CHAPTER VI

SUMMARY AND CONCLUSIONS

By combining discrete sensitivity analysis and a modified Gauss-Newton optimization algorithm within an existing two-dimensional, open-channel simulation code, the large computational cost of design optimization has been greatly reduced. By using discrete sensitivity analysis, the cost of estimating the design space gradient has been reduced since additional function evaluations are no longer necessary. By using the Gauss-Newton optimization method, super-linear convergence of the design variables has been achieved for these sample cases, greatly reducing the total number of design iterations. As a result, a highly effective design can be found within a reasonable amount of time. Also, because of the use of the complex Taylor's series expansion method to generate highly accurate Jacobian matrices, the design space gradient is typically accurate to between six and eight significant digits, and the use of the Levenberg-Marquardt constant with the Gauss-Newton method yields a stable optimization algorithm. The various components of the design optimization strategy can be applied to optimization problems in a variety of disciplines involving different sets of governing differential equations, including the Navier-Stokes equations for incompressible and compressible flows, the groundwater equations for flows in aquifers and the transport equations for contaminant transport and salinity migration. These methods can even be applied to explicit simulation codes because the complex Taylor's series expansion method can be used to generate the Jacobian matrix at steady-state using the explicit or implicit discretized equations.

Because the code used in this research, HIVEL2D, simulates flow through high-velocity open-channels, the resulting design optimization code can be applied to open-channel design problems that can be adequately simulated via the shallow water equations. To apply this method to open-channel design, an effective objective function needs to be chosen. Since uniform flow has many nice characteristics, the objective function used in this research measures the non-uniformity of the flow. Also, because the depth in a channel is a primary concern for flood prevention, depth is used as the variable to study. In Appendix E, it has been shown that constant depth flow is a solution to the shallow water equations in a straight channel, which implies that the global minimum of the objective function for a straight channel is attainable under certain circumstances. The choice of design variables for a particular open-channel flow design example follows current design practices, such as using ramped beds in circular bends.

To demonstrate this design optimization strategy, the method has been applied to supercritical channel contractions, expansions, circular bends and bridge piers. For the straight wall contraction and the circular bend, the resulting designs compare well with the analytic inviscid results. For the curved wall contractions and expansions, the design method generates designs with multiple wave patterns. These wave patterns have been manipulated so that nearly uniform flow is generated downstream of the transition. For the channel bend, the transverse bed slope is a curve whose shape is controlled by 50 design variables. In spite of the potential complexity of a 50 dimensional design space, the design optimization strategy converges to the optimal shape within five design iterations. For the bridge pier example, the objective function is the sum of two separate objective functions, one measuring the non-uniformity of the flow under the bridge and the another measuring the non-uniformity after the bridge piers. The resulting flow was much more uniform that the flow for the initial design as shown by a 97% reduction in the objective function.

In this research, a design optimization strategy that is computationally efficient and robust has been developed. This strategy can be applied to a wide range of design optimization disciplines and simulation codes, such as aircraft and ship design, estimation of dispersion coefficients in the transport equations, and determination of parameters for groundwater modeling. In particular, this strategy has been applied to the design of high-velocity open-channel flows. Successful application requires knowledge of flow characteristics through open-channels and of current design concerns and methods within this discipline. As shown by the examples, this design optimization process generates highly accurate design space derivatives efficiently by combining the complex Taylor's series expansion method within discrete sensitivity analysis and rapidly identifies a highly efficient design by using a modified Gauss-Newton method. Thus, for problems that can be accurately simulated via the shallow water equations, this design optimization strategy can be quite useful in identifying the region of the design space containing the designs that produce nearly uniform flow.