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Optimizing Water Level Monitoring Station Networks using GIS

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A GIS toolset is currently under development, to optimize the water level monitoring stations network in South Florida Water Management District (SFWMD). SFWMD uses the water levels recorded by the monitoring stations to perform water balances useful in the every day management of the district. Although accuracy of the water balances depends on the quality and quantity of measured data, economic and operational constraints make it difficult to maintain elaborate monitoring stations networks. This ArcObjects toolset selects the optimal set of stations from the existing monitoring stations network based on a tolerance level specified by root mean square error in the water level estimation. The applicability of the tool is demonstrated by employing it in the Kissimmee River basin.

Network Optimization Study

To minimize its operational cost and the increase in costs of future expansions of the network the SFWMD needs to optimize spatially its current network of stage and flow measuring stations. This paper discusses a pilot study for flow and stage network optimization in a limited area of the SFWMD — the Kissimmee River Basin. The SFWMD is located in central and southern Florida; it covers a total area of almost 18,000 square miles. The Kissimmee River Basin (Figure 1), located in the northern part of the SFWMD, comprises the Upper Chain of Lakes, the channelized Kissimmee River and Lake Okeechobee.

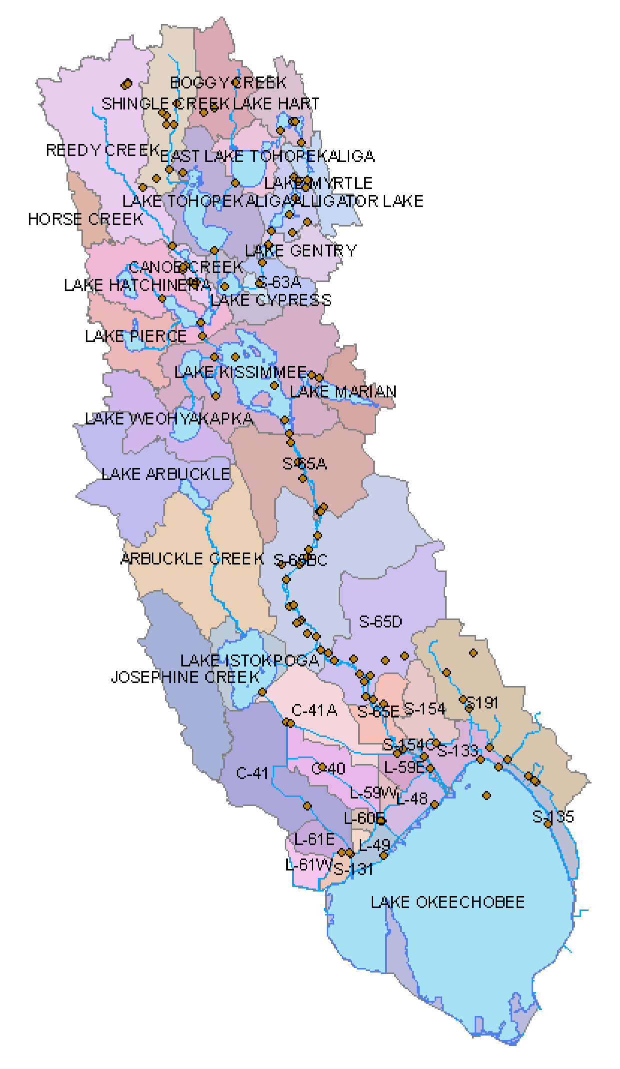

Figure 1. Kissimmee River Basin

The purpose of this study is to create a GIS toolset to find the optimal subset from the existing set of stations that can estimate stages within an admissible error. Currently, the network optimization toolset is implemented in ArcMap using VBA. Figure 2 shows the Station Network Optimization Toolbar.

Figure 2. Station Network Optimization Toolbar

There are two components to this project: stations in lakes and stations in streams. The separation of these two components results from the fact that lakes tend to have horizontal surfaces while streams tend to have water levels that follow hydraulic profiles. This paper focuses on the toolset developed to optimize the network in lakes.

Network Optimization Process and Network Optimization Tools

The process of spatially optimizing the flow and stage network of stations involves four main steps (Figure 3) described next.

