MULTI-OBJECTIVE OPTIMIZATION APPROACH FOR LAND USE ALLOCATION BASED ON WATER QUALITY CRITERIA

by

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ABSTRACT

Surface water contamination by point and nonpoint sources of pollution is a major concern for public and government agencies around the world due to the excessive contamination of water bodies. Water is an important resource for any community to support life, economic development, recreation facilities, and aesthetic values. According to estimates by the United States Environmental Protection Agency (USEPA), about 40% of the monitored national water supplies does not meet established quality standards. For Puerto Rico, the 2002 water quality inventory reports 70% of monitored river miles impaired (PREQB, 2002). Sediment loadings and nutrients concentrations are one of the major contaminants reaching water bodies producing serious consequences in ecological systems, human health, water provisioning, and recreational activities. Additionally, the list of impaired waters of Puerto Rico states that all the reservoirs fail to meet existing aquatic life criteria for dissolved oxygen resulting in an eutrophication condition characterized by an elevated nutrient levels status (PREQB, 2003).

Puerto Rico is facing the need to develop and implement Total Maximum Daily Loads (TMDL's) for impaired lakes and rivers listed by the USEPA. As part of the efforts to reduce and mitigate the pollution issue, this investigation is presented to evaluate the Río Grande de Arecibo watershed, located in the north-central Puerto Rico using an integrated land use planning metodology at the watershed.

The integrated land use allocation scheme developed in this research consist firstly of a water quality analysis and simulation for a ten years period (1995-2005) using the

Hydrological Simulation Program Fortran (HSPF). The watershed simulation includes the hydrology, sediments, and nutrients components (Total Nitrogen species and Total Phosphorus). These variables will provide data to generate the annual loadings and annual export coefficients intervals of the species by land use in the watershed and are used as input in the second stage of the methodology.

The second stage of this research consists of a multi-objective optimization approach using the Multi-objective Linear Programming (MOLP) method and taking into account the inherent uncertainty associated with the watershed in terms of hydrometereological, physical, and socio-economic conditions. For this reason, the land use export coefficients intervals were used as input for the decision variables in the MOLP model. A total of six different hypothetical scenarios were evaluated reflecting possible conditions in the future growth pattern at the watershed in the time study horizon (year 2025).

Complementing the previous stages, a Geographycal Information System (GIS) was developed for the optimal land use suggested ranges allocation from the MOLP model. This part of the research incorporates the concept of spatial optimal units based on the constraints in the watershed from a spatial point of view and seeks for the available areas that comply with the MOLP requirements. At this stage, additional constraints were incorporated in the land use integrated planning metodology responding to physical and socioeconomic characteristics in the study area.

Finally, the watershed integrated land use planning methodology is combined with an analysis and evaluation of institutional, political, fiscal, and environmental indicators for municipalities that integrates the Río Grande de Arecibo (RGA) watershed. This component allows defining the environmental capability of each municipality in order to forecast successful level in the implementation of the complete methodology suggested by this research in terms of optimal land use planning.

Findings of this research will provide the base work to find possible solutions to difficult issues related to land use planning for preservation, forestry, agriculture, and urban development while maintaining the viability of water quality and quantity. The final purpose of this research is not to designate a particular landuse for an area within RGA, rather, it is to establish the landuse distribution within RGA that help the municipalities comply with USEPA and the Puerto Rico Environmental Quality Board (PREQB) water quality standards.

Puerto Rico is one of the most densely countries in the world, consequently has the future conditions of many locations around the world with limited land resources and a very high population density that demands jobs, infrastructure, and housing. The proposed methodology offers a unique way to incorporate modeling approaches for watershed management, individual system components and the administrative capability of participating municipalities.

RESUMEN

La contaminación en aguas superficiales por fuentes puntuales y no puntuales es una preocupación actual para agencias públicas y de gobierno alrededor del mundo debido a la excesiva contaminación de los cuerpos de agua. El agua es un recurso importante para cualquier comunidad como soporte de vida, desarrollo económico, facilidades de recreación y valor estético. De acuerdo a estimados de la Agencia de Protección Ambiental de los Estados Unidos de Norteamérica (USEPA, por sus siglas en inglés), cerca de un 40% de los cuerpos de agua monitoreados no cumplen con los estándares de calidad de agua. En Puerto Rico, el inventario de calidad de agua del año 2002 reporta que el 70% de los ríos monitoreados están afectados (JCA, 2002). Las cargas de sedimentos así como las altas concentraciones de nutrientes figuran como las causas principales del deterioro produciendo serias consecuencias a los sistemas ecológicos, la salud humana, abasto y actividades recreacionales. Además, la lista de aguas deterioradas de Puerto Rico estipula que todos los reservorios violan los estándares de calidad de agua para el oxígeno disuelto resultando en una condición de eutrofización caracterizada por un elevado estatus nutricional.

Actualmente Puerto Rico está experimentando un desarrollo con respecto al programa de Cargas Diarias Máximas Permitidas (TMDL’s, por sus siglas en inglés) para los ríos y lagos definidos como impactados y deteriorados de acuerdo a la lista de la Junta de Calidad Ambiental. Como parte de este esfuerzo para reducir y mitigar los problemas de contaminación, se presenta esta investigación para evaluar la cuenca hidrográfica del Río

Grande de Arecibo localizada en la región Central-Norte de Puerto Rico usando una metodología integrada de planeamiento de uso del suelo en la cuenca.

La metodología integrada de planeamiento de uso del suelo desarrollada en esta investigación consiste de varias etapas, la primera de ellas consiste en la simulación y análisis de un modelo de calidad de agua por diez años (1995-2005) usando el programa *Hydrological Simulation Program Fortran* (HSPF). El modelo de calidad de agua en la cuenca incluye la simulación hidrológica, de sedimentos y de nutrientes (Nitrógeno Total y Fósforo Total) para generar las cargas anuales e intervalos de los coeficientes de exportación por uso del suelo de las especies analizadas en la cuenca, utilizados como insumo para la segunda parte de la metodología desarrollada en esta investigación.

La segunda etapa de la metodología consiste de un análisis de optimización multiobjetivo utilizando Programación Lineal Multi-Objetivo (MOLP, por sus sigla en inglés) y considerando la incertidumbre inherente asociada a la cuenca en términos de condiciones hidrometereológicas, físicas y socio-económicas. Por esta razón los intervalos de los coeficientes de exportación generados por uso de suelo y contaminante fueron utilizados como entrada en las variables de decisión del modelo de optimización. Un total de seis escenarios hipotéticos que reflejan las posibles condiciones en el patrón de crecimiento en la cuenca en el horizonte de tiempo de análisis (año 2025), fueron evaluados.

Como complemento de las etapas previas, un Sistema de Infromación Geográfico (SIG) fue desarrollado para la localización espacial de los rangos sugeridos por el modelo de optimización. Esta parte de la investigación incorpora el concepto de unidades espaciales óptimas basado en restricciones en la cuenca de tipo espacial buscando las áreas óptimas disponibles que cumplan con los requirimientos de la etapa de optimización multiobjetivo. En esta etapa se incorporan restricciones adicionales en la metodología integrada de planeamiento de uso del suelo que responden a características físicas y socioeconómicas en el área de estudio analizada.

Finalmente, la metodología desarrollada se combina con un análisis y evaluación de indicadores institucionales, fiscales, políticos y ambientales para las municipalidades pertenecientes a la cuenca del Río Grande de Arecibo. Este componente permite definir la capacidad ambiental asociada a cada municipalidad así como pronosticar el nivel de éxito en la implantación de la metodología de planeamiento de uso del suelo desarrollada en esta investigación.

Las conclusiones de esta investigación proveen la base para encontrar posibles soluciones a temas díficiles relacionados a planeamiento de uso del suelo para preservación, conservación forestal, desarrollo agrícola y urbano manteniendo la viabilidad en la cantidad y calidad de agua.

Puerto Rico es uno de los países más densamente poblados del mundo, razón por la cual reúne las condiciones a futuro de muchos sitios alrededor del mundo con recursos limitados y una alta densidad poblacional que demanda trabajos, infraestructura y vivienda. La metodología propuesta ofrece una manera única de de incorporar distintos componentes de simulación para manejo integrado de cuencas, componentes individuales y capacidad administrativa de los municipios participantes.

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DEDICATION

To God Almighty for all his blessings, love and support in my life.

I dedicate this work to my father Gerardo Villalta Aguilar

and my mother María Felicia Calderón Zumbado, my example of life and guide,

my lovely wife Alejandra Rojas González and

my daughter and inspiration Mariajosé Villalta Rojas.

To my brothers, Pablo, Silvia and María Fernanda,

Also dedicate this work to Yadira González González and to the memory of my

grandparents Rosa Aguilar Aguilar and Jorge Villalta Molina

as well as my uncle Jorge Villalta Aguilar.

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LIST OF COMMONLY USED TERMS/ACRONYMS

BASINS Better Assessment Science Integrating point and Nonpoint Sources. A multipurpose environmental analysis system developed by EPA, of which HSPF is a component.

BMP Best Management Practice. Remedies implemented to address water quality problems and to achieve compliance with water quality standards.

DEM Digital Elevation Model. Refers to a type of gridded GIS data containing land surface elevations; useful in watershed delineation.

DM Decision maker.

GQUAL Section of HSPF dealing with general quality.

GIS Geographic Information Systems.

HSPF Hydrological Simulation Program- FORTRAN.

HYDR Section of HSPF dealing with reach and reservoir hydraulics.

IMPLND Impervious Land Segment; or the HSPF module which simulates processes on impervious land segments.

IQUAL Section of HSPF dealing with general quality constituents on impervious land surfaces.

IWATER Section of HSPF dealing with hydrology on impervious surfaces.

LA Load Allocation. The portions of a TMDL's pollutant load allocated to a nonpoint source of a pollutant, including atmospheric deposition or natural background sources.

MAE Mean Absolute Error.

MOLP Multiobjective optimization linear programming

MOS Margin of Safety. A required element of a TMDL that accounts for uncertainty and lack of knowledge.

NSE Nash-Sutcliffe Efficiency.

NPS Non-point source. Sources of pollution no considered to be point sources (e.g., runoff and associated processes on the land surface).

TMDL Total Maximum Daily Load. Required by the Clean Water Act to establish limits of what a stream segment can assimilate and still meet instream water quality standards.

PERLND Pervious Land Segment; or the HSPF module which simulates processes on pervious land segments.

PQUAL Section of HSPF dealing with general quality constituents on pervious land surfaces.

PS Point Source. Sources of pollution that enter transport routes at discrete, I dentifiable locations.

PWATER Section of HSPF dealing with hydrology on pervious surfaces.

R Correlation coefficient.

R^2 Determination coeffcient.

RCHRES Reach or Reservoir; or the HSPF module which simulates processes related to reaches or reservoirs.

RMSE Root Mean Squared Error

UCI User's Control Input; a text file containing HSPF input parameters and specifications.

USDA United States Department of Agriculture

USEPA United States Environmental Protection Agency**.**

USGS United States Geological Service.

WDM Watershed Data Management; a binary file type commonly used by HSPF for managing timeseries data.

WLA Waste Load Allocation. The portions of a TMDL's pollutant load allocated to a point source of a pollutant.

CHAPTER 1

INTRODUCTION

1.1 JUSTIFICATION

The link between watershed management and water resources is more evident in Puerto Rico than in any other place within the United States. Puerto Rico is one of the most densely populated areas in the world, therefore it represents the future for other locations in terms of land use and water resources. By understanding the linkage between land use and population one can quantify them and generate new knowledge about land utilization and water resources for the benefit of communities around the world.

Surface water contamination by point and nonpoint sources of pollution is a major concern for public and government agencies in the United States and Puerto Rico. The major cause of water pollution in the United States is nonpoint source inputs where species like total phosphorus cause eutrophication of surface water around the country (U. S. EPA, 1996).

A similar scenario is observed in Puerto Rico where according to the 2002 water quality inventory approximately 70% of the river miles being monitored were impaired due to either high sediment load or bacterial counts (PRQB, 2002). Rivers are the main transport mechanism of nutrients, specially nitrogen and phosphorus, to lakes and coastal waters (Castillo et al., 2000). In the same context, the list of Impaired Waters of Puerto Rico

(305(b)-303(d)) states that all our reservoirs fail to meet existing aquatic life criteria for dissolved oxygen resulting in an eutrophication condition, characterized by an elevated nutritional status (Martínez et al, 2005).

Nutrient pollution problems may arise from numerous sources from all types of land use (agricultural, urban, rural, or industrial) and atmospheric deposition. Residential land use can be an important contributor depending on lawn fertilization level and status of septic systems. Farmers apply nutrients using different approaches, and nutrients entering waterways from agricultural practices (crop land) vary greatly depending on management techniques. Typically, streams and other surface waters receive relatively small amounts of nutrients from forest land, and relatively large amounts from land uses that involve soil disturbance and fertilizer applications (Maryland Department of Natural Resources, 2004). Agriculture is the nation's leading nonpoint source contributor, responsible for degrading approximately 60% of the impaired river kilometers and 50% of the lakes hectares of the United States (U.S. EPA 1997).

Water quality issues are extremely important for the general public due to the excessive contamination of water bodies. Water is an important resource for any community to support life, economic development, recreation facilities, and aesthetic values. The lack of adequate urban planning, urban sprawl, increase of impervious areas and a dynamic population and industrial/agricultural sectors endanger the quality and quantity of water.

Puerto Rico is experiencing an ongoing development in the Total Maximum Daily Loads (TMDLs) program for lakes and rivers listed as impaired waters (303d. list) by the Environmental Protection Agency (EPA), and the local Puerto Rico Quality Board (PREQB). At this time, only two projects are approved by the EPA; the Río Cibuco and the Río La Plata watersheds. Both TMDL's were developed to treat fecal coliforms as the principal cause of impairment.

As part of this effort, this investigation is presented to evaluate the Río Grande de Arecibo watershed, located in the north-central Puerto Rico. In this area, the Dos Bocas dam has a catchment area of 43,713 ha and extends to municipalities of Utuado, Jayuya, Adjuntas, and Ciales, with an estimated population of 91,608 (U.S. Census Bureau, 2000). The watershed is the catchment area for two reservoirs: Lake Dos Bocas and Lake Caonillas, the region's drinking water supply.

Findings of this project will provide the base work to find possible solutions to difficult issues related to land use planning for preservation, forestry, agriculture and, urban development while maintaining the viability of water quality and quantity. The study uses an optimization approach and considers the inherent socio-economic issues that are associated with land use planning. The study also makes an effort to quantify and incorporate municipal capability to plan, executed and implements strategic land use management plans with specific goals and objectives.

This integrated optimization approach is conducted to achieve a robust decision management program that is based on science but incorporates socio-economic drivers, sustainable concepts and municipal capabilities. This tool will allow the compliance with the different water quality regulations to ensure the necessary quality of the waters.

This project will also provide basic tools for predicting nutrients export coefficients in a watershed context based on a simulation using the Hydrological Simulation Program-FORTRAN and provide a planning tool to regulatory agencies in Puerto Rico to be used in land use management programs.

Puerto Rico is one of the most densely countries in the world, consequently has the future conditions of many locations around the world with limited land resources and a very high population density that demands jobs, infrastructure, and housing. The proposed methodology offers a unique way to incorporate modeling approaches for watershed management, individual system components and the administrative capability of participating municipalities.

1.2 OBJECTIVES

The overall objective of this thesis is to understand and model the dynamics of nutrients and sediments in a tropical watershed and postulates hypothesis about the possible pattern of land use growth that complies with existing and proposed environmental goals. At the end of this research, recommendations for allocation of new land use growth, therefore land use changes within the study area will be made. The developed methodology would be utilized as a planning tool for local and government agencies.

The specific objective of this project is:

1. To develop an integrated optimization technique for land use planning using water quality continuous simulation analysis based on specific water quality objectives and using a Multi-Objective Linear Programming (MOLP) model implemented in a GIS platform. The upper RGA watershed is used as a development and validation test site.

1.3 STRATEGY

A methodology for watershed management and land use optimization for future possible growth in the Río Grande de Arecibo (RGA) watershed is presented in this investigation. Environmental regulatory goals are proposed as constraints in the interactive multiobjective optimization approach taking into account the maximum regulated loads in water bodies in the RGA area.

To solve the problem, a water quality simulation was performed using the Hydrological Simulation Program Fortran (HSPF) between 1995 and 2005. Hydrologic, sediment and water quality simulation was simulated as a useful basis tool for system evaluation and future scenarios evaluation.

Land use export coefficients were obtained from water quality model and used as input in the multiobjective optimization approach, the second stage of the investigation. For this purpose, an uncertainty approach is proposed to find optimal values in land use future development taking into account the inherent uncertainty of the system.

Finally, optimization results are implemented in a Geographical Information System (GIS) database to consider the spatial component of the land use expansion and associated it to existent physico-geographical and socio-economic conditions in the region. GIS database is used as an automated tool to distribute the optimal values obtained in the optimization analysis.

1.4 OVERVIEW OF THE THESIS

This work presents a theoretical background in Chapter 2, including a detailed literature review of the theory and important principles. Chapter 3 gives a detailed overview of the study area including geographical, physical and socio-economic characteristics, actual condition and health of system. Chapters 4, 5 and 6 present and discuss the results from the water quality model, multiobjective optimization approach, and GIS land allocation methodology respectively in the watershed. Chapter 7 evaluates the environmental capacity at the municipalities in the RGA watershed and forecast the successful level of the entire methodology of this research. Chapter 8 concludes this dissertation summarizing the most important findings of the investigation and outlines areas for future research.

CHAPTER 2
THEORETICAL BACKGROUND

2.1 INTRODUCTION

The proposed work entails three important phases: initially with a water quality simulation using the Hydrological Simulation Program Fortran (HSPF), then a stochastic multi-objective optimization approach, and finally a land allocation model all in an integrated methodology to meet the local and federal water quality standards.

