. Besides the requirements for the water level requirements for the flow velocity are defined as well. Normally, the average flow velocity in the canals may not exceed 0.20 m/s. A higher flow velocity may result in erosion of the canals. For a small number of locations, however, a higher maximum flow velocity is acceptable.

METHODOLOGY

It is necessary to fulfil the above-mentioned criteria for the design load. For this, the discharge load of the polder areas as well as the wind load are considered. To represent all possible loads of the water system five different design loads are defined with the aid of various combinations of wind and discharge. For each of these design loads the water system has to fulfil the criteria for the water level and the flow velocity.

The minimization of the bottom level and the criteria are translated into an object function. With this function, the validity of the chosen design dimensions is determined and the evaluation of the individuals can be made. An elevated bottom makes the design dimensions better suited, a lower bottom less so. In the case where both the flow velocities and water levels do not fulfil the criteria, the object function will become less appropriate. Because an elevated bottom often results in a higher flow velocity and larger hydraulic grade, this will lead to a lower validity in case the criteria are not fulfilled. The result of the optimization yields a set of bottom levels which represents the minimum design dimensions that precisely fulfil the requirements of the system.

COMPUTATIONS

To determine the optimal set of bottom levels using a genetic algorithm all calculations are completely automated. The optimization can be divided into the following steps (see Figure 2):

1. First, an initial generation is defined. For the water system of Rijnland a generation consisting of 100 individuals (100 different combinations of bottom levels) has been used.
2. These 100 individuals are translated into 100 input files that are used by SOBEK to describe the dimensions of the canals.
3. For each input file in SOBEK 5 design loads are calculated. This totals 500 calculations for each generation to determine the flow velocity and water level for each location in the water system.
4. An evaluation of the individuals is made with the output of SOBEK.

5. After the evaluation, the genetic operators selection, crossover and mutation are applied. This leads to a new generation of 100 individuals.
6. Restart at the second step until for a number of generations no better individuals are found.

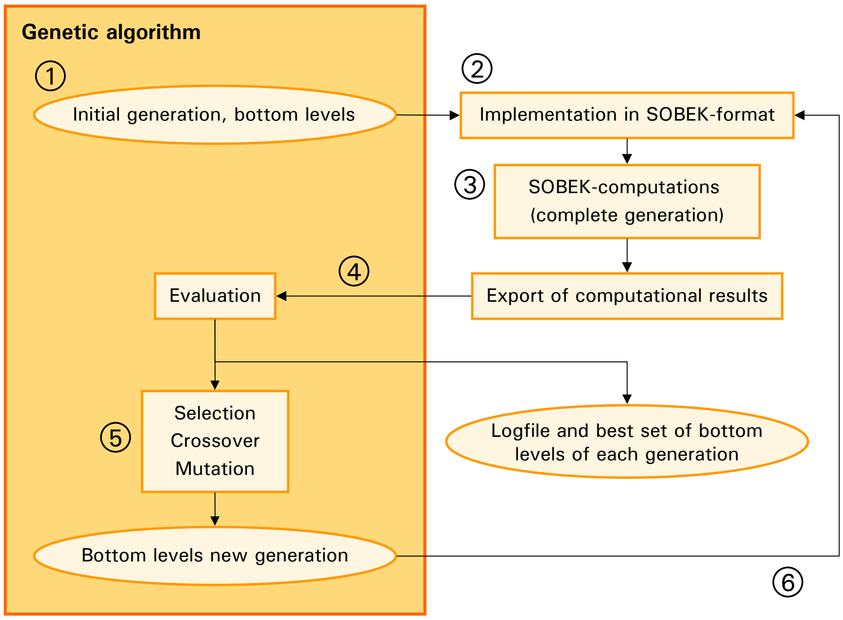

Figure 2. Steps in the computations with the genetic algorithm.

RESULTS

The calculations show that after about 160 generations an optimal solution is found. To accomplish this 80.000 model computations with SOBEK were needed. One calculation takes approximately 15 seconds; the total computation time therefore is about two weeks. The process is fully automated so the user isn't required to take action during the computations. A logfile is continuously kept active to keep track of the computational results during the whole procedure.

Using this method, the optimal design dimensions for a complex water system can be determined in a robust way. The result for the case of Rijnland consists of a set of 427 bottom levels which represents the minimum design dimensions. The requirements of the water system are then precisely met.

When a mathematical optimisation is desired, quantification of the requirements for the main canals is necessary. Often, these requirements are different from the requirements of the canals used in the past. Due to this change as well as an optimal tuning of the bottom levels of the canals, both lowered and elevated design dimensions are found. Where the flow velocity in the current situation doesn't fulfil the requirements, lower bottom levels are found. Elevations occur in those canals that sufficiently meet the criteria in the current situation.

The result of the optimisation shows that about 55% of the design dimensions in the register can be elevated, often with more than half a meter. Approximately 20% of the dimensions should be decreased to fulfil the criteria. Analysis of the results shows that the necessary lowering is often caused by the demanded minimum water level at the pumping stations.

Considering the pre-defined definitions in the register the most important conclusion is that large parts of the canals appear to have large built-in safety margins with respect to the current requirements of a water system. If these safety margins are not taken into account the maintenance expenses can be considerably decreased.

RECOMMENDATIONS FOR FUTURE RESEARCH

With this optimisation the minimal canal dimensions have been determined. Within this investigation only the bottom level of the canals is considered variable. By including information about the length of the canals in the objective function this information may also be taken into account. Using this alternate method, the minimum volume of the design dimensions is optimised so longer canals will receive more weight in the optimisation routine.

CONSEQUENCES EXTENSION PUMPING CAPACITY

At this moment Rijnland is preparing to upgrade the capacity of one of the pumping stations (Katwijk). Due to the increase of the pumping capacity the main canals have to transport a larger amount of water to the pumping station of Katwijk. Using the optimisation technique discussed in this paper the effects of the increased capacity on the design dimensions can be made clear quickly.

REFERENCES

[1] Baoding Liu, "*Uncertain Programming*", 1st edition, John Wiley & Sons, (1999).