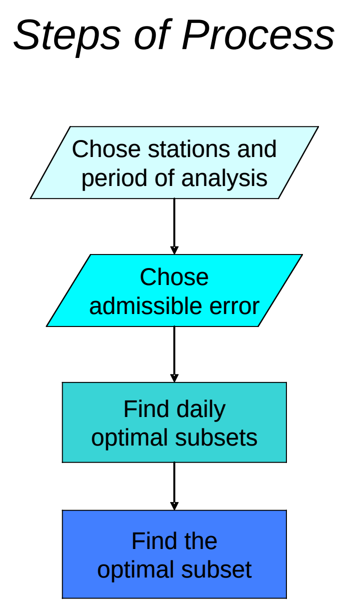

Figure 3. Network Optimization Process Steps

Step 1: Chose stations and period of analysis

The first step requires users to select a set of stations and the period of analysis. It is important to choose stations that have the same period of record, and whose operating conditions do not change during the period of analysis. It is recommended to choose at least two years of data to arrive at good results. Figure 4 shows a selected set of stations in Lake Kissimmee that have stage measurements from 10/1/2001 to 9/30/2003.

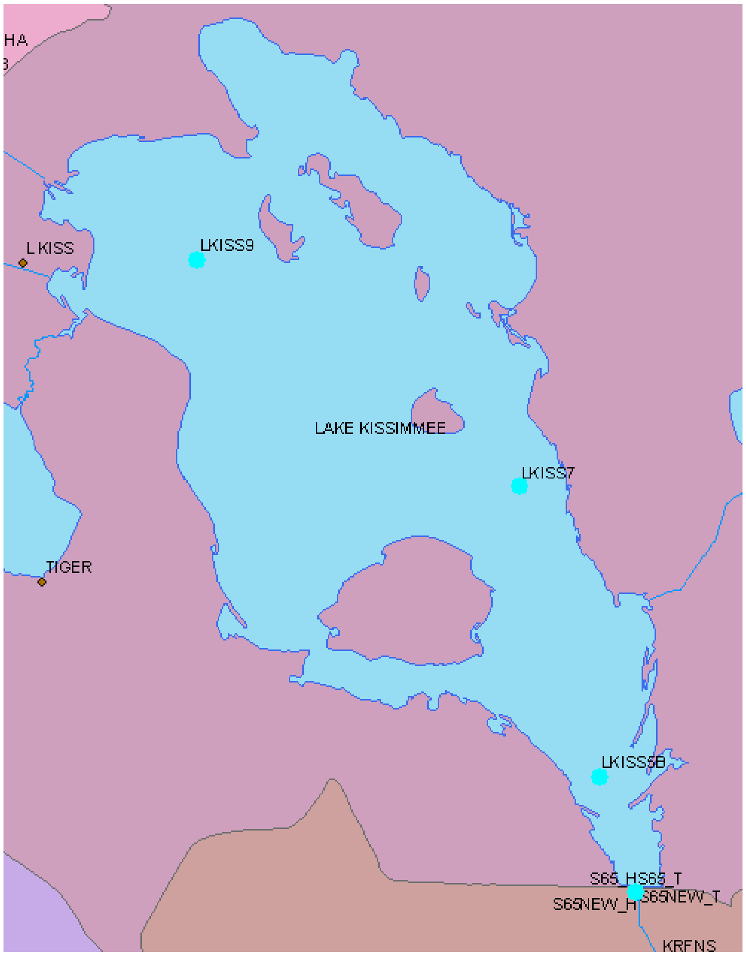

Figure 4. Selected stations in Lake Kissimmee
(LKISS9, LKISS7, LKISS5B, and S65_H)

Step 2: Choose admissible error

The goal of the optimization process is to choose from a set of stations, a subset of stations where the water elevation levels obtained from this subset are within an admissible range of root mean square error. To optimize a network *n* stations in a lake to a minimum number of *r* stations ($r < n$) the root mean square error is defined as:

$$RMSE = \sqrt{\frac{1}{n-r}\sum_{i=1}^{n-r}(I_i - M_i)^2}$$

Where I_i is the interpolated water elevation value and M_i is the water elevation measured value, both for station *i*. For preliminary assessments, the admissible *RMSE* suggested by SFWMD is between 0.05 and 0.1 ft.

Step 3: Find daily optimal subsets

The third step identifies the optimal set of stations for each day. The water elevations for stations that are not in the optimal subset are computed by using inverse square distance method as shown below:

$$I_i = \frac{\sum_{j \neq i} \frac{M_j}{d_{i,j}^2}}{\sum_{j \neq i} \frac{1}{d_{i,j}^2}}$$

Where $d_{i,j}$ is the distance between station i and station j (Figure 5).