2.2 WATER QUALITY MANAGEMENT

This section introduces a revision of different researchs focused on the water quality watershed framework management; including first in a regulatory context, one of the principal policies on water quality management, the Clean Water Act (CWA). An overview of previous research on water quality management follows the above cited introduction.

2.2.1 Regulatory Context: The Clean Water Act

Growing public awareness and concern for controlling water pollution led to enactment of the Federal Water Pollution Control Act Amendments of 1972 by Congress. As amended in 1977, this law became commonly known as the Clean Water Act (CWA, 1972). The Act established the basic structure for regulating discharges of pollutants into the waters of the United States. It gave EPA the authority to implement pollution control programs such as setting wastewater standards for industry.

The CWA does not deal directly with ground water or with water quantity issues. It is the cornerstone of surface water quality protection. The statute employs a variety of regulatory and no regulatory tools to sharply reduce direct pollutant discharges into waterways, finance municipal wastewater treatment facilities, and manage polluted runoff. These tools are employed to achieve the broader goal of restoring and maintaining the chemical, physical, and biological integrity of the nation's waters so that they can support the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water (USEPA, 1972).

For many years following the passage of the CWA in 1972, federal, state, tribal, regional and local governments focused mainly on the chemical aspects of the "integrity" goal. The first efforts of the Clean Water Act, in the early decades of it implementation, focused on the point sources, regulating discharges from traditional point source facilities, such as municipal sewage plants and industrial facilities, with little attention paid to runoff from streets, construction sites, farms, and other "wet-weather" sources.

Starting in the late 1980s, evolution of CWA programs has occurred in three aspects. First, more attention has been given to physical and biological integrity. Second, efforts to address polluted runoff have also increased significantly. For nonpoint runoff, voluntary programs, including cost sharing with landowners are the key tool. For "weather point sources" like urban storm sewer systems and construction sites, a regulatory approach is being employed. Third, evolution of CWA programs has included something of a shift from a program-by-program, source-by-source, and pollutant-by-pollutant approach to more holistic watershed based strategies. Under the watershed approach equal emphasis is placed on protecting healthy waters and restoring impaired ones. A full array of issues are addressed, not just those subject to CWA regulatory authority. Involvement of stakeholder groups in the development and implementation of strategies for achieving and maintaining state water quality and other environmental goals is another hallmark of this approach (USEPA, 2003d).

As enacted in 1972, an important part of the CWA – section 303 – establishes the water quality standards and Total Maximum Daily Load (TMDL) programs. Water quality standards are set by states, territories, and tribes. They identify the uses for each waterbody, for example, drinking water supply, contact recreation such as swimming, and aquatic life support such as fishing, and the scientific criteria to support that use. A TMDL specifies the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards and allocates pollutant loadings among point and nonpoint pollutant sources. The TMDL has three components, the point loads, nonpoint loads and a margin of safety to ensure that the waterbody can be used for the purposes the state has designated and also account for seasonal variation in water quality. Under section 303(d) of the 1972 CWA, states, territories, and tribes are required to develop lists of impaired waters. These impaired waters do not meet water quality standards that states, territories, and tribes have set for them, even after point sources of pollution have installed the minimum required levels of pollution control technology. The law requires that these jurisdictions establish priority rankings for waters on the lists and develop TMDLs for these waters. While TMDLs have been required by the CWA since 1972, until recently, EPA, states, territories, and tribes have not developed many (USEPA, 2003c).

2.3 WATERSHED SIMULATION

Watersheds models are fundamental to water resources assessment, development and management. They are employed to understand dynamic interactions between climate and land-surface hydrology (Singh, 2002).

2.3.1 Development of Watershed Models

In the 1960's the digital revolution made possible the integration of models of different components of the hydrologic cycle and simulation of virtually the entire watershed. One of these models was the contribution of the Stanford watershed model-SWM (now HSPF) by Crawford and Linsley in 1966. This was probably, the first attempt to model virtually the entire hydrologic cycle. Simultaneously, a number of some what less comprehensive models were developed. Examples of such models are the watershed models of Dawdy and O'Donnell (1965) and HEC-1 (Hydrologic Engineering Center 1968). Another kind, the semidistributed models capable of accounting for the spatial variability of hydrologic processes within the watershed were developed, as illustrated by tank models developed by Sugawara et al in 1967 (Singh, 2002).

Indeed there has been a proliferation of watershed hydrology models since the development of SWM or HSPF, with emphasis on physically based models.

The digital revolution was the beginning to other revolutions, namely, numerical revolution and statistical simulation. The power of computers increased exponentially and, as a result, advances in watershed hydrology have occurred at an unprecedented pace during the past 35 years. During the decades of the 1970's and 1980's, a number of mathematical models were developed not only for simulation of watershed hydrology but also for their applications in other areas, such as environmental and ecosystems management. Development of new models or improvement of previously developed models continues today (Singh, 2002).

2.3.2 Currently Used Watershed Models

Several well known general watershed models are in current use in the United States and elsewhere. Based on the model purpose, the construction of its components can vary significantly, responding these models to required different purposes. HEC-HMS is a model from the U.S Army Corps of Engineers, considered the standard model in the private sector in the United States for the design of drainage systems, quantifying the effect of land use change on flooding, etc. HSPF and its extended water quality model are the standard models adopted by the Environmental Protection Agency (EPA). Several countries have different preferences for one or another model. Per example, the UBC and WATFLOOD models are popular in Canada for hydrologic simulation. The RORB and WBN models are commonly employed for flood forecasting, drainage design, and evaluating the effect of land-use change in Australia. TOPMODEL and MIKE-SHE are the standards models fro hydrologic analysis in many European countries. The ARNO, LCS and TOPIKAPI models are popular in Italy. Tank models are well accepted in Japan. The Xinanjiang model is commonly used model in China.

2.3.3 Classification of Watershed Hydrology Models

A watershed hydrology model is an assemblage of mathematical descriptions of components of the hydrologic cycle. The model structure and architecture are determined by the objective for which the model is built. Singh (Singh, 1995 a), classified hydrologic models based on (1) process descriptions; (2) time scale; (3) space scale; (4) techniques of solution; (5) land use, and (6) model use.

Analytical solutions can be obtained only in very simple cases, although the mathematical equations embedded in watershed models are continuous in time and often space. Numerical methods, included in computational subroutines like finite differences, finite element, boundary element, and boundary fitted coordinate, are required for practical cases. The most general formulation case involves partial differential equations in three space dimensions and time. If the spatial derivatives are not considered, the model is “lumped”, that is the HSPF case, otherwise it is said to be “distributed”, and the solution is a function of space and time and include all the terms of the general formulation.

Statistical tools, including regression and correlation analysis, time series analysis, stochastic processes, and probabilistic analysis are necessary to analyze the output to provide this type of information. Because of uncertainties in model structure, parameter values and precipitation, and other climatic inputs, uncertainty analysis and reliability analysis can be employed to examine their impact.

2.3.4 New Developments and Challenges in Watershed Models

New data collection techniques, including remote sensing, satellites, and radar received a great deal of attention in the 1980’s and continue to do so. Major advances have been made in recent years in remote sensing and radar and satellite technology, which are going a long way in alleviating the scarcity of data that is one of the major difficulties in watershed hydrologic modeling.

Geographical Information Systems (GIS), database management systems (DBMS), and graphic visual design tools are some of the new techniques available. Integration of these techniques with watershed hydrology models is useful in a number of significant functions like: designing, calibrating, modifying, evaluating and comparing watershed hydrology models (Singh, 2002).

2.4 HYDROLOGICAL SIMULATION PROGRAM-FORTRAN (HSPF)

This section presents a summary of the Hydrological Simulation Program Fortran (HSPF), in the modeling of hydrology, erosion and water quality processes. A detailed description of HSPF can be obtained in the User's manual, Version 12, (Bicknell *et al*., 2001). HSPF has various characteristics, including a process-based, lumped, continuous model developed under EPA sponsorship to simulate hydrology and water quality processes in pervious or impervious areas. The first version of HSPF was released in 1980; version 12 is the most recent. Figure 2.1 shows the history in the development of HSPF, based its origin on previously developed models: 1) Hydrocomp Simulation Programming (HSP), a refined version of Stanford Watershed Model (SWM), 2) NonPoint Source (NPS) Model, 3) Pesticide Transportation Runoff (PTR) and their further modification Agricultural Runoff Management (ARM) Model, and 4) Sediment and Radionuclides Transport (SERATRA) (Bicknell *et al*., 2001). The HSPF model has been improved in database, input management and algorithms for such processes as in stream sediment-nutrient, wetlands capabilities and best management practices. Actually, HSPF is continuously being improved by EPA, USGS, Hydrocomp, Inc. and AQUATERRA consultants.

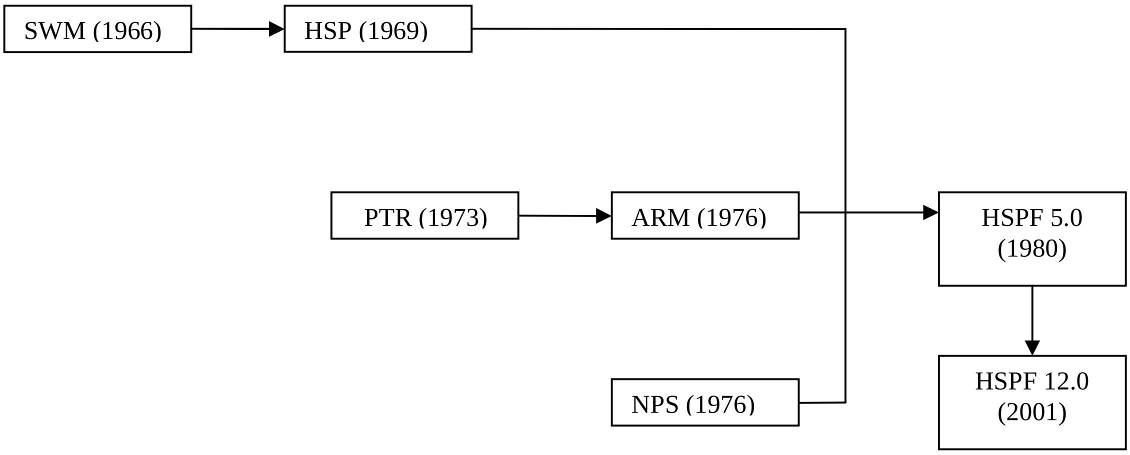


Figure 2.1. Development history of HSPF

HSPF has three application modules (PERLND, IMPLND and RCHRES), and five utility modules. PERLND simulate the runoff and water quality processes in pervious areas, IMPLND make the same in impervious areas and during routing through reservoir and reaches, the RCHRES module is used for routing in channels (Donigian *et al.*, 1995). Time series (i.e., meteorological and flow observed data) are accessed, manipulated and analyzed in the utility modules. One of the most utility modules used is the WDM Util, utilized in the input time series required data.

Before using HSPF, the watershed area must be delineated in homogeneous land areas called Hydrologic Response Units (HRUs). For each HRU the combination of weather, soil, land use, topographic and geologic properties is unique, giving rise to its “semi-distributed” model structure. HRUs can be impervious or pervious areas, which are modeled independently. Each HRU requires input data such as rainfall, temperature, potential evapotranspiration, and parameters related to land use, soil characteristics, and agricultural practices to simulate hydrology, sediments, nutrients and pesticides (Donigian *et al*., 1995).

Hydrological simulation in HSPF has its origin in the Stanford Watershed Model (Linsley *et al*., 1988). A flow diagram of the hydrological components of HSPF is shown in Figure 2.2. This diagram is a reservoir-type model consisting of five reservoirs, each allowing different types of inflow and outflow. Inflows and outflows are simulated in HSPF as a water-balance accounting. Each pervious land segment simulated by the PERLND module, considers the following processes: interception, evapotranspiration, surface detention, surface runoff, infiltration, shallow subsurface flow (interflow), base flow, and deep percolation (Donigian *et al*., 1995).

HSPF uses the physical and empirical formulations to model the movement of water within each HRU. Interception loss is simulated by assuming an interception storage capacity (about 0-0.2 inches) according to the type of vegetation on the land segment. Volume of interception storage must be filled before excess precipitation can reach the land surface; intercepted water is subsequently evaporated.

Infiltration is calculated using the following relationships (Bicknell *et al*., 2001), which are based in the work of Phillip (1957):

$$IBAR = INFFAC * \frac{INFILT}{\left(\frac{LZS}{LZSN}\right)^{INFEXP}} \tag{1}$$

And the relationship given by:

$$IMAX = INFILD * IBAR \tag{2}$$

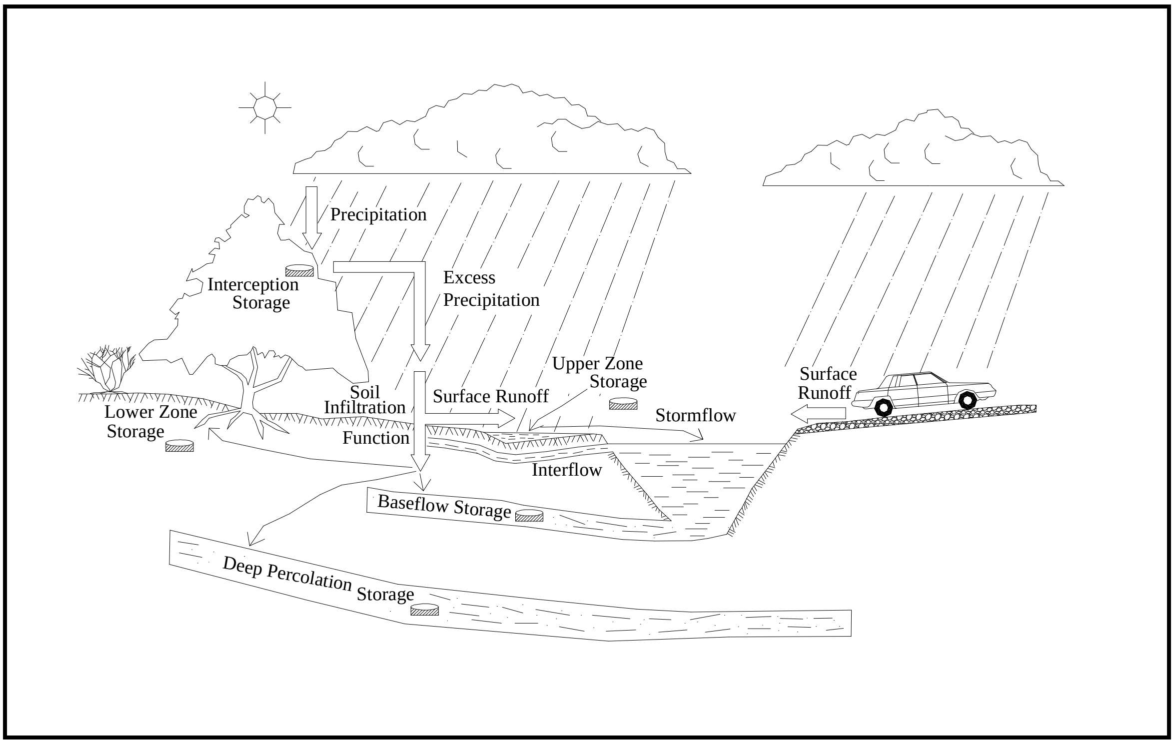


Figure 2.2. Flow diagram of hydrologic components simulated (From Bicknell et al., 2001)

$$IMIN = IBAR - (IMAX - IBAR) \qquad (3)$$

$$RATIO = INTFW * (2.0^{\left(LZS/LZSN\right)}) \qquad (4)$$

where $IBAR$ is the mean infiltration capacity over the land segments (in/interval); $INFILT$ is the infiltration parameter (in/interval); LZS is the lower zone storage (in); $LZSN$ is the parameter lower zone nominal storage (in); $INFEXP$ is the exponent parameter greater than one; $INFFAC$ is the factor to account for frozen ground effects (if applicable); $IMAX$ is the maximum infiltration capacity (in/interval); $INFILD$ is the parameter giving the ratio of maximum to mean infiltration capacity over the land segment; $IMIN$ is the minimum infiltration capacity (in/interval); RATIO is the ratio of the ordinates of line II an line I (see Bicknell *et al*., 2001, figure 4.2(1).3-3, p. 61); and $INTFW$ is the interflow inflow parameter.

Values of $INFILT$ are related to NRCS hydrologic soil groups classification. $LZSN$ is related to the annual precipitation and soil characteristics of the study area. While HSPF does not distinguish between Hortonian and saturation excess overland flow, it is possible to simulate saturation excess overland flow by adjusting the parameter value $INFEXP$ in equation 1. Increasing the value of $INFEXP$ will have the effect of reducing the infiltration rate for moisture content.

A portion of surface runoff becomes upper-zone storage, simulating both depression storage and upper-soil storage, and the balance becomes overland flow. Infiltrated water that does not go into interflow or lower-zone storage is finally placed in the active groundwater storage. Active ground water storage is divided into deep percolation and ground water storage. Deep percolation is simulated as a sink. Ground water storage controls the base flow and it is modeled by the relationship:

$$AGWO = KGW * AGWS * (1 + KVARY * GWVS) \quad (5)$$

where $AGWO$ is the ground water outflow (in/interval); $AGWS$ (in) is ground water storage; $GWVS$ (in) is an index based on inflow to ground water storage; and $KVARY$ (in^{-1}) is an input adjustment parameter which allows variable ground water recession rates. The parameter KGW (in^{-1}) is defined as:

$$KGW = 1.0 - AGWRC^{(DELT60/24.0)} \quad (6)$$

where, $DELT60$ is the number of hours in each time step; and $AGWRC$ (in/in) is the minimum observed daily recession constant of ground water flow. $AGWRC$ is calculated as the ratio of the current ground water discharge to the discharge 24 hours earlier.

