ABSTRACT OF THE DISSERTATION

A SPATIAL DECISION SUPPORT SYSTEM FOR BASIN SCALE ASSESSMENT OF IMPROVED MANAGEMENT OF WATER QUANTITY AND QUALITY IN STREAM-AQUIFER SYSTEMS

Challenges in river basin management have intensified over the years, with expanding competition among water demands and emerging environmental concerns, increasing the complexity of the decision making framework. State-of-the-art technology is required for assisting water resource managers and decision makers in gaining a better understanding of the river system and in evaluating management alternatives towards optimal utilization of water resources. The sustainability of irrigated agriculture in alluvial valleys is being threatened by increasing pressures from municipalities to acquire agricultural water rights at elevated prices, degradation of agricultural water sources and lands due to salinization, irrigation-induced non-point source contamination of the stream-aquifer system, and non-beneficial consumption of water. A comprehensive spatial-decision support system (*River GeoDSS*) is developed herein to provide assistance in the development and evaluation of management strategies, including structural rehabilitation, for achieving agricultural sustainability, environmental enhancement, and water conservation in irrigated stream-aquifer systems. The *River GeoDSS* provides a comprehensive treatment of water quantity and quality objectives based on conjunctive surface and groundwater modeling within the complex administrative and legal framework of river basin management.

The *River GeoDSS* provides sophisticated tools that allow accurate system simulations and evaluation of strategies while minimizing the technological burden on the user. A unique characteristic of the *River GeoDSS* is the integration of models, tools, user interfaces and modules, all seamlessly incorporated in a geographic information system (GIS) environment that encourages the user to focus on interpreting and understanding system behavior to better design remediation strategies and solutions. The modeling system integrates the comprehensive river basin management model MODSIM with the 3D numerical groundwater quantity/quality model MODFLOW-MT3DMS. The *River GeoDSS* integrates these existing modules with a new artificial neural networks (ANN) module for natural and irrigation return flow quantity and quality evaluation and salt transport through reservoirs, as well as a new water quality module (WQM) for conservative salt transport modeling of conjunctive use of surface water and groundwater resources in the river basin network. The *River GeoDSS* incorporates Geo-MODSIM, a fully functional implementation of MODSIM within the ArcMap interface to the ArcGIS™ geographic information system (ESRI, Inc.). Also incorporated within the *River GeoDSS* is Geo-MODFLOW, a new MODFLOW-MT3DMS results analysis tool in the ArcMap interface. In this research, innovative methodologies are developed for applying ANNs in efficiently coupling surface and groundwater models and carrying out the reservoir salt transport modeling. The WQM's conservative salt transport algorithm, incorporating groundwater contributions within the surface water salinity routing, is fully embedded within the modeling subsystem.

The core *River GeoDSS* is customized to provide comprehensive analysis of alternative solutions to achieving agricultural, environmental, and water savings goals in the Lower Arkansas River Basin in Colorado as a case study for demonstrating the viability of the *River GeoDSS*. The alternatives include basin-scale evaluation of combinations of strategies including (1) aquifer areal recharge (from over irrigation) reduction, (2) canal seepage reduction, (3) improved subsurface drainage under irrigated lands, (4) vertical drainage, and (5) modified reservoir operations, with assurance of physical and administrative compliance. The *River GeoDSS* applied to the Arkansas River Valley allowed comparing benefits and improvements of management strategies, illustrated their potential to reduce waterlogging and soil salinity, salt load to the river, and non-beneficial evapotranspiration in a strategic planning environment.