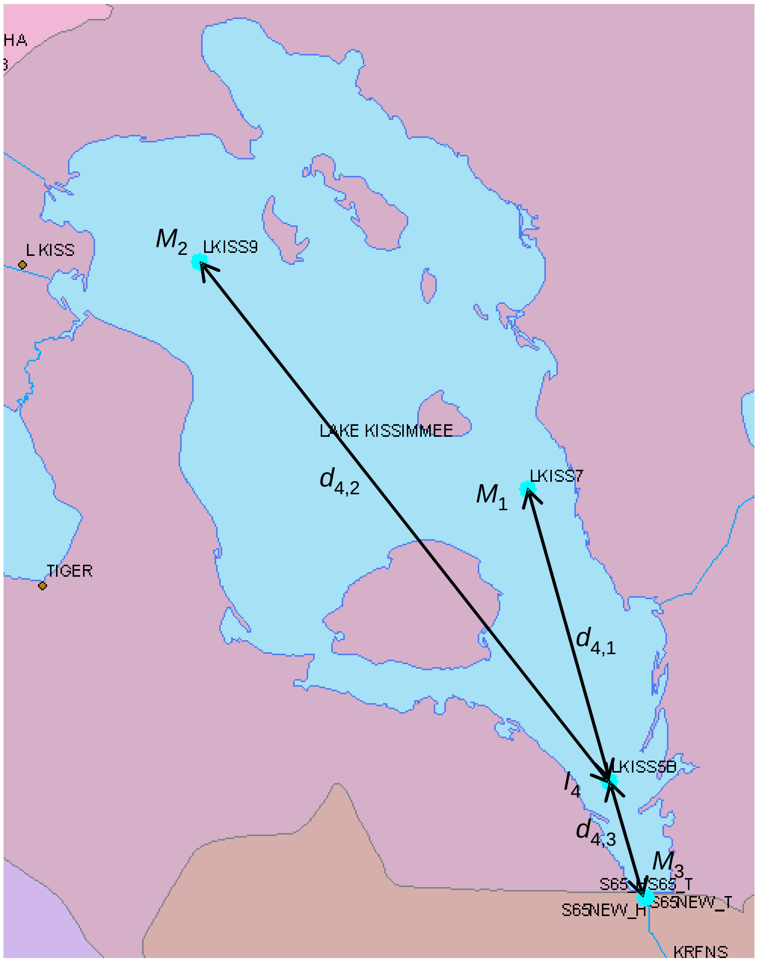

Figure 5. Distances between stations

The number of combinations of *r* stations chosen from a set of *n* stations is given by

$$C_r^n = \frac{n!}{r!(n-r)!}$$

If *r*, the size of the subset, remains constant, the number of combinations grows with *n*. A direct evaluation of each combination could be computationally intensive. For that reason, the genetic algorithm method of optimization is used to find the subset of *r* stations that gives the minimum *RMSE*.

Optimization of a set of stations for a given date may be performed by specifying the range of number of stations in subset or by specifying an admissible *RMSE*. Figure 6 illustrates the extension of this process for a given period.