Actual evapotranspiration (SAET) is an important value of the water balance, and it is simulated in response to the potential evapotranspiration (PET) rate. Water evaporates first from the riparian vegetation (wetlands). Further SAET is satisfied sequentially by interception storage, upper zone storage, active ground water and lower-zone storage where each storage has a different resistance to evaporation. In this way the maximum potential of each storage is depleted either until all storages have contributed their maximum amount to evapotranspiration or until the PET has been fully satisfied.

Snowmelt is simulated in HSPF as a complex energy balance problem. It is a result of a series of routines that computed net radiation exchange on the snow surface, convection and condensation melt, heat transfer from the earth to the bottom of the snowpack where the soil is not frozen, and melt due to the rainfall. Input data used by HSPF for snowmelt obtained from direct measurements include precipitation, dewpoint temperature, wind speed cloud cover, solar radiation and evapotranspiration. This module is omitted in the here proposed investigation, because the study area does not have this condition.

The flow routing takes place in two regimes, one of them the overland flow plane and another in the river channel network. In the first case, overland flow is routed by using a modified form of the Chezy-Manning equation, and in the second case employs the “kinematic wave” routing technique to move water from one reach to the next in the river channel network (RCHRES module). Flow is modeled as unidirectional implying only the simulation in the main channel river and no floodplains. Complete mix is assumed by the model in streams and lakes (Bicknell *et al*., 2001). For each reach, a fixed relationship is assumed between water level, surface area, volume and discharge using the called FTABLE, which is specified by the user. HSPF calculates hydraulic parameters such as hydraulic radius, shear stress and velocity, assuming that the cross-section of the reach is constant throughout the reach.

Simplification of the real world using conceptual parameters has the advantage of avoiding the need for giving the physical dimensions of the flow system (Bicknell *et al*., 2001). This approach reduces input requirements and, more importantly, gives the model its generality (Linsley *et al*., 1988). Parameters as percentage of impervious area, average length of overland flow and average slope overland flow can be determined from the Geographical Information System (GIS) data base including Digital Elevation Models (DEMs). Others parameters pertaining to infiltration, soil-moisture zones, and interflow are determined by calibration or comparison with observed hydrographs (Linsley *et al*., 1988).

Calibration of HSPF implies as in others models, an adjusting of the model parameters, trying to minimize the difference between simulated and observed flows, and is often accomplished by using HSPEXP (Lumb *et al*., 1994), an expert system for the calibration of HSPF. Acceptable results for each calibration are fixed by the modeler and the phase to be searched for before proceeding to the next calibration phase.

Production and removal of sediments are based on ARM and NPS predecessor models (Donigian *et al*., 1995). These equations were originated from a sediment model created by Moshe Negev (Negev, 1967) and influenced by Meyer and Wischmeier (1969) and Onstad and Foster (1975). Whereas HSPF does not use the USLE specifically, several concepts of both models are analogous. Removal of sediment by water is simulated as washoff of detached sediment due to the rainfall and other sediment scour from the soil matrix. Sediment is detached from the surface pervious areas as a function of rainfall intensity, land cover, land management practices, and soil detachment properties (Donigian *et al*., 1995).

Once in the main channel, sediments are transported based on the SEDTRN module that includes the transport, deposition and sediment carry out. SEDTRN is based on the SERATRA (Sediment and Radionuclides Transport) developed by Batelle Laboratories. (Onishi and Wise, 1979).

HSPF uses three functions in the instream sediment transport, Toffaletti, Colby and a potency function. Compared to others sediment hydraulic transport models, HSPF capabilities for the sediment transport in the river is limited. Sediment transport models like HEC-6 from the U.S Army Corps of Engineers are more robust in the simulation of sediments and include a lot of sediment transport functions depending on different factors like material transported size, hydrodynamic conditions, transport mechanism (bed load, suspended or total load approach), etc. (U.S. Army Corps of Engineers, 1993). In this sense HSPF tries to simulate the sediment transport in the river but taking into account those limitations.

PQUAL module simulates water quality constituents or pollutants in the outflows from a pervious land segment using simple relationships with water and/or sediment yield. Any constituent can be simulated by this module section. The user supplies the name, units and parameter values appropriate to each of the constituents that are needed in the simulation.

The occurrence of a water quality constituent in both surface and subsurface outflow can be simulated. The behavior of a constituent in surface outflow is considered more complex and dynamic than the behavior in subsurface flow. A constituent on the surface can be affected greatly by adhesion to the soil and by temperature, light, wind, atmospheric deposition, and direct human influences. Section PQUAL is able to represent these processes in a general fashion. It allows quantities in the surface outflow to be simulated by two methods. One approach is to simulate the constituent by association with sediment removal. The other approach is to simulate it using atmospheric deposition and/or basic accumulation and depletion rates together with depletion by washoff; that is, constituent outflow from the surface is a function of the water flow and the constituent in storage. A combination of the two methods may be used in which the individual out fluxes are added to obtain the total surface outflow. Concentrations of quality constituents in the subsurface flows of interflow and active groundwater are specified by the user. The concentration may be linearly interpolated to obtain daily values from input monthly values.

PQUAL allows the user to simulate up to 10 quality constituents at a time. Each of the 10 constituents may be defined as one or a combination of the following types: $QUALSD$, $QUALOF$, $QUALIF$, and/or $QUALGW$. If a constituent is considered to be associated with sediment, it is called $QUALSD$. The corresponding terms for constituents associated with overland flow, interflow, and groundwater flow are, *QUALOF*, *QUALIF* and *QUALGW*, respectively. Note that only a *QUALOF* may receive atmospheric deposition, since it is the only type to maintain a storage. However, no more than seven of any one of the constituent types (*QUALSD*, *QUALOF*, *QUALIF*, or *QUALGW*) may be simulated in one operation. The program uses a set of flag pointers to keep track of these associations.

Better Assessment Science Integrating Point and Nonpoint Sources (BASINS) is a GIS interface that transfers data to WinHSPF (interface that provides complete access to all HSPF modules), for setting up a new simulation. These data contain the following information: number of reaches, reaches lengths, number of land segments, number of land uses, and areas of each land use contributing to each reach. These parameter files are created automatically when WinHSPF is launched from BASINS (Duda *et al.*, 2001).

Other components of BASINS, with which WinHSPF is integrated, are the Watershed Data Management Utility (WDMUtil) v2.27 program (Hummel *et al.*, 2001) and The Generation and Analysis of Model Simulation Scenarios (GenScn) software v2.3 (Kittle *et al.,* 2001). GenScn is available from within WinHSPF for viewing and analyzing model input and output. WDMUtil and GenScn are independent of WinHSPF.

The required meteorological data for the WinHSPF program is stored in a Watershed Data Management (WDM) file format. The WDMUtil is a windows-based program which has been developed to add new stations, edit or fill in missing data, compute variables required for WinHSPF, and format the file (WDM) for input into WinHSPF.

2.5 MULTI-OBJECTIVE OPTIMIZATION

2.5.1 Introduction

Optimization refers to finding one or more feasible solutions to arrive at optimal or good decisions in complex problems. A significant portion of research and application in the field of optimization considers a single objective, although most of the natural world problems involve the use of more than one objective which are conflicting in nature.

When an optimization problem involves more than one objective function, the task of finding one or more optimum solutions is known as multi-objective optimization (MOOP) (Deb, 2001). In such situations, it may be impossible to find a single solution that optimizes the conflicting objectives. Instead, we may seek a compromise solution based on the relative importance of each objective and simultaneously optimize the conflicting objectives group.

Different solutions may produce trade-offs (conflicting scenarios) among different objectives. A solution that is extreme (in a better sense) with respect to one objective requires a compromise in other objectives (Abbas et al., 2001). In multiobjective optimization, there may not exist a solution that is best with respect to all objectives.

Instead, there are equally good solutions which are known as Pareto optimal solutions (Deb, 2001). A Pareto optimal set of solution is such that when we go from any one point to another in the set, at least one objective function improves and at least one other worsens (Yee et al., 2003). Neither of the solutions dominates over each other. All the sets of decision variables on the Pareto front are equally good and is expected to provide flexibility for the decision maker. Normally, the decision about "what the best answer is" corresponds to the so-called decision maker (Coello, 1999).

2.5.2 Solution Methods

Classical and evolutionary algorithms are two main groups of solution methods for handling multiobjective optimization problems. Classical methods is basically a term used to distinguish them from evolutionary algorithms, because the approach between those is different. Classical methods have been around for at least the past forty years and a lot of algorithms were developed by researchers. Evolutionary algorithms have started to receive significant attention during the last decade, although the origins can be traced back to the late 1950s.

2.5.2.1 Classical Methods

In classical methods researchers have attempted to classify algorithms to various considerations. Cohon classified them in 1985 into *Generating methods* and *Preference-Based methods* (Deb, 2001). In the generating methods, a few non-dominated solutions are generated for the decision maker, who then chooses one solution from the obtained. No a priori knowledge of relative importance of each objective is used. On the other hand, in the preference-based methods, some preference of the objectives is considered. Authors like Hwang and Masud in 1979, Miettinen in 1999 and Timothy Marler in 2005 suggest a classification acordingly on how the decision maker articulates or incorporates preferences. (Deb, 2001; Marler, 2005)

The non-preference methods do not require any information about the relative importance in the objectives, but a heuristic is used to find a single optimal solution (Deb, 2001). *A priori articulation of preferences* implies that the user indicates the relative significance of the objectives functions or indicated desireg goals before running the optimization algorithm. *A posteriori articulation of preferences* entails selecting a solution from a group of mathematically equivalent solutions after the algorithm has run; the decision maker imposes preferences on a set of solutions (Marler, 2005).

Progressive articulation of preferences requires that the decision maker continually provide imput during the running of the algorithm. Using this approach can be relatively efficient (in terms of computational effort), since is strives to produce only a subset of the complete set of potential solutions.

Another classification of algorithms is based on the way the search directions are defined at each intermediate solution. Classical optimization methods can be classified into two distinct groups: direct search methods and gradient based methods (Deb, 1995). In direct search, only the objective functions and restrictions are used to guide the search, whereas the gradient-based methodology use derivatives for objective functions and constraints of first and second order.

In terms of computational efficiency, the direct search methods are slower than gradient-based methods due to the unused derivative information, requiring many functions evaluations for convergence. The principal limitation in the gradient based search is with non continous functions. Since nonlinearities and complex interactions among variables exist in real world problems, the search space usually contains more than one optimal solution, divided into local and global optimal solution. Classical methods are sometimes attracted to those local solutions avoiding the real global solution and then reporting a wrong solution to the problem (Deb, 2001).

2.5.2.2 Evolutionary Algorithms

Evolutionary algorithms (EA) are search methods that take their inspiration from natural selection and survival of the fittest in the biological world. EA differ from more traditional optimization techniques in that they involve a search from a "population" of solutions, not from a single point. Each iteration of an EA involves a competitive selection that weeds out poor solutions. The solutions with high "fitness" are "recombined" with other solutions by swapping parts of a solution with another. Solutions are also "mutated" by making a small change to a single element of the solution. Recombination and mutation are used to generate new solutions that are biased towards regions of the space for which good solutions have already been seen.

EA are often viewed as a global optimization method and different approaches from different authors exist. *Genetic algorithms* (GA), mainly developed in the USA by Holland, *Evolutionary strategies* (ES), developed in Germany by Rechenberg and Schwefel and *Evolutionary programming* (EP). Each of these constitutes a different approach; however, they are inspired by the same principles of natural evolution (Pohlheim, 2005).

Advantages from the evolutionary algorithms are the gain of flexibility and adaptability to the task at hand, in combination with robust performance (although this depends on the problem class) and global search characteristics. In fact, evolutionary computation should be understood as a general adaptable concept for problem solving, especially well suited for solving difficult optimization problems, rather than a collection of related and ready-to-use algorithms (Back, 1997).

Genetic algorithms are by far the most common global optimization technique that is used with multiobjective optimization problems (Marler, 2005). This approach have been extensively used in various problem domains, including the sciences, commerce, and enginnering and together with Evolution Strategy (ES) approach are the baselines algorithms in most of the popular evolutionary algorithms (EA) (Deb, 2001). Figure 2.3 depicts the working principle of genetic algorithms, including the most important operators like reproduction, crossover, and mutation.

The initial formulations of GA, ES, EP and GP considered their application to unconstrained problems. Although most research on EAs continuous to consider unconstrained problems, a variety of methods have been proposed for handling constraints.

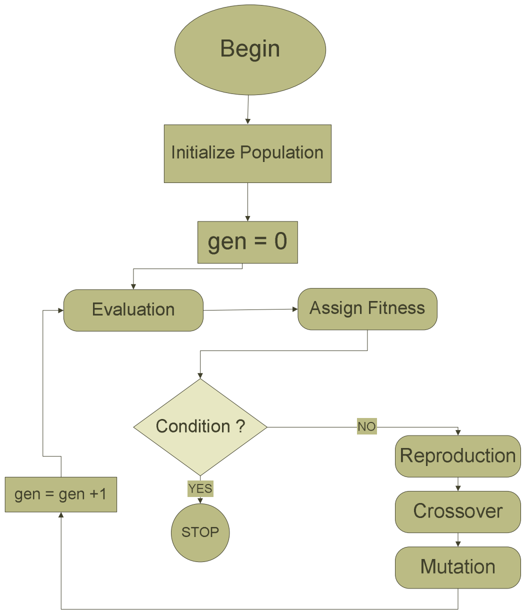


Figure 2.3. Genetic algorithm working principle flow chart

2.5.3 Uncertainty in multiobjective linear programming (MOLP)

In many modeling situations it is unreasonable to assume that the coefficients or functions in optimization problems are deterministically fixed values. Most real-world situations are characterized by an inexistent or scarse data, difficult to obtain or estimate or sometimes the system is subject to changes. All of this combinations create uncertainty in the analyzed system and deterministic optimization techniques are not sufficient to model uncertainties sources associated to variation in model parameters.

There are several approaches to tackle uncertainty in mathematical programming models and in most of them uncertainty is directly related to coefficients of decision support models. Fuzzy multiobjective optimization, stochastic multiobjective optimization, and multiobjective linear programming with interval coefficents are some approaches (Oliveira and Henggeler, 2006).

In fuzzy multiobjective optimization is important to define a so called *membership function* that simulates a possibilistic distribution in variable coefficients. Probability distributions are needed for the stochastic based approach and finally in linear programming with interval coeffcients only a range of variation of the parameters is needed (Oliveira and Henggeler, 2006).

2.5.3.1 Fuzzy Multiobjective Optimization

In real world problems, sometimes the uncertainty in the variables and parameters of a model play an important role in decision making. Fuzzy set theory is used in those cases and it is a field of the mathematics that enables one to model systems that involve non-quantitative human reason, perception and interpretation (Marler, 2005)

With fuzzy multiobjective optimization, objectives and constraints are treated equivalently. The membership function concept is used to model the objectives and constraints an it is developed based on the experience and insigth of the user.

Fuzzy sets theory is thus identified as an alternative approach to handle vagueness associated with planning objectives and impreciseness involved in the parameter values, where deterministic models are not sufficient to model that kind of conditions.

2.5.3.2 Multiobjective linear stochastic programming

Forty-five years ago, stochastic programming was set up independently by Beale, Dantzig, Charnes and Cooper, and others who observed that for many linear programs to be solved, the values of the presumably known coefficients were not available. They suggested replacing the deterministic view by a stochastic one assuming that these unknown coefficients or parameters are random and their probability distribution P is known and independent of the decision variables (Dupaková, 2002).

The above mentioned fuzzy multiobjective approach uses possibilistic distributions to tackle uncertainty in mathematical programming models. A probalistic approach incorporates probability distributions to describe variability or lack of information in variables, but this approach requires adequate information to define the best selection in the probability distribution.

In practice, complete knowledge of the probability distribution is rare and using this assumption we could introduce a new type of uncertainty which concerns the probability distribution (Dupaková, 2005). Probability distribution function (pdf) requires an adequate knowledge of analyzed variables and is the starting point to avoid mistakes that may lead to bad, costly decisions.

Several approaches have been proposed to solve the stochastic programming. Two main categories are found in the literature (Croicu, 2005). In the first methods called “one-stage programming”, the decision has to be taken in advance of any information about the randomness; other than the probability distribution. Second class is the namely “recourse approach” or so-called “two stages programming” that permits improvements after the random events have presented themselves (Croicu, 2005).

The chance constrained approach (CCP) is a solution to the one-stage programming approach and consists in maximizing the expected value of the objectives while respecting a certain degree of feasibility for the random constraints. This approach solves converting into a deterministic the stochastic original problem. Main differences between chance constrained programming and stochastic programming with recourse is that they use different measures for risk (Abdelaziz, 2005).

Another possible stochastic formulation, called robust optimization, recognizes that it may be impossible to determine a solution that is feasible for all scenarios. It forms an optimization problem that minimizes a weighted sum of cost and infeasibility (Croicu, 2005).

2.5.3.3 Multiobjective linear programming with interval coefficients

Interval programming is another one of the approaches to tackle uncertainty in mathematical programming models. This approach possesses some interesting characteristics because it does not require the specification or the assumption of probabilistic distributions (as in stochastic programming) or possibilistic distributions (as in fuzzy multiobjective programming). Interval programming just assumes that information about the range of variation of some (or all) of the parameters is available, which allows to specify a model with interval coefficients (Oliveira and Henggeler, 2007).

This approach includes algorithms dealing with uncertainty in the objective functions, others handle uncertainty in both the objective functions and the rigth hand side (RHS) of the constraints and some algorithms include uncertainty in all the coefficients of the model.

Two different approaches were considered by Inuiguchi and Kume (1994) to solve the multiobjective linear programming with interval coeffcients optimization problem. The first one called "satisficing approach" consist of a transformation in each objective function. Lower bound, upper bound, and the central value of the intervals are used in order to obtain a compromise solution. The second approach called "optimizing approach" extends the concept of efficiency used in traditional MOLP to the interval objective function and two kinds of efficient solutions are suggested, one called ‘‘necessarily efficient’’ if it is efficient for any given objective function coefficient vectors within their admissible range of variation and the second solution is said ‘‘possibly efficient’’ if it is efficient for at least one of the given objective function coefficient vectors within their admissible range of variation (Inuiguchi and Kume, 1991).

2.5.4 Multi-Objective Optimization Applied to Water Resources

Many research programs in the field of water resources and system planning have focused on the goal that pursues the sustainable land development, water resources conservation, and water quality management by using deterministic multi-objective programming techniques (Chang *et al.*, 1995). Goicoechea and Duckstein in 1976 illustrated the use of multi-objective programming models in a watershed land management project without considering environmental factors. Van and Nijkamp in the same year presented a multi-objective decision model for optimizing regional development, environmental quality control and industrial land use. Das and Haimes (1979), applied multi-objective optimization techniques in a river basin planning project. Two broad based planning objectives considered in their project are: economic development and environmental quality. Both impacts of point and nonpoint source pollutants on water quality were evaluated in its various land management scenarios. Later Ridgley and Giambelluca (1992) applied a water balance simulation model for calculating groundwater recharge as it varies with land use in a multi-objective programming framework.

Beck explained that the random character of the natural processes governing water resources, the estimation errors in parameters of water quality models, and the vagueness of planning objectives and constraints are all possible sources of uncertainty (Beck, 1987).

Chang in 1995 and 1997 incorporated the uncertainty in the analysis using a fuzzy multi-objective approach. (Chang *et al.*, 1995; and Chang *et al.*, 1997).

2.6 LAND ALLOCATION ANALYSIS AND GIS MODELING

Results obtained from a multi-objective optimization approach, that specifies the future growth of a particular land use according with several constraints, can be implemented with a spatial tool that allows to find and recommend specific location of the future amount of each land use based on spatial criterias like the terrain slope, available infraestructure, existing land use, conversion preference, etc. Both analysis can be a part of an integrated methodology for land and load allocation procedure. Load allocation is the part of a TMDL water quality restoration plan that assigns reductions to meet identified targets. The load may be divided by land use (rangeland, cropland), or activity (construction, timber harvest) or assigned to subwatersheds or tributaries.

The relative cost of achieving reduction targets may be greater for some contributors than others. State law requires Environmental Quality Agencies to consider “the environmental, social, and economic costs and benefits” of implementing a TMDL water quality restoration plan.

Geographical Information Systems (GIS) are defined as a set of tools for collecting, storing, retrieving at will, transforming and displaying spatial data from the real world for a particular set of purposes (Burrough, 1986). From it early days, GIS has been used extensively in many fields and it is considered a decision support system by many researchers, among them Densham and Rushton (1998). Coupling GIS with other general and analytical models has great potential to expand the decision support capabilities of GIS.

The incorporation of analytical models into geographic information systems (GIS) has emerged as a promising research area attracting planners and other resources managers (Wang *et al.*, 2004). Bennett (1997); Djokic and Maidment (1993), and Greene (1996) are examples of land allocation models that assign loads to land use.

Expert systems or mathematical models are decision support tools used in the called Decision Support Systems (DSSs) land use planning models. The mathemathical models most commonly applied in land use allocation systems correspond to multi-criteria evaluation techniques, mathematical programming applications or spatial simulation models (Santé et. al, 2006)

Mathematical programming, when applied to land use planning, seeks the combination of land uses that optimizes one or more objective functions subject to a series of constraints and this is the reason why some land allocation systems are supported by an optimization analysis that recommends the ranges of land use by sub-area at the end of the study period.

However, spatial units applied in the optimization modeling are not detailed enough to implement the optimal land use changes. In this respect, a GIS based land allocation model is developed to recommend strategies for implementing the optimization modeling results.

Linear programming models allow decision makers to translate spatially their results into a map of optimum land use allocation. Aerts et al. (2003) present the results from minimize the development cost of a land use plan and to maximize the compactness of areas with the same use.

Wang et al. (2004) used a land allocation system based on GIS approach and as a part of an integrated system containning two parts, a optimization analysis and complemented with the refered land allocation interfase.

In-Young Yeo (2005) developed a multistage hierarchical optimization for the land use allocation to control non point source water pollution at a high level of spatial resolution (30 m per cell). The methodology was applied to the Old Woman Creek watershed, located in the southwestern basin of Lake Erie (Ohio). They illustrated how the non point source of pollution (NPS) levels can be reduced by changing the spatial configuration of land uses in a watershed (In Young *et al.*, 2005).

2.7 WATER QUALITY RESEARCH IN PUERTO RICO

Puerto Rico, the fourth largest island in the Caribbean Sea is actually one of the most densely populated territories of the world (1,112 people / Km^2) (U.S. Census Bureau, 2000). Conditions in the island including abruptly topography, high precipitation, short distances between central mountains to coastal areas and typically tropic zones conditions are very important conditions to evaluate in terms of hydrologic and water quality issues.

Additionally, rapid land use changes over the last century with conversion tendencies to urban built-up areas and heavy environmental regulations constitute a set of ideal conditions to researchers in terms of water quality issues. About regulations, Puerto Rico as commonwealth of the United States of America is in the process to implement the Total Maximum Daily Loads (TMDL's) program proposed by the Environmental Protection Agency (EPA) to achieve water quality standards in impaired waters. In this sense Puerto Rico has 68% of waters impaired for aquatic life and 77% for swimming activities (PREQB, 2002).

Different works in the last 20 years were done taking into account water quality issues, associated to nutrients and sediment exportation from land uses and water quality evaluations. Ortiz-Zayas et al. (2006) evaluated the urban influences on the nitrogen cycle in Puerto Rico. Nitrogen yield calculations were conducted in several watersheds of different anthropogenic influences. Results obtained reveal that disturbed watersheds export more nutrient loads than undisturbed areas, associated mainly to land use and mean annual runoff. Ortiz-Zayas concluded in this work about the need of more comprehensive measurements to a better description in the local nitrogen cycle (Ortiz et al., 2006).

In the same research line, McDowell quantify the export of suspended sediments, dissolved and particulate carbon and nitrogen, dissolved nitrogen and phosphorus and major cations and anions from three montane tropical rainforest watersheds in Puerto Rico. It considered different characteristics, including: size, elevation, soil, slope, vegetation and, runoff to assess the variability in the output results (McDowell et al., 1994, 1995).

In terms of nutrients export coefficients, Ramos-Ginés (1998) conducted a research for Total Nitrogen (TN) and Total Phosphorus (TP) in the Lago de Cidra in central Puerto Rico, taking into account the land use effect in the estimates. Fourteen data collection sites were included to monitor rainfall, surface runoff, reservoir stage, water quality, and reservoir withdrawals during a one year period. Storm runoff events carrying a lot of suspended sediments, were included in this research. One important contribution in this study was the quantification of land use export coefficients for several land uses in the area (Ramos-Ginés, 1998).

Corvera-Gomringer in 2005 quantified the concentration and discharges of Total Kjeldahl Nitrogen (TKN), total and dissolved phosphorus (TP and DP) and total suspended sediments (TSS) during storm events in Río Grande de Añasco watershed in the western Puerto Rico area (Corvera, 2005).

Sotomayor-Ramírez summarized TP concentration, historical trends, and relationships between biological and chemical parameters in eleven rivers of Puerto Rico, during 1989 through 1997. It was found that four rivers had median TP concentration in excess of 0.1 mg/L which is considered a threshold limit for eutrophication. It was found that many surface bodies of Puerto Rico exceed the TP concentration limit proposed by the EPA for rivers (0.1 mg/L) and lakes (0.05 mg/L) (Sotomayor et al., 2001)

In 2005 Martínez reported the obtained results in the determination of nutrient criteria for lakes and reservoirs of Puerto Rico. The objective of the study was to establish a reference condition that could serve as the framework of numeric criteria for nutrients. Water quality parameters included were total kjeldahl nitrogen (TKN), TP and chlorophyll a (chl a). Some of the results showed an eutrophic group according to the trophic state index approach (TSI) for TP. Reservoirs ranked in the eutrophic group includes Lago Caonillas, Cidra, Curias, Guayabal, Guayo, Guineo, La Plata, Loco, Luchetti, Melania, Dos Bocas and Toa Vaca (Martínez et al., 2005).

In 2006, and as a continuation of the determination nutrient criteria study in lakes and reservoirs, a progress report about the same topic but in rivers and streams of Puerto Rico was presented by the Martínez research group. Objectives of the work included a review of historical data of rivers and its tributaries to develop the framework for establishment of reference conditions, establish the chemical status of known impacted rivers and characterize the nutritional status of reference rivers minimally impacted by human activities (Martínez et al., 2006)

Two research works using HSPF were done in Puerto Rico in the last five years, representing the first efforts of implementing this EPA endorsed model for TMDL development. Díaz was the first one doing a hydrologic and sediment simulation (calibration and validation) in Caonillas watershed, a part of the Río Grande de Arecibo watershed. Results show the effect of extreme hydrologic conditions in sediment transport and simulation processes. Hurricanes Hortensia and Georges produced 24 % and 58.5 % of the total sediment load (1,348,041 tons) in a three year validation period (Díaz, 2004).

Suárez in 2005 studied the sediment export coefficient for different sub watersheds and land uses in the Río Grande de Arecibo watershed. It was found sediment export coefficient for agricultural, forest, urban, rangeland and barrenland in the area. The suspended sediment loads were estimated for Lake Caonillas (9.7 x 10^6 metric tons) and Lake Dos Bocas (15.9 x 10^6 metric tons) in the simulated period (Suárez, 2005).

CHAPTER III

DESCRIPTION OF STUDY AREA

3.1 PHYSYCAL AND GEOGRAPHIC CHARACTERISTICS

The upper Río Grande de Arecibo (RGA) watershed study area is located in north central Puerto Rico, confined within latitudes 18°11’ and 18°20’ N and longitudes 66°32’ and 66°46’ W. RGA drains approximately 451 Km^2 (45,000 ha) at the Lago Dos Bocas, the watershed outlet point (Figure 3.1).

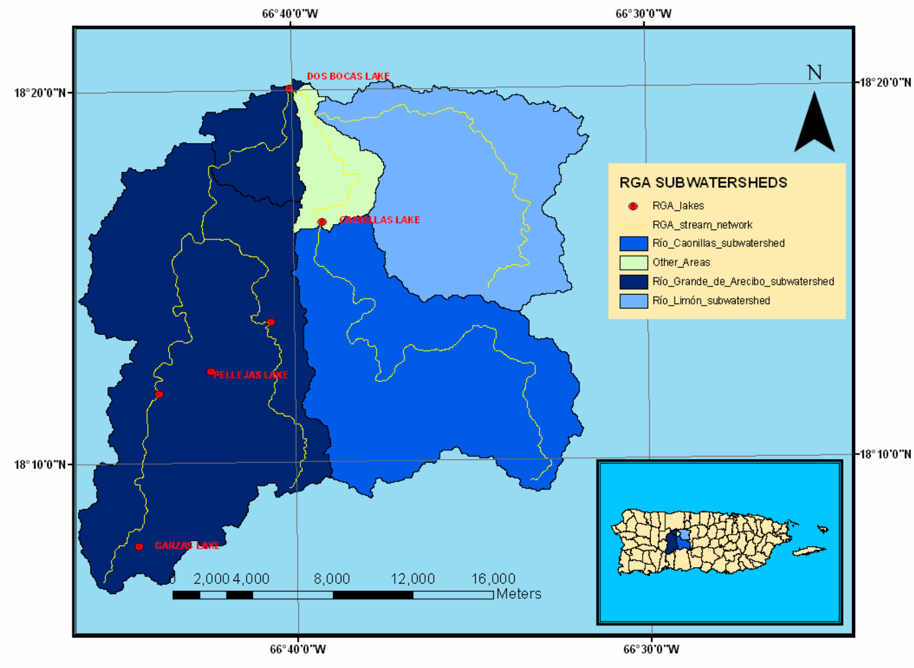


Figure 3.1. Río Grande de Arecibo study area

The study area has a mean basin slope of 36% and average annual precipitation of 2,235 mm (88 in). Elevation in the area ranges from 99.6 meters above mean sea level at Lago

Dos Bocas to 1,338 meters, the highest point of the watershed and Puerto Rico (Cerro Punta).

For analysis purposes the total watershed was divided into three sub-watersheds (Figure 3.1); Caonillas, Limón and Río Grande de Arecibo sub-watersheds corresponding to the three main drainage systems in the area. Table 3.1 summarizes the hydro-geomorphologic characteristics of these three sub-watersheds.

Table 3.1. Sub-watersheds hydro-geomorphologic characteristics.

Sub-watershed	Drainage Area (Km^2)	Average land slope (m/m)	Mean Elevation above mean sea level (m)	Mean annual precipitation (mm)*	Mean Annual flow** (m^3/s)
Río Grande de Arecibo	186.43	0.341	501.1	1,948	5.30
Río Caonillas	123.80	0.372	691.5	1,476	2.90
Río Limón	93.86	0.336	450.9	2,125	2.71

*, ** Data obtained from USGS data base. Data computed for RGA and Limón from 2000-2005 and Caonillas from 1996-2005.

The majority land use in the watershed is classified as forest land (76.6%), rangeland (12.7%), agricultural land (6.2%), urban or built-up (3.07%). Pasture and Barren land are minor categories in the area.

Two soils series, Humatas and Pellejas, add up to 41 % of total soils, becoming the main classes in the RGA watershed (USDA, 1982). These soils are deep, very steep and well to excessively drainage conditions. For Humatas clay, the permeability and available water capacity is moderate, runoff is very rapid and fertility is medium. In Pellejas case permeability is moderate in the upper layers and rapid in the lower, water capacity is moderate, runoff is rapid and fertility is low to medium (USDA, 1982). Figure 3.2 depicts the main soil classes in the RGA watershed.

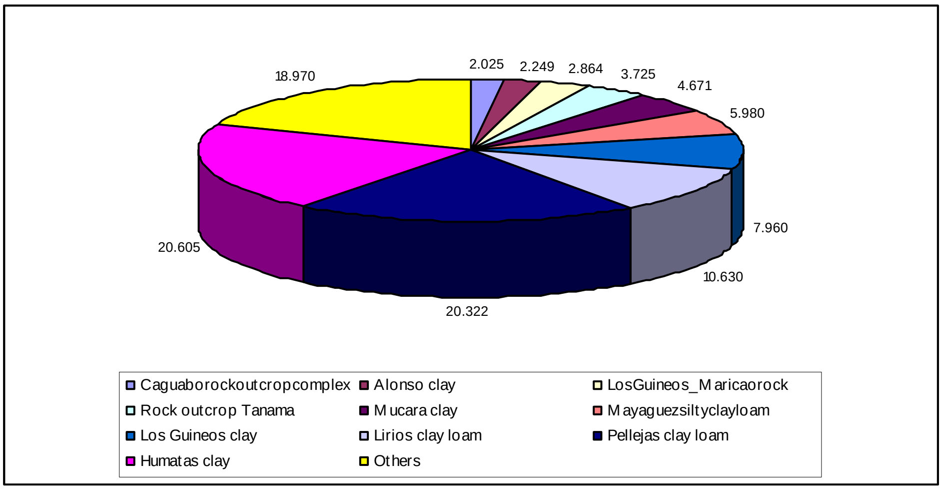


Figure 3.2. Main soil classes in the RGA watershed

The climate in the study area is subtropical, with high elevation, and cool temperatures year round, with cold nights in the winter. Winter average low temperature is 12°C in the towns and 10°C in the forest areas. Summer is warm (27°-29°C) in the daytime and cool at nighttime (15°-17°C).

3.2 SOCIO-ECONOMIC CHARACTERISTICS OF THE STUDY AREA

Municipalities within the Río Grande de Arecibo (RGA) watershed belong to Puerto Rico Central Region (CR) as enacted by the Puerto Rico Planning Board (PRPB, 2002). The study area included municipalities of Jayuya, Adjuntas, Utuado and Ciales. Although Jayuya is the only municipality totally within the RGA watershed perimeters, Adjuntas and Utuado have about half of its boundaries within the study area.

According to the last Poblational and Housing Census of 2000, territorial extension, population and poblational density are summarized in Table 3.2. (www.census.gov/census2000/states/pr.html).

Table 3.2 Territorial extension, population and poblational density in RGA municipalities

Municipality	Total Area (Km^2)	Total Water Area (Km^2)	Total Land Area (Km^2)	Population (2)	Density (Population /Km^2) (2)	% Area(1) Inside RGA
Adjuntas	173.81	1.09	172.72	19,143	110.83	48.4
Ciales	173.04	0.44	172.60	19,811	114.78	18.21
Jayuya	115.49	0.00	115.49	17,318	149.96	99.5
Utuado	297.82	4.01	293.81	35,336	120.27	71.54
TOTAL	**760.16**	**5.54**	**754.62**	**91,608**	**121.40***	
CentralRegion	2,025.84	14.89	2,010.94	384,946	191.43	
Puerto Rico	13,790.39	4,920.82	8,869.57	3,808,610	429.40	

*average value;
(1) Based on Total Land Area column.
(2) U.S. Census Bureau 2000 (www.census.gov/census2000/states/pr.html).

Territorial extension of municipalities within RGA area corresponds to a 5.51% of the total extension of the Island. Puerto Rico Census (2000) established a population of 91,608 habitants corresponding to a 2.41% of the total in the island and average density of 121 population / Km^2. Figure 3.3 depicts the municipalities and the percent of extension contained within the RGA study area.

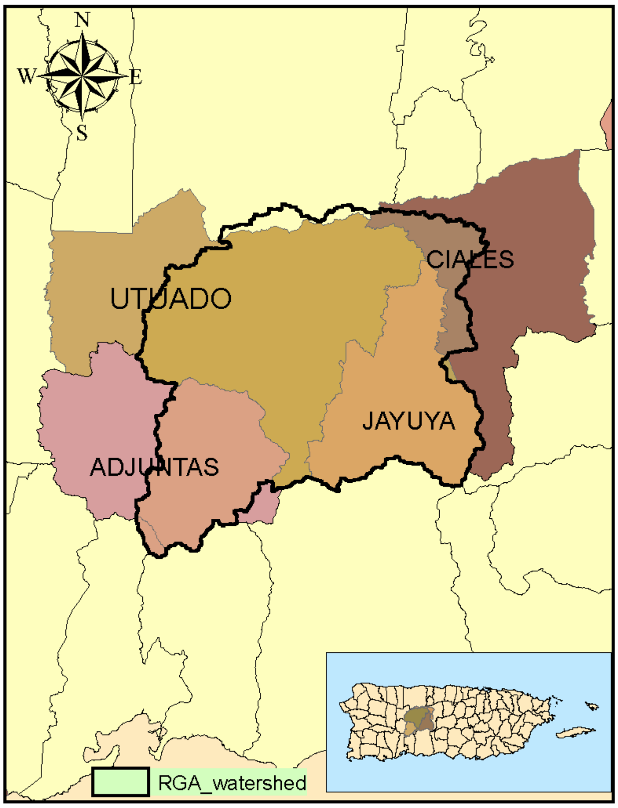


Figure 3.3. Municipalities within the RGA watershed

Table 3.3 shows the breakdown as to urban and rural population in the four municipalities contained in the watershed limits, based on data from the 2000 Census for Puerto Rico.

Table 3.3 Urban and rural population distribution in RGA municipalities

Municipality	Total Population (1)	Population Inside RGA(2)	Urban Population	% Urban Population	Rural Population	% Rural Population
Adjuntas	19,143	9,265	10,934	57.1	8,209	42.9
Ciales	19,811	3,608	14,374	72.6	5,437	27.4
Jayuya	17,318	17,318	11,400	65.8	5,918	34.2
Utuado	35,336	25,279	23,500	66.5	11,836	33.5

(1) Total population d by municipality according Census 2000 (U.S. Census Bureau 2000; www.census.gov/census2000/states/pr.html).

(2) Partial municipality population inside the RGA watershed.

The population in the municipalities was predominantly rural in the 50's and 60's. Nevertheless, urban population kept on growing consistently until the 80's. Table 3.3 shows a dramatically change in tendency, with almost a complete urban rather than rural population due to changes in the definition and criteria defining those areas.

Population projections are useful for planning and decision making. Table 3.4 summarizes data census between 1970 and 2000 and forecasts the population for 2010 and 2020 based on previous years.

Table 3.4 Population between 1970 to 2000 and projections for 2010 and 2020 in RGA watershed

Municipality	1970	1980	1990	2000	2010	2020
Adjuntas	18,691	18,786	19,451	19,143	19,164	19,073
Ciales	15,595	16,211	18,084	19,811	21,035	22,007
Jayuya	13,588	14,722	15,527	17,318	18,598	19,624
Utuado	35,494	34,505	34,980	35,336	35,938	36,166

In 2005, the PRPB prepared a report containing population projections for the municipalities of Puerto Rico. Figure 3.4 shows the historical data and projections for 2025 in the RGA municipalities.

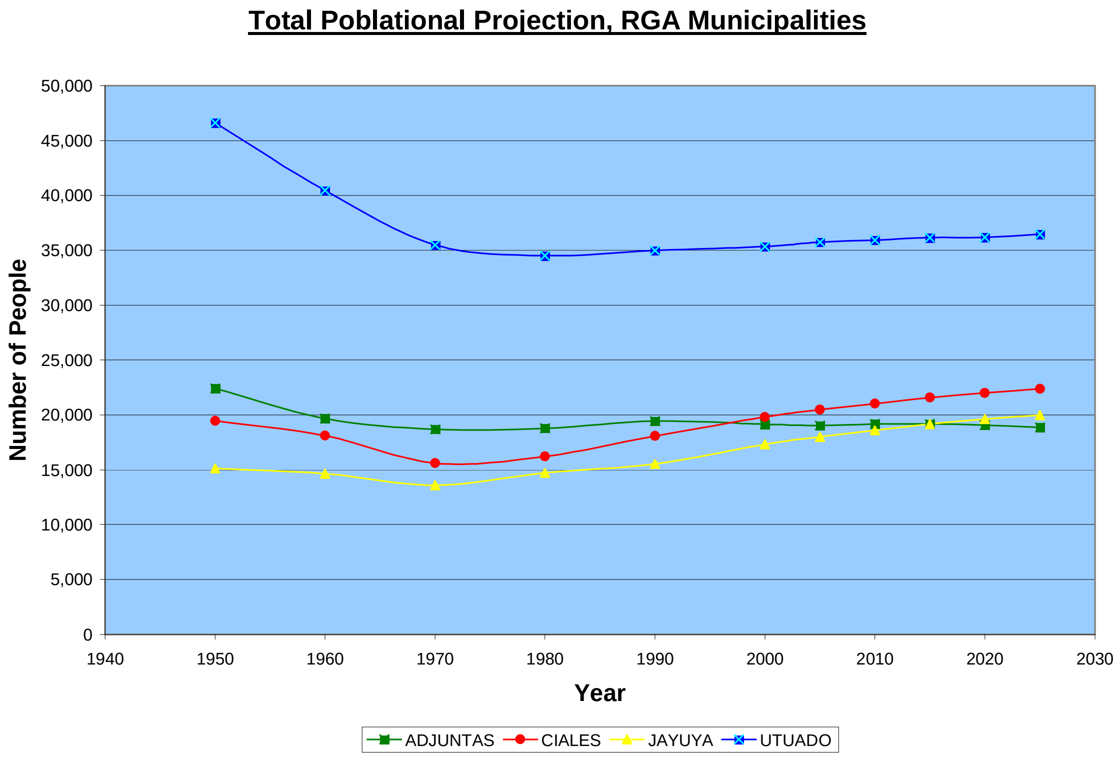


Figure 3.4. Historical and future projection population in RGA municipalities

Population projections as well as housing demand are important variables to estimate the planned growth in an area along with the socio economic requirements. There is a direct positive correlation between population and housing, therefore the estimated housing growth of the municipalities within the RGA watershed until 2009 is shown on Table 3.5.

Table 3.5 Actual and projected housing demand until 2009 in RGA municipalities

Municipality	Actual housing	Housing units number Social interest demand	Without subsidy	Total* housing demand
Adjuntas	6,715	317	149	466
Ciales	6,886	312	166	478
Jayuya	5,591	247	155	402
Utuado	12,471	592	295	887

* Source: PRPB, 2006.

In relation to the economy of the zone, the unemployment in the Central Region (CR) is around 23,847 people unemployed, meaning a rate of 24.6 % versus 19.2% for Puerto Rico as a whole. Jayuya (31.1%) is the municipality contained in the RGA watershed with the highest unemployment rate reported in 2000 followed by Adjuntas (30.9%), Utuado (30.0%) and Ciales (23.7%).

Associated to unemployment in the municipalities, the rate of participation at the Central Region shows a decrease between 1990 and 2000. Increment in the groups of sixteen years old and more, increase in the civil working group and decrease in the unemployment rate are some causes of decrease in the rate of participation (PRPB, 2006).

Agriculture is the main economic activity in the study area and coffee is one of the most important crops cultivated in the RGA municipalities. According to the 2002 USDA Agricultural Census, Utuado is the third largest coffee producer in Puerto Rico. Crops such as bananas, oranges and plantains are also predominant in the area. It has also been successful with livestock and pigs. Industrially, Utuado counts with a few companies that produce textiles, paper and stone and Jayuya has the Baxter Healthcare Corporation.

3.3 ANALYSIS OF SYSTEM DATA AND HEALTH OF RIVERS AND LAKES

The review of available historical data is an important step for a detailed analysis of the system. This analysis together with the assessment of data can help identify the major environmental problem in the study area and emphasized it in the modeling purpose and post processing analysis. Aspects such as spatial patterns in the monitored data can help determine how many subwatersheds are necessary to divide the entire study area to capture those spatial variations. This section presents an inspection and assessment through the years of water quality data in order to obtain an overview of the system and its needs.

The majority of data available and included in this assessment was compiled based on queries from the U.S. Geological Survey (USGS) at four stations in the RGA watershed as shown in Figure 3.5 and for normal flow conditions (no extreme events were monitored). Data from 1995 to 2005 was used for calibration and validation purposes in the HSPF water quality simulation.

Assessment parameter includes, NO_3^-, TP, $NH_3^+ + NH_4^+$ and DO. A water quality standard is given by the Puerto Rico Environmental Quality Board (PREQB, 2003) and a new proposed regulation based on the National Nutrient Criteria Program requirements from the EPA is given by Martínez in 2006 (Martínez et.al,2006). Observed and water quality standards were compared as an indicator of potential water quality problems. This analysis allows us to understand the existent and historical conditions in the Río Grande de Arecibo watershed.

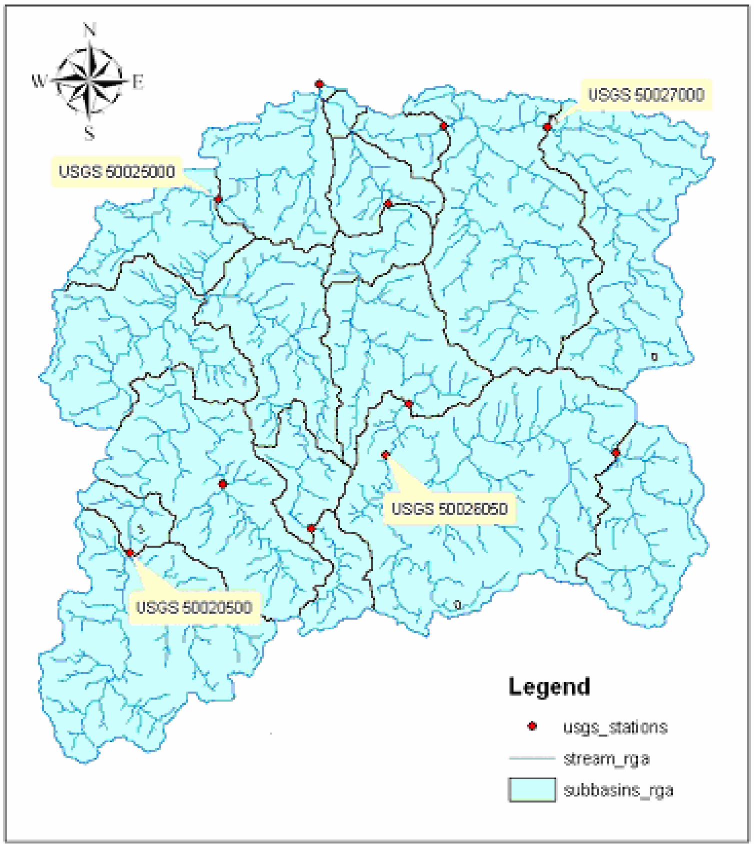


Figure 3.5. USGS Water quality stations, RGA watershed.

3.3.1 Water quality parameters assessment

Table 3.6 summarizes the water quality limits in rivers and streams in Puerto Rico given by the PREQB in 2002 and for surface waters classified as SD and intended for use as a raw source of public water supply, propagation and preservation of desirable species as well as primary and secondary contact recreation. A new proposed regulation is also included in this table.

Table 3.6 Water quality target level

Water quality parameter	Units	PREQB[1] Target Level	Proposed new regulation[2]
Dissolved Oxygen (DO)	mg/l	>5.0	ND
Fecal coliforms	Colonies/100 ml of fecal coliforms	200*	ND
Total Dissolved Solids (TDS)	mg/l	<500	ND
Total Phosphorus (TP)	mg/l as P	< 1	< 0.05
Total Nitrogen (TN)	mg/l as N	ND	< 1
Total Amonnia (TAM)	mg/l as N	< 1	ND

ND: No determined
[1] PREQB, 2003; [2] Martínez et al., 2006
* A geometric mean of at least 5 consecutives samples.

3.3.1.1 Assessment of the water temperature (WT)

Water temperature in rivers and streams is an important physical parameter in water quality simulation due to the direct interaction with other parameters like the dissolved oxygen (DO) (Figures 3.6 to 3.8). Water temperature affects rates of other quality processes and is a critical habitat characteristic for fish and other organisms (Donigian, 2002).

In terms of habitat, tropical watersheds have advantages due to the natural warm temperatures in water bodies. Monitored rivers within the RGA watershed shows a cycle in water temperature parameter with a low decrease between October to February and an increase between June to September coinciding with the winter and summer seasons in the island. The ranges of temperature oscillate between 21ºC to 33ºC (70ºF to 91ºF approximately).

3.3.1.2 Assessment of the dissolved oxygen (DO)

The dissolved oxygen (DO) monitored at the RGA stations has concentrations surpassing the 5 mg/l threshold established by the PREQB regulation. Topography in the study area plays an important role in the high values of DO observed because the aeration due to water circulation at considerable slopes dominates the process.

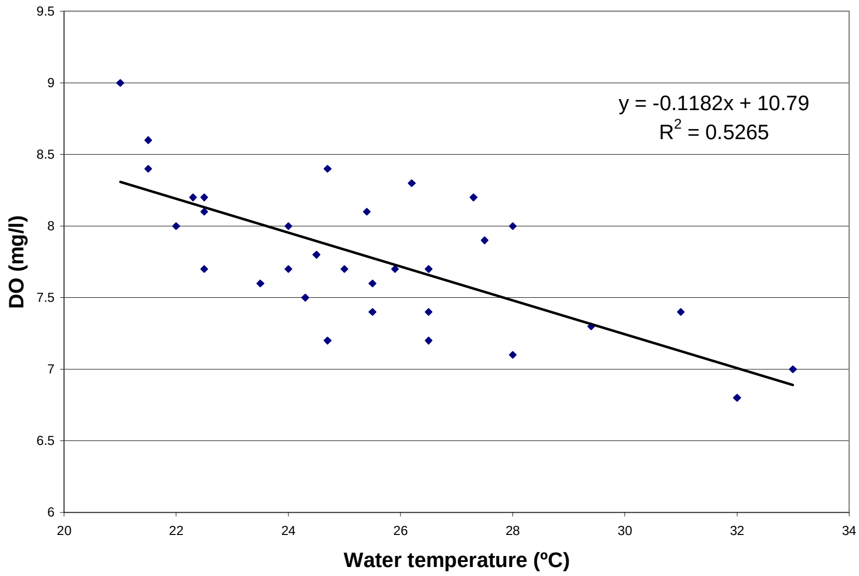


Figure 3.6. DO vs water temperature regression analysis. Río Grande de Arecibo near Utuado; USGS 50025000 (1995-2002)

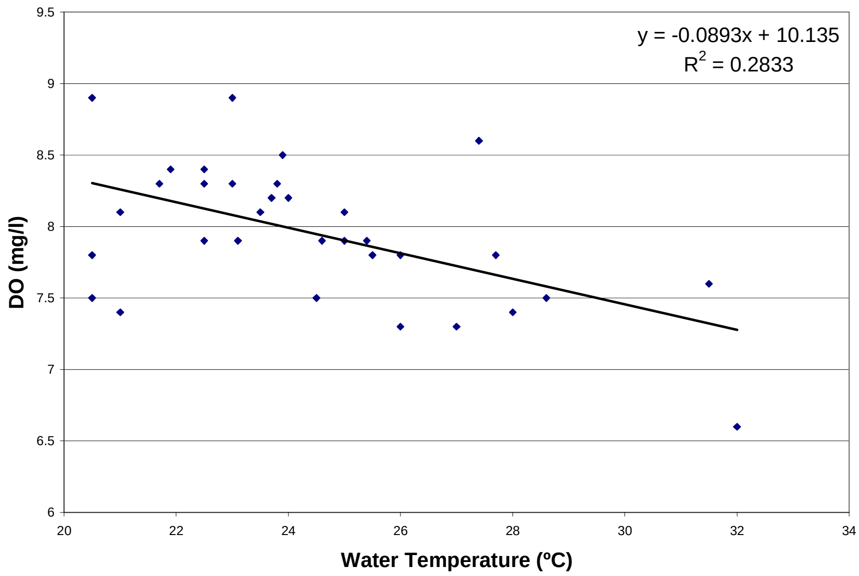


Figure 3.7. DO vs water temperature regression analysis. Río Caonillas above Lago Caonillas; USGS 50026050 (1995-2002)

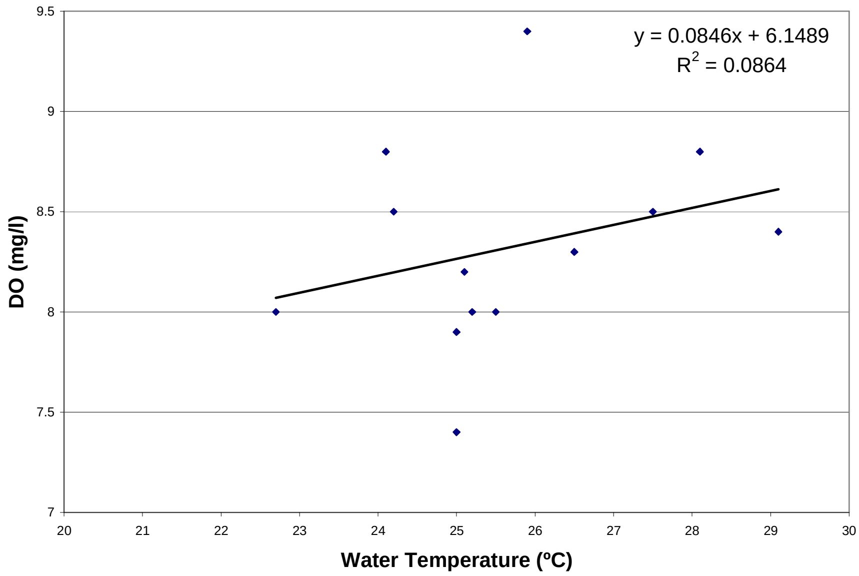


Figure 3.8. DO vs water temperature regression analysis. Río Limón above Lago Dos Bocas; USGS 50027000 (2000-2004)

Figures 3.6 and 3.7 show an inverse correlation between water temperature and dissolved oxygen in the USGS Río Grande de Arecibo station near Utuado and Río Caonillas above Lago Caonillas. The scarcity of data in the USGS 50027000 station is most likely producing a non usual positive correlation between those two parameters as shown in Figure 3.8. Additionally, low R^2 value in the USGS 50026050 station can be attributed to the influence from urban areas discharging near to this water quality station and tending to consume the available dissolved oxygen.

3.3.1.3 Assessment of the total phosphorus (TP)

The majority of the data in the USGS stations had concentrations below the regulatory value established by the PREQB. Comparing this historical data to the new proposed limits given by the Numeric Nutrient Criteria protocol from EPA (Martínez et al., 2006), a lot of points are outside the new environmental limit concerning TP and ammonia species.

Figures 3.9 to 3.11 show the TP historical data from 1979 to 2004 in the USGS stations. It is important to notice that under the new stricter proposed regulation, an average of 85% of the sampled data does not met the scientific based standard for good water quality conditions in rivers and streams.

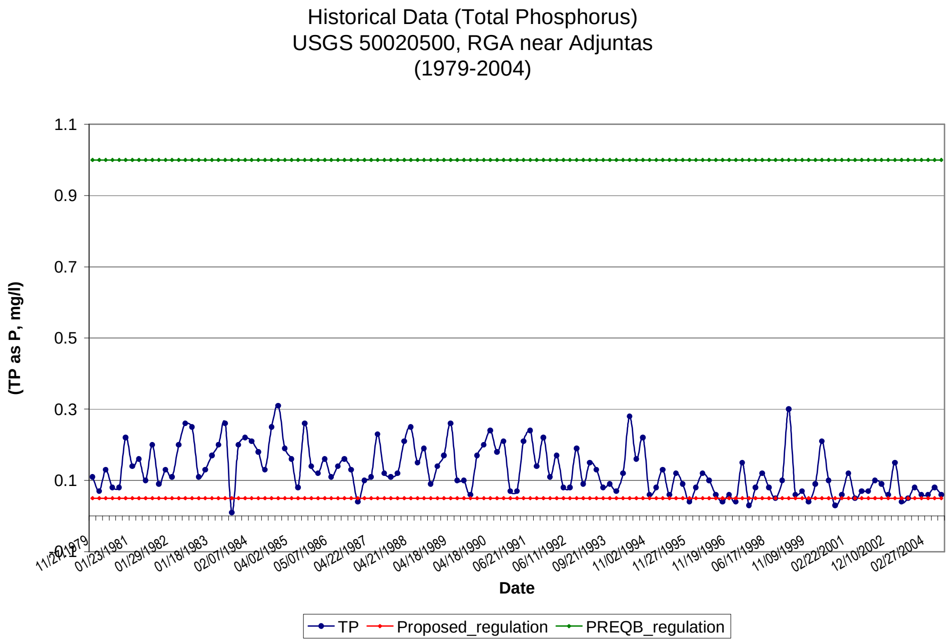


Figure 3.9. Historical TP data vs actual and proposed regulations, USGS 50020500

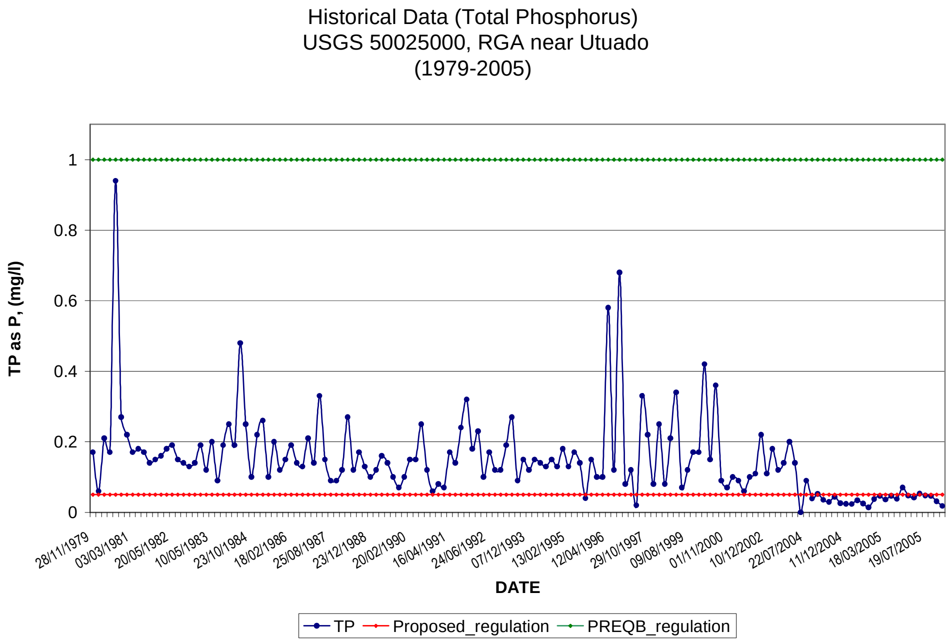


Figure 3.10. Historical TP data vs actual and proposed regulations, USGS 50025000

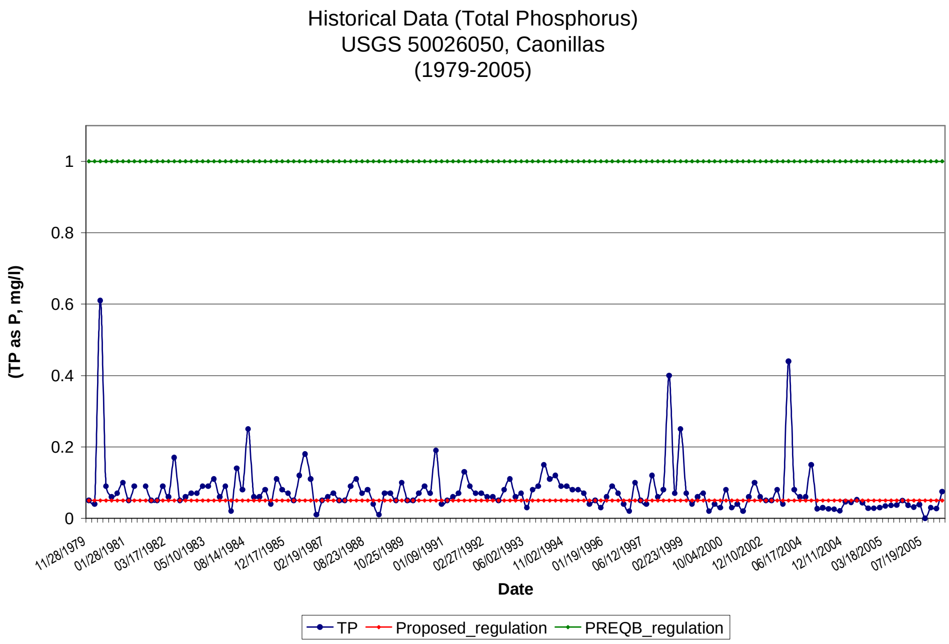


Figure 3.11. Historical TP data vs actual and proposed regulations, USGS 50026050

3.3.1.4 Assessment of the total ammonia ($NH_3 + NH_4^+$) and nitrates (NO_3^-)

Although the actual standard only considers Total Ammonia (TAM) as regulated nitrogen specie, the proposed new regulation takes into account the Total Nitrogen (TN) defined as the sum of total ammonia, total nitrates and organic nitrogen. In terms of TAM concentrations (mg/l), all the available historical data meets the actual PREQB regulation of 1 mg/l in rivers classified as SD.

In all cases, the major component of the total nitrates is the Nitrate rather than the Nitrites. Comparing concentrations between TAM and Total Nitrates the average ratio is about 1 to 10. Figures 3.12 to 3.14 shows the TAM and Total Nitrates historical data in the USGS stations included in this assessment.

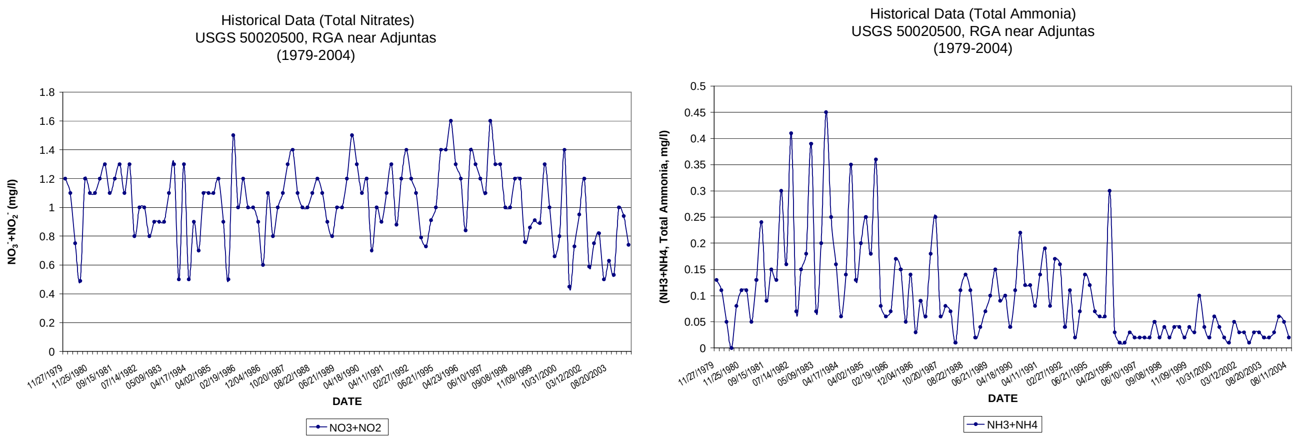
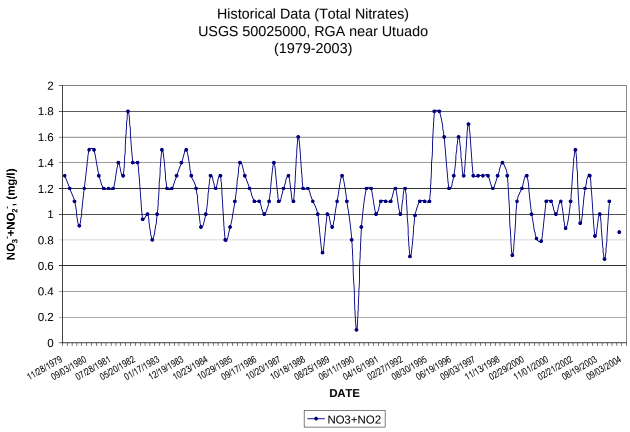


Figure 3.12. Historical Total Nitrates and Total Ammonia. USGS 50020500 station



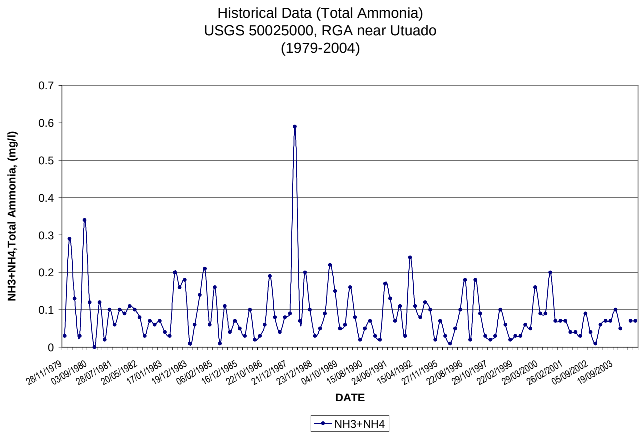
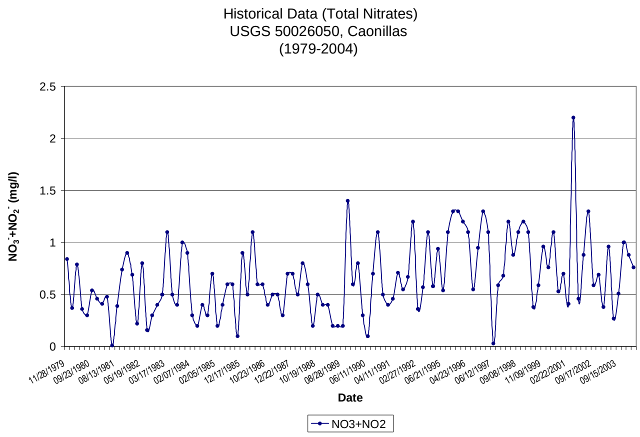


Figure 3.13. Historical Total Nitrates and Total Ammonia. USGS 50025000 station



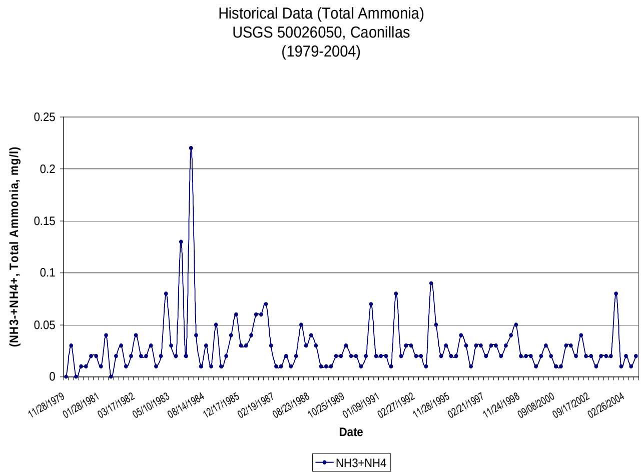


Figure 3.14. Historical Total Nitrates and Total Ammonia. USGS 50026050 station

According with the "Determination of Numeric Nutrient Criteria" (EPA 2000), references conditions are defined as the lower 25th percentile value of the frequency distribution of all available data for specific species. This concept involves rivers with minimal impact from human activities implying minimum pollutant conditions. In Puerto Rico, the developed reference conditions show a value for NO_3^- of 0.42 mg/l. USGS 50020500 and 50025000 stations has a 100 and 99% above this regulation meaning an anthropogenic effect on those sites due to the majority of urban areas (Adjuntas and Utuado municipalities respectively) near to them. USGS 50026050 station has a 68.42% above the regulation that implies a lower urban influence with respect to other stations.

3.3.1.5 Assessment of N/P ratio

Nutrients in water bodies receptors create environmental degradation increasing algae biomass growth. Rivers, streams and eventually lakes and ponds are adversely impacted by nitrogen and phosphorus loadings and produce problems like the eutrophication defined as a condition characterized by an elevated nutritional status. In addition to nutrients, algae growth is limited by light intensity, affecting the photosynthetic rates, species composition and diversity.

Differences in the N/P ratio patterns between streams and lakes are due to various reasons. The velocity in rivers is a predominantly difference between both imposing different constraint on the biogeochemistry phenomena (Sterner, 2001). Other factors like the proximity to the substrate and the available food produce differences among the rivers and lakes N/P ratios.

In this section, the N/P ratios are evaluated in terms of defining the limiting nutrient in the aquatic system. The limiting nutrient is a concept defined as a chemical needed for plant growth but is available in smaller quantities than needed for algae to increase their abundance. The USGS river water quality stations as well as data compiled at the Lago Dos Bocas reservoir were included in the N/P ratio analysis.

To define the limiting nutrient in the USGS stations within the RGA, Chapra in 1997 gave a very useful rule of thumb for rivers and streams based on N/P ratio. A value less than 7.2 suggests that nitrogen is limiting and higher values imply that phosphorus will limit the algae growth. Table 3.7 summarizes the results obtained including the sample size, descriptive statistics and the N/P ratio values. The results obtained indicate that phosphorus is the limiting nutrient in the aquatic system of the RGA watershed.

Table 3.7 Calculated value of N/P ratio at the USGS sampling stations

USGS Station	Sampling size (n)	Mean	Range	Mean N/ Mean P
USGS 50020500	111	12.62	3.80-37.21	10.60
USGS 50025000	111	11.78	0.62-36.09	8.94
USGS 50026025	106	13.53	0.80-37.75	10.91

According to Martínez et al. (2005) a complete monitoring study using the entire reservoir network available in Puerto Rico was used to evaluate the water quality on them and define the reference conditions according to the USEPA Numeric Criteria Guidelines. Nineteen reservoirs were evaluated including the Lago Caonillas and Lago

Dos Bocas within the RGA watershed to find the reference conditions, a first step in the development of the nutrient criteria establishment process (Martínez et al., 2005). At least two points were monitored, one at the entrance (riverine station) and one in the lacustrine zone near to respectively dam, showing differences (95%) in the concentration results obtained with higher nutrient values at entrance.

Table 3.8 shows the statistical results based on the chemicals analyses obtained by Martínez et al., 2005. One of the most important conclusions of this report is the need to control nitrogen and phosphorus loading to lakes of Puerto Rico.

Table 3.8 Chemical analysis summary in reservoirs within the RGA watershed*

Lake	Statistical Parameter	Chlorophyll a (µg/L)	TKN (mg/L)	TP (mg/L)	DOC (mg/L)	TSI (Chl a)	TSI (TP)
Caonillas	Mean	14.71	0.42	0.04	3.05	53.48	55.12
	Median	10.51	0.42	0.04	2.66	53.68	57.34
	25^{th} Percentil	6.13	0.31	0.021	2.27	48.39	48.05
Dos Bocas	Mean	15.54	0.43	0.070	2.87	51.46	60.83
	Median	7.01	0.36	0.050	2.07	49.70	60.55
	25^{th} Percentil	5.57	0.23	0.028	1.45	47.44	51.82

* From Martínez et al., 2005

Unlike the results obtained in the rivers N/P ratio analysis, in lakes and reservoirs the results evidenced that both nutrients were the limiting factors. This conclusion is in contrast with patterns found in temperate rivers, where phosphorus has been also identified as the sole controlling factor to algae growth.

Based on the Trophic State Index (TSI) approach by Carlson in 1977, both reservoirs fall in the eutrophic group (values higher than 50), with respect to the TSI for phosphorus (TSI(TP)), as a basis for a continuum of trophic states of lakes and reservoirs.

3.3.1.6 Point sources pollution

Definition of point sources refers to a direct discharge of pollutants to a waterbody through a discrete conveyance such as a pipe or channel. The National Pollutant Discharge Elimination System (NPDES) program by the U.S Environmental Protection Agency (USEPA) gives the regulation in Puerto Rico for point discharges.

The RGA watershed area has in use twelve NPDES permits corresponding to Utuado, Adjuntas and Jayuya municipalities. Major permits belong to water treatment plants and waste water treatment plants in the area. NPDES were included in the HSPF water quality model as direct inputs to the main reaches in the watershed. Pollutants species considered are the total nitrates as nitrogen ($NO_3^- + NO_2^-$), total ammonia ($NH_3 + NH_4^+$) and TP as phosphorus. Figure 3.15 depicts the positioning of the twelve NPDES point sources within the study area and the respective county.

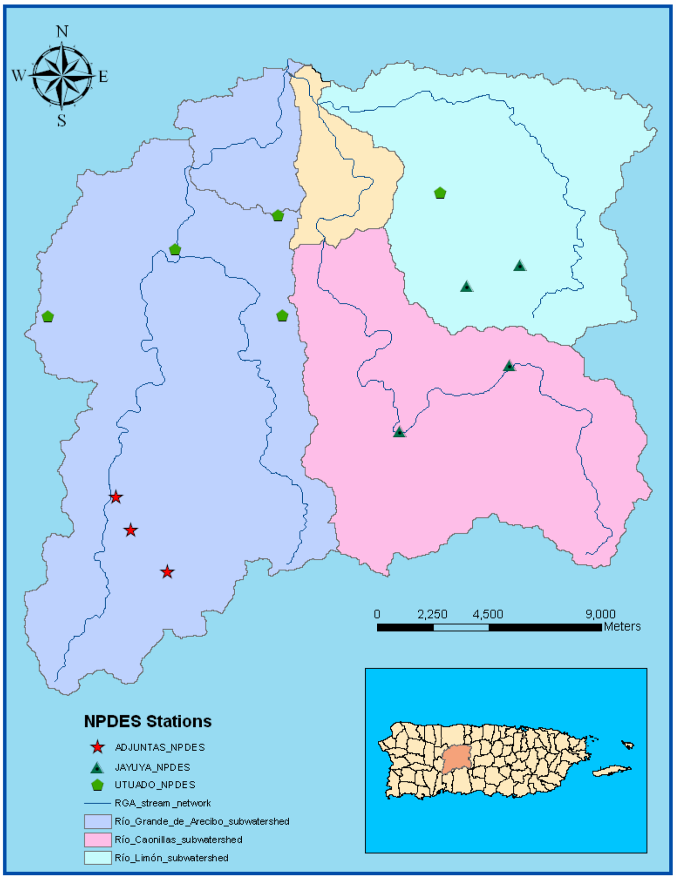


Figure 3.15 Operating NPDES at RGA watershed

CHAPTER IV

WATER QUALITY MODELLING

4.1 ABSTRACT

In this study, a water quality model of the RGA watershed was developed using HSPF to understand and quantify the impact of land use in nutrient and sediment loading into Lago Dos Bocas. From the calibrated and validated water quality model, nutrient and sediment export coefficients were developed and related to land use in the RGA watershed. The water quality watershed model incorporates simulation of pollutant runoff from the land surface and in stream processes. This chapter discusses the non point source simulation, and the required data for model development.

Version 12 of HSPF was utilized as the software for the watershed modeling. HSPF is a part of BASINS 3.1 (USEPA, 2004), a GIS data analysis and modeling system designed to support watershed based analysis and TMDL development. The time period simulation is ten years from 1995 to 2005 year.

This project will provide a planning tool for regulatory environmental agencies in Puerto Rico to develop better watershed management programs and to better understand the behavior of tropical watersheds in an integrated approach.

4.2 METHODOLOGY

The following section details the construction of the hydrologic, sediments and water quality model using HSPF. Different inputs required in the BASINS-HSPF program allows the creation of a User's Control Input (UCI) file that contains all input data, except time series. Data contained in the UCI file includes the parameters values and control specifications. HSPF also uses a meteorological data or time series for the entire simulation period.

Time series in the model were added using the Watershed Data Management Utility (WDM Utility) useful for data manipulation (Aqua Terra Consultants, 2004a). Win_HSPF is an interface used for the UCI file edition and time series handling.

Finally, for model performance evaluation and once the model was set up and running, a model calibration and validation analysis were performed using the Gen Scenarios tool and using the program's guidelines and literature values.

4.2.1 HSPF Model input data

Required data for the continuous water quality simulation using BASINS-HSPF are divided in two groups, first the geospatial data generated by a Geographical Information System (GIS) and hydro meteorological data. Geospatial data are based on different covers including watersheds boundaries, rivers, outlet points, land use and soil maps for hydrological conditions. Hydro-meteorological input data necessary for the study include precipitation, evaporation, solar radiation, air and dew point temperature, cloud cover and wind velocity, all of them hourly for program requirements.

4.2.1.1 Geographical Information System Data

The GIS input data was first created using the program Watershed Modeling System (WMS 6.1) from Brigham Young University (2004). This program was used to create some of the layers required in the GIS database. The layers generated by WMS include, watersheds boundaries, stream network and outlets points. For watershed delineation and characterization, the WMS software use digital elevation models (DEMs).

DEMs were obtained from the U.S. Geological Survey with a grid cell size of 30 m by 30 m. The geodesic horizontal datum is the Universal Transverse Mercator (UTM), North American Datum, 1927. (USGS, 2001)

DEMS included in the model correspond to municipalities of Jayuya, Ciales, Utuado, Adjuntas, Florida and Monte Guilarte. Each sub watershed outlet match the USGS observation point. At the outlet, the study group monitored flow rate, suspended sediment concentrations and water quality. Figure 4.1 shows the watershed boundaries and the border shape file created by WMS and imported into BASINS.

Table 4.1 summarizes some of the main characteristics obtained from the WMS analysis in the three principal sub-watersheds that conforms the entire RGA watershed.

Table 4.1 Sub-watersheds geomorphologic characteristics.

Sub-watershed	Drainage Area (Km^2)	Average land slope (m/m)	Mean Elevation above mean sea level (m)
Río Grande de Arecibo	186.43	0.341	501.1
Río Caonillas	123.80	0.372	691.5
Río Limón	93.86	0.336	450.9

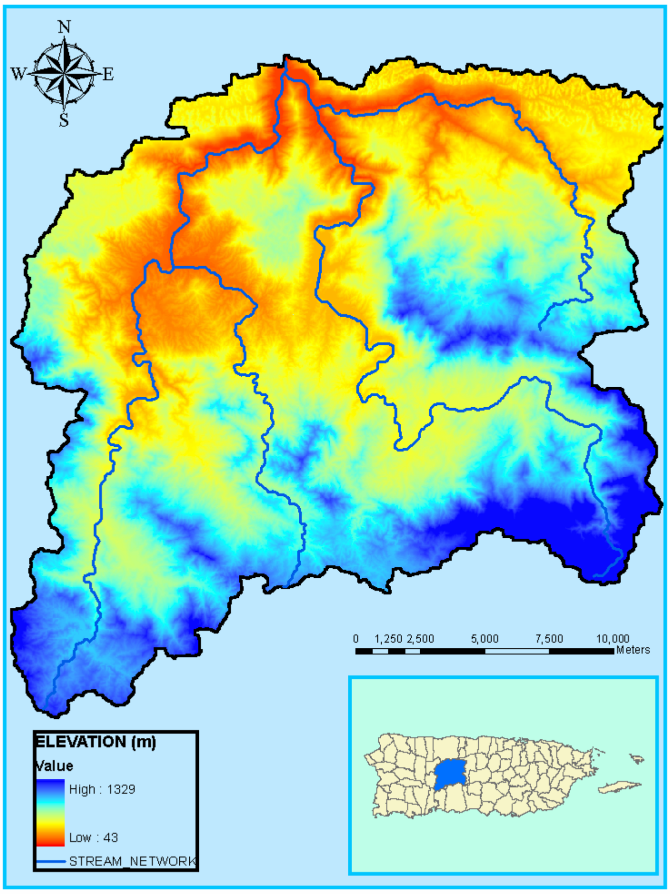


Figure 4.1. WMS watershed delineation and stream networks

Land Use Distribution

Land use layers in the Río Grande de Arecibo watershed were created based on available 2004 ortho-corrected images from the USGS database (USGS, 2004), land use maps from the Puerto Rico Planning Board (PRPB, 1977), and a landuse map of RGA by CSA Group (CSA, 2000). Ground truthing was done by direct inspection and consultation with Extension Agents of the Agricultural Extension Service located in all towns within the RGA.

Ground truthing was conducted using Global Positioning System (GPS) (Trimble, Geo Explorers).

Major land use groups included agricultural cropland (Agriculture), secondary forest (Forest), urban/sub-urban (Urban), herbaceous rangeland (Rangeland), fertilized pasture (Pasture), Barrenland (Barren) and water bodies. Table 4.2 shows the existing land use and respective percentages in the entire RGA watershed (Figure 4.2).

Table 4.2 Land use distribution in Río Grande de Arecibo watershed as of December 2008.

Land Use Code	Land Use Name	Area (Ha)	Percent Area (%)
4	Forest	34,326	76.28
6	Rangeland	5,724	12.72
3	Agricultural	2,804	6.23
1	Urban or built-up	1,382	3.07
12	Water	324	0.72
2	Pasture	284	0.63
7	Barrenland	158	0.35

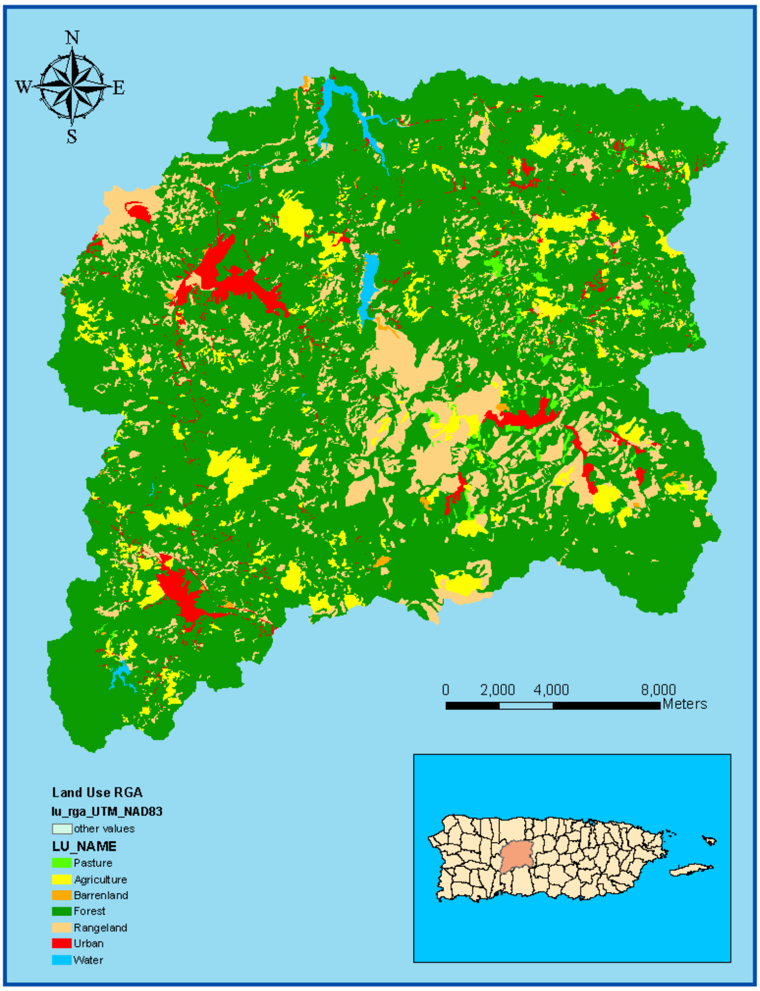


Figure 4.2. Land use distribution in RGA watershed, based on CSA (2000), PRPB and current observations. December 2008.

Soils Distribution

Soils properties were obtained from the *Soil Survey Geographic Database* (SSURGO), from the National Resources Conservation Service (NRCS) of the Department of Agriculture (USDA). Hydrologic group in the study area and land capability were extracted from the database for characterization in hydrologic and land capability development (USDA-NRCS, 2002).

Additionally, the *Soil Survey of Arecibo Area Northern Puerto Rico* by the United States Department of Agriculture in cooperation with the College of Agricultural Sciences, University of Puerto Rico was used in the soil analysis (USDA, 1982).

Table 4.3 is an extract of the soil data, showing the respective percentage in hydrologic group in the area. Figure 4.3 depicts the hydrologic group layout and Figure 4.4 summarizes the soils land capability in RGA watershed

Table 4.3 Hydrologic soil group distribution in Río Grande de Arecibo watershed.

Hydrologic Group	Percent (%)
A	1.50
B	45.18
C	37.04
D	14.44
ND*	1.84

*ND, Non Determined

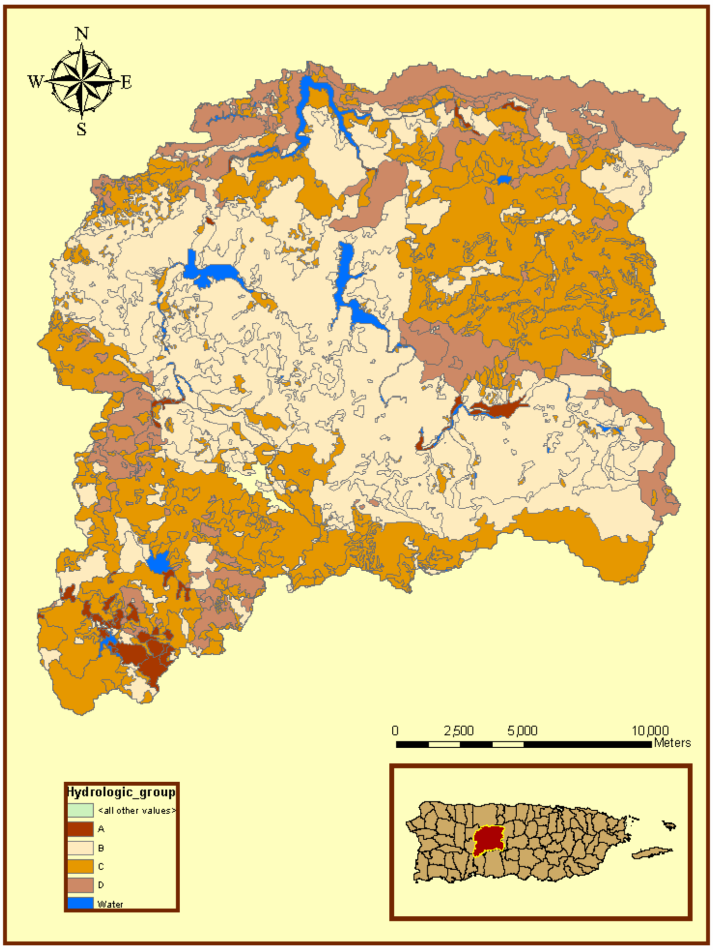


Figure 4.3. Hydrologic soil group distribution in RGA watershed

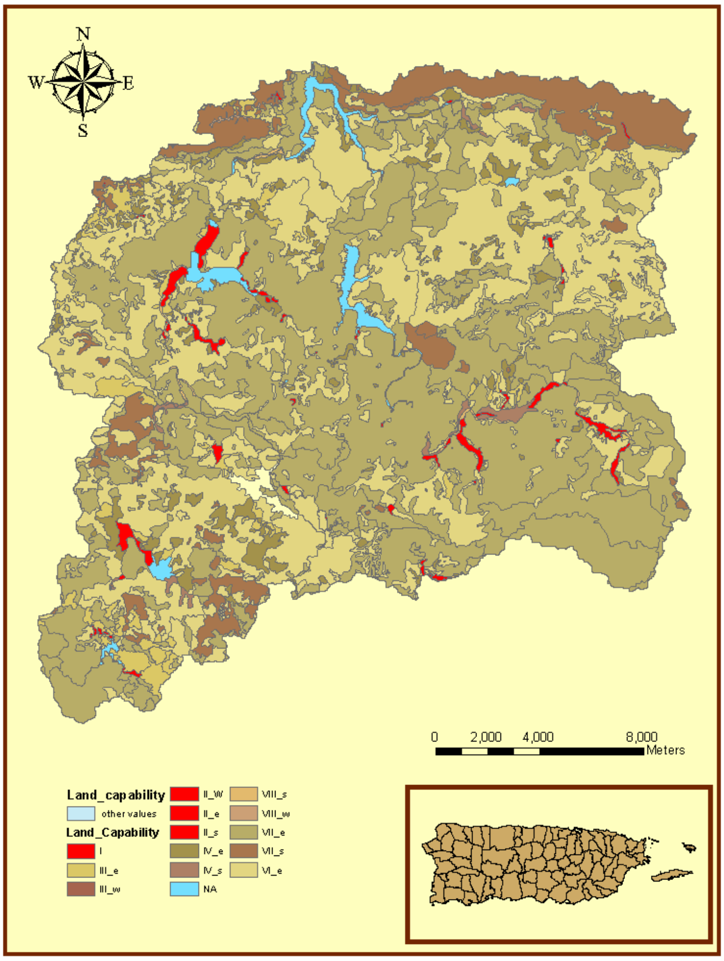


Figure 4.4. Land capability classifications in RGA watershed, adapted from USDA data, 1982)

Based on Table 4.3 the main hydrologic soil groups in RGA are B and C, corresponding to moderate to slow infiltration rate and consequently moderate well drained conditions.

Land capability classes will be used in the optimization analysis to find the best areas for agricultural growth associated with land use covers.

4.2.1.2 Meteorological Data

Hydrologic processes are both, temporal and spatial meaning that depends on environmental changes conditions and spatial input variability. HSPF requires weather data in an hourly format.

Meteorological time series were created using the WDM Utility in HSPF. The data format and period are indicated in Table 4.4.

Table 4.4 Hydro-meteorological data used in the water quality simulation

Hydro-meteorological series	Data time step	Data period
Precipitation	Hourly	1995/01/01 to 2005/12/31
Potential Evapotranspiration	Hourly	1995/01/01 to 2005/12/31
Air temperature*	Hourly	1995/01/01 to 2005/12/31
Wind velocity*	Hourly	1995/01/01 to 2005/12/31
Solar Radiation	Hourly	1995/01/01 to 2005/12/31
Dew Point temperature*	Hourly	1995/01/01 to 2005/12/31
Cloud Cover*	Hourly	1995/01/01 to 2005/12/31

* Data from the National Oceanic and Atmospheric Administration (NOAA)

Precipitation data was obtained from six USGS stations containing rainfall data in time intervals of 5 to 15 minutes. Figure 4.5 details the spatial localization of rainfall stations in RGA watershed.

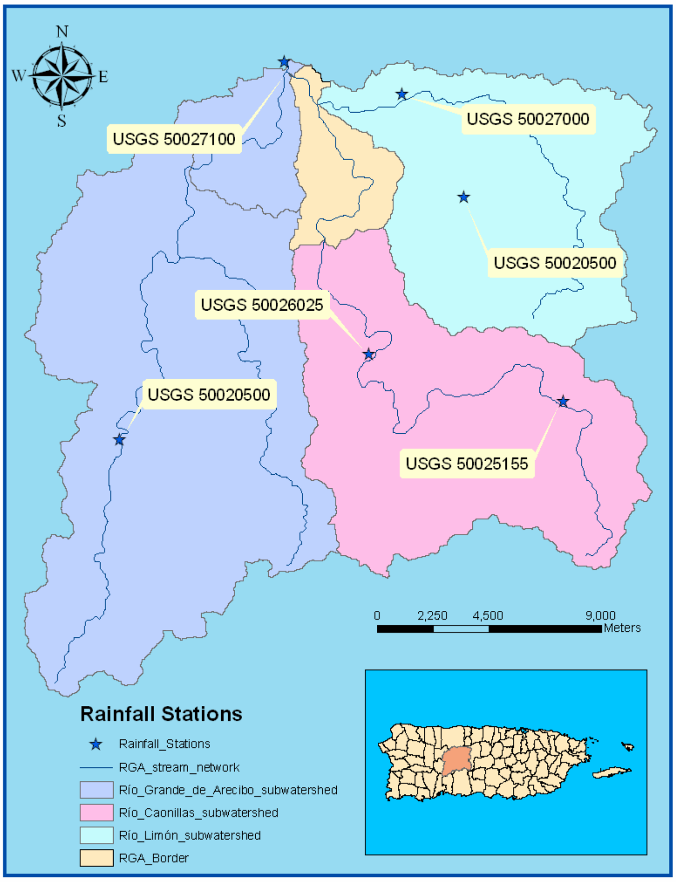


Figure 4.5. Precipitation stations by USGS within RGA watershed

Potential evaporation was obtained from Díaz (2004). This data was downloaded from the BASINS data base sets (USEPA, 2003a). Five stations in Puerto Rico are included in this data base. Corozal station was chosen because its elevation is closer to the RGA watershed mean elevation.

The potential evaporation data was included in BASINS-HSPF until 2002 and updated to 2005. A Hamon temperature method to convert data to hourly evapotranspiration was used (Díaz, 2004).

Solar radiation was downloaded from the Carribean Atmospheric Research Center (CARC) located at the University of Puerto Rico at Mayagüez. Data was converted from $\frac{\mu mol}{s * m^2}$ to Langleys required for HSPF (AtmosCARIB, 2006).

Additional meteorological data including wind velocity, cloud cover, air temperature and dew point temperature was taken from the National Oceanic and Atmospheric Administration (NOAA), Aguadilla International Airport station.

Atmospheric deposition is another important input in water quality simulation. For this study the data was obtained through the National Atmospheric Deposition Program/National Trends Network (NADP/NTN). Because no NADP/NTN data collection sites are located within the RGA area, it was necessary to apply data from a nearby site located in the Puerto Rico north east region near El Yunque National Forest (http://nadp.sws.uiuc.edu, 2006).

Output meteorological data was needed for model calibration and validation. This data included, mean daily flow, suspended sediment concentrations, water temperature, total phosphorus, nitrates and total ammonia concentrations for each station in the 1995 to 2005 period.

Table 4.5 shows mean daily flow, sediment and water quality stations and the available data used for model performance evaluation.

Table 4.5 Time period for mean daily flow, sediments and water quality stations

USGS Station	Time Period					
	Mean daily flow (cfs)		Sediments (mg/l)		Water quality (mg/l)	
USGS 50020500 Río Grande de Arecibo near Adjuntas	2000-03-28	2002-09-29	2000-09-30	2002-09-29	1995-01-01	2004-06-23
USGS 50021700 Río Grande de Arecibo above Utuado	1999-06-01	2002-09-29	2000-09-30	2002-09-29	----	----
USGS 50024950 Río Grande de Arecibo below Utuado	1996-04-16	2002-09-29	1999-09-30	2002-09-29	----	----
USGS 50025000 Río Grande de Arecibo near Utuado	----	----	----	----	1995-01-01	2004-06-24
USGS 50025850 Río Jauca at Paso Palma	2000-05-17	2002-09-29	2000-09-30	2002-09-29	----	----
USGS 50025155 Río Saliente at Coabey near Jayuya	1999-09-30	2002-09-29	2000-09-30	2002-09-29	----	----
USGS 50026025 Río Caonillas at Paso Palma	1995-09-30	2002-09-29	1998-09-30	2002-09-29	----	----
USGS 50026050 Río Caonillas above Lago Caonillas	----	----	----	----	1995-01-01	2004-06-17
USGS 50026200 Río Caonillas below Lago Caonillas	2000-12-12	2002-09-29	2000-09-30	2002-09-29	----	----
USGS 50026400 Río Yunes, Road 140 near Florida.	2000-06-21	2002-09-29	1999-09-30	2002-09-29	----	----
USGS 50027000 Río Limón above Lago Dos Bocas	----	----	----	----	1995-01-01	2003-11-18

---- Not data included

Additional water quality data reported from Martínez (2006) was incorporated in the 2004-2005 period for validation purposes.

4.2.2 HSPF Final model assembling

Once the GIS and the meteorological data are collected and incorporated, a channel network creation is the final step in the model assembling for simulation process. For this purpose a conceptual model need to be created taking into account sub-watersheds created previously by WMS, rivers and lakes and the connections between all of these elements.

For RGA, the channel network was divided into 14 reaches and 4 reservoirs. HSPF and specifically WinHSPF module create the rivers and lakes as a RCHRES (reach-reservoir element). For rivers and lakes geometry definition, the function FTABLE was used to introduce the depth-discharge and depth-volume relations respectively, the area and flow data of each river cross section. For Lago Caonillas and Lago Dos Bocas data in FTABLE was taken from the USGS survey studies in these lakes. (Sóler-López, 2001a; 2001b).

Hydrologic response units (HRU) were used to define 18 sub-watersheds. HRU's correspond to areas with similar geomorphologic characteristics and similar hydrological behavior like precipitation, soils type, land use, and evapotranspiration. Additionally, the outlet points were defined taking into account the monitoring stations. Figure 4.6 shows the hydrologic-hydraulic schematic created by WinHSPF. It shows all the elements included in the model (rivers, lakes and subbasins).

For multi-objective optimization analysis it is important to denote that this schematic shows the three main sub-watersheds; Río Caonillas with RCHRES from 10 to 12 (Lago Caonillas), Río Limón sub-watershed from 16 to 18 RCHRES and the Río Grande de Arecibo sub-watershed from the 1 to 9 RCHRES. RCHRES 6 correspond to Lago Dos Bocas, the outlet point of the system.

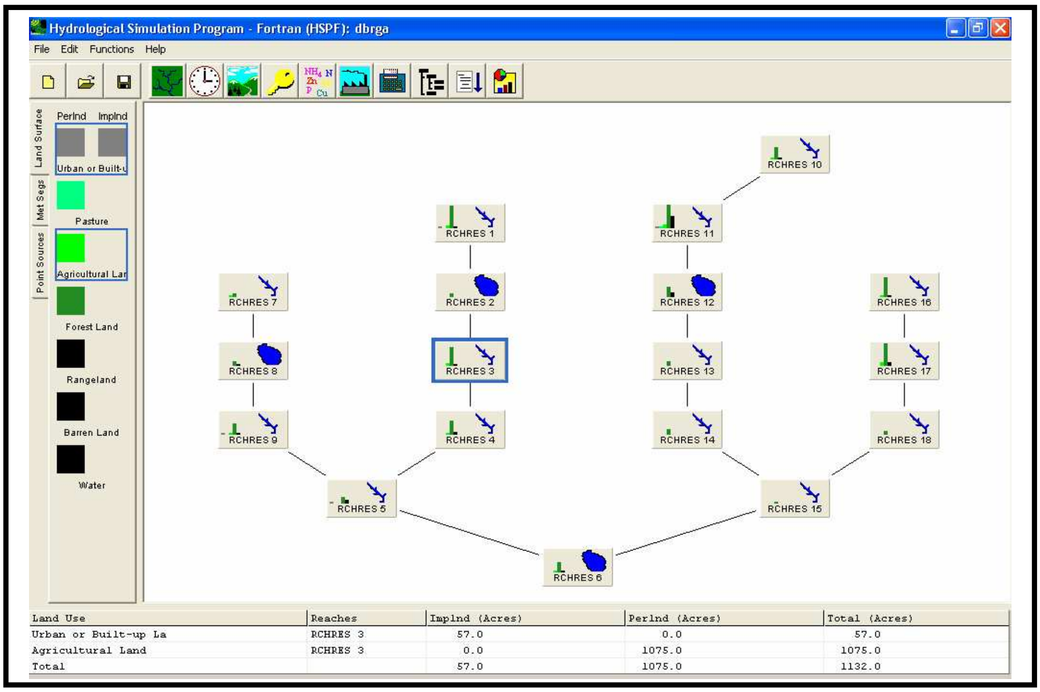


Figure 4.6. RGA hydrologic-hydraulic model schematic

4.2.3 Water quality simulation approach

The simulation of nutrient loadings and oxygen from the land-use non-point sources was conducted using the PQUAL and IQUAL simplified approach contained in HSPF. This simplified approach simulates each water quality constituent independently based on simple relationships with water or sediment. This approach was selected to simulate the nutrient transport process for all the land uses in the study area. Particularly, for the agriculture, land use this simulation approach represents the best selection due to scarcity of data for use of the more advanced AGCHEM module.

The PQUAL and IQUAL sections of HSPF, for pervious land and impervious land, respectively, were employed to model the loading from land uses for the following species: TAM ($NH_3 + NH_4^+$) as N, total nitrates ($NO_3^- + NO_2^-$) as N and TP as P.

In the PQUAL and IQUAL modules, water quality constituents in the surface outflow can be simulated by two methods. One of the methods is used to simulate the water quality concentration as a function of sediment removal and the other simulates the concentration of constituents using atmospheric deposition and/or basic accumulation and depletion rates together with depletion by washoff (Bicknell et al., 2000). For TP , the first approach was used and the second one for the N species according to HSPF requirements.

The equations used to simulate washoff of water quality constituents in PQUAL are detailed below (Bicknell et al., 2001). The storage of constituents on the land surface is calculated using equation 4.1, to account for the accumulation and removal processes based on an accumulation rate and a unit removal rate.

$$SQO = ACQOP + SQOS * (1.0 - REMQOP) \qquad (4.1)$$

where SQO = storage of available quality constituent on the land surface (Kg*ha^{-1});

$ACQOP$ = accumulation rate of the constituent on the land surface (Kg*ha^{-1}day^{-1})

$SQOS = SQO$ at the start of the interval, and

$REMQOP$ = unit removal rate of the stored constituent (day^{-1})

$ACQOP$ is the most critical parameter for water quality modeling and consequently an accurate estimation of it is very important (Bicknell *et al*., 2001).

The amount of washoff water quality constituents from the land surface is determined by the following equation. This washoff is a function of the pollutant storage, the surface outflow and the constituent availability to washoff.

$$SOQO = SQO * (1.0 - e^{-SURO*WSFAC}) \tag{4.2}$$

$SOQO$ = washoff of the quality constituent from the land surface (Kg*ha^{-1}hr^{-1})

SQO = storage of available quality constituent on the land surface (Kg*ha^{-1})

$SURO$ = surface outflow of water (cm*hr^{-1})

$WSFAC$ = susceptibility of the quality constituent to washoff (cm^{-1})

Getting back to the accumulation rate of water quality constituents, the ACQOP parameter was calculated using several information sources about storm water quality studies like compiled by Harper for Central and South Florida area for ten land uses and eight pollutant categories (Harper, 1994). Reported data from Harper was in terms of event mean concentration (EMC), reason for which a conversion to accumulation rate was required. The conversion was accomplished by multiplying the EMC by an estimated annual runoff volume (function of precipitation and runoff coefficients). Equation 4.3 and 4.4 shows the procedure to change from EMC to ACQOP.

$$ARV = (MAR) * (RC) * UCF \qquad (4.3)$$

where ARV = Annual runoff volume;

MAR = Mean annual rainfall;

RC = Land use runoff coefficient;

UCF = Units conversion factor and;

$$ACQOP = (EMC) * (ARV) * UCF \qquad (4.4)$$

where $ACQOP$ = accumulation rate of the constituent on the land surface;

EMC = Mean runoff concentration;

ARV = Annual runoff volume

UCF = Units conversion factor

Conversions from EMC to ACQOP were done for all the land use categories in the RGA watershed and directly entered into the model to simulate pollutant transport in perland and imperland areas going to rivers and lakes simulated with RCHRES module.

For instream simulation, HSPF simulates several physical, chemical and biological processes within a stream reach using the RCHRES module depicted in Figure 4.7 with the respective sub-modules. Instream simulation is based on the assumption of a completely mixed system with unidirectional flow (1D longitudinal flow simulation). The input of water, sediments and water quality species to a stream reaches includes contributions from upstream reaches, point and non point sources.

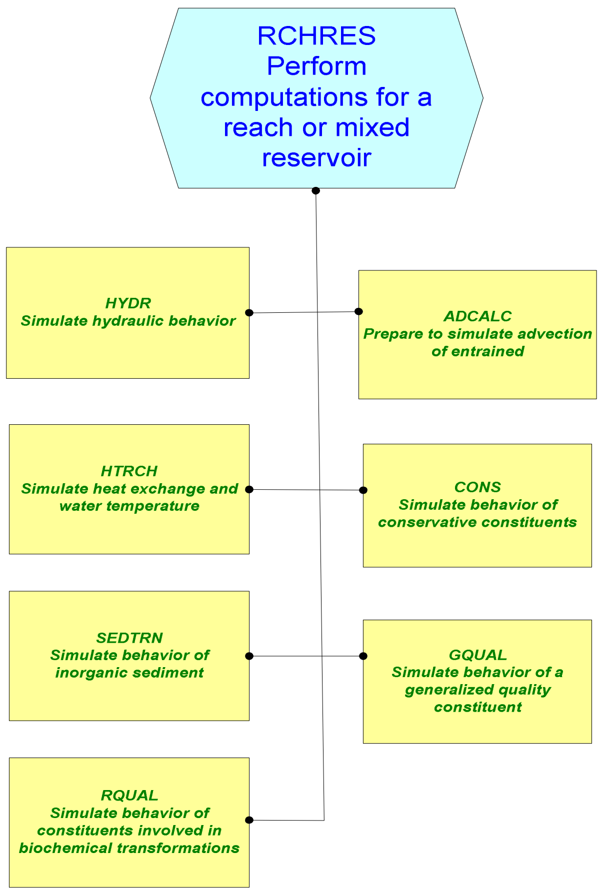


Figure 4.7 RCHRES module structure (Bicknell et al., 2001)

Instream simulation includes process like sediment transport, water temperature, dissolved oxygen (DO) and nutrients simulation.

Point sources defined as direct inputs to water bodies through a discrete source like pipes were added in the HSPF simulation using the available NPDES (National Pollutant Discharge Elimination System). NPDES is a regulatory program by the USEPA to assign maximum allowed pollutant concentrations.

The USEPA Envirofacts Warehouse Data is a database that offers access to the Permit Compliance System (PCS) and it was used to estimate the maximum concentrations and