Enrique Triana
Civil and Environmental Engineering Department
Colorado State University
Fort Collins, CO 80523
April 2008

PREFACE

The development of *River GeoDSS*, a spatial-decision support system, originated many years of research at field, regional, and basin scales in the Lower Arkansas River Valley (LARV) in Colorado by Colorado State University (CSU) professors Drs. John Labadie, Timothy Gates, and Luis Garcia. The *River GeoDSS* is designed and developed as a flexible adaptable decision support tool to address water resource system-specific issues. The *River GeoDSS* uses MODSIM, a CSU developed and maintained software, as the main modeling engine. The author actively participated in the development of MODSIM version 8 (MODSIM 8), which gives him an invaluable understanding of the model and its state-of-the-art customization capability, essential in the successful implementation of *River GeoDSS*. The initial application of the *River GeoDSS* is in the LARV, Colorado, where earlier investigations identified the need for a basin-wide alternative evaluation tool in moving towards a pilot program implementation of improved water management and salinity control strategies that were developed at field and regional scales. The Lower Arkansas River (LAR) *GeoDSS* is founded upon an unprecedented effort in extensive field monitoring and data collection and many years of field and regional–scale detailed numerical models development by the CSU research team. The *LAR GeoDSS* application presented herein is a promising starting point to developing a tool that can be utilized to answer many emerging questions that will dictate the future of this irrigated river valley.

The *River GeoDSS* final product is a decision support system with core functionality (e.g., the Geo-MODSIM input/output tools, Geo-MODFLOW output display, water quality and artificial neural network modules, and the scenario manager output control) that can be used in any river system with limited case-specific functionality. Customization is necessary to adapt the tool for specific challenges in other basins. The Arkansas River customized version is fully functional for the specific purposes that it was developed for; further improvements and development direction identified during the course of this research are presented.

ACKNOWLEDGMENTS

The author wishes to express sincere appreciation to Prof. John Labadie and Prof. Timothy Gates for their invaluable guidance, assistance, and support during the many years of development of this research project. Their continual encouragement and advice played a key role in the success and completion of this work. The author also would like to recognize the input and comments to the research by his committee members, Prof. Luis Garcia and Prof. Charles Anderson.

Special thanks go to Dr. Phil Burkhalter, for his early work and support on the Arkansas River MODFLOW-MT3DMS regional-scale groundwater model, and to Eric Morway for his assistance in working with, analyzing and understanding the behavior and the assumptions of the regional-scale groundwater model. The author acknowledges Marc Baldo's contribution to the water quality module algorithm design and thanks him for the MODSIM training and support in the early stages of this research. Thanks also are extended to all of the members of the CSU Arkansas River Valley Research Team for their dedication and contributions in building the invaluable framework for this research work.

This research was only possible with the funding and cooperation of many agencies interested in improving conditions in the Arkansas River Valley such as: the Colorado Agricultural Experiment Station, the Colorado Water Resources Research Institute, the Southeastern Colorado Water Conservancy District, the Lower Arkansas Valley Water Conservancy District, the U.S. Bureau of Reclamation and many others. The author appreciates the Colorado Division of Water Resources (Division

2) personnel for their unconditional cooperation, data sharing, and help in understanding the administrative complexity of the Arkansas River system.

Finally, thanks to my wife, my parents, my brother and numerous friends, who endured this long process with me, always offering unconditional support and love.

For my wife Marcela and my sons Mateo and Felipe

TABLE OF CONTENTS

CHAPTER 6

CHAPTER 7

CHAPTER 8

LIST OF FIGURES

Number *Page*

LIST OF TABLES

Number *Page*

LIST OF ABBREVIATIONS

ANN: Artificial Neural Network

CDWR: Colorado Division of Water Resources

CSU: Colorado State University

DSS: Decision Support System

LARV: Lower Arkansas River Valley

LAR: Lower Arkansas River

NRCS: Natural Resource Conservation Service

SDSS: Spatial Decision Support System

USBR: U.S. Bureau of Reclamation

USGS : United States Geological Survey

LIST OF CD CONTENTS

CD CONTENTS DESCRIPTION

ANN TRAINING FILES

MATLAB FILES AND INTERFACES

DISSERTATION FILES. PDF FILES

APPENDIX II (Electronic Only)

River GeoDSS INSTALL (.msi FILE)

LAR GeoDSS SAMPLE FILES

Mode A

Mode B

NEXRAD BATCH PROCESSING FILES