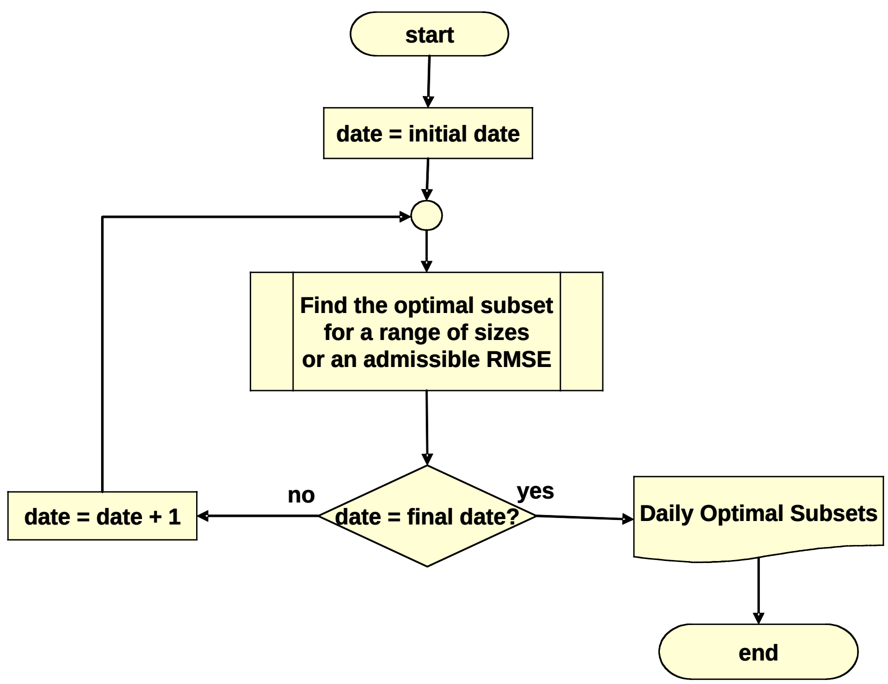

Figure 6 Identification of the daily optimal subsets of the period

Step 4: Find the optimal subset

Finally, the optimal daily subsets of station results obtained in the step 3 are analyzed to get the optimal subset of stations for the entire period of analysis. This analysis is a two-step process. The first process identifies day by day the optimal station subset that has simultaneously an *RMSE* smaller than or equal to the admissible *RMSE* and the smaller number of stations. The second process computes the relative frequency for the entire time series period where the station subset complies with the constraint of the admissible *RMSE*. The station subset with the highest relative frequency becomes the optimal subset of stations for the period of analysis. Figure 7 shows the optimal subset of the stations *(LKISS7, LKISS9 and S65_H*) for Lake Kissimmee for the period of analysis (10/1/2001 to 9/30/2003).

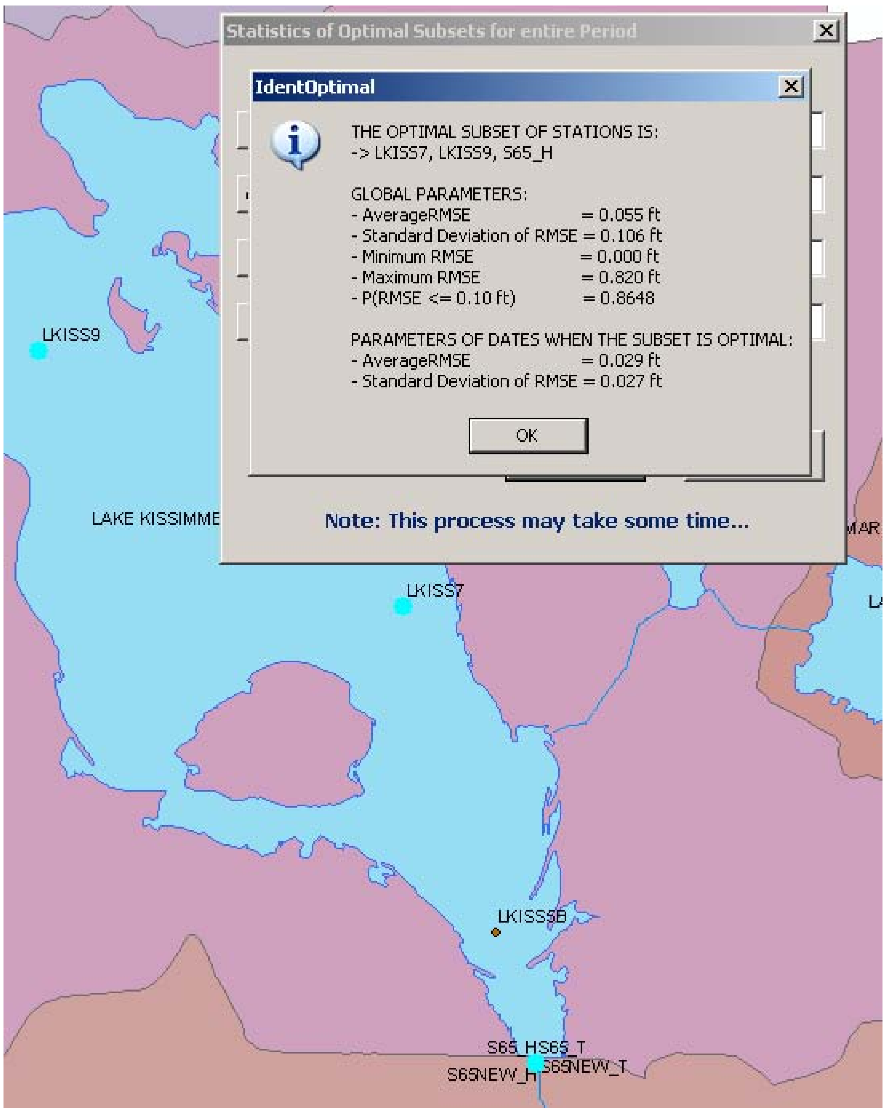

Figure 7. The optimal subset of stations of Lake Kissimmee is LKISS7, LKISS9 and S65_H.

CONCLUSION

This paper briefly demonstrated, using the water elevation stations in Lake Kissimmee, the applicability and use of the ArcGIS toolset developed to optimize the SFWMD network of water elevation gages. Future work includes extension of this toolset to optimize stations along the streams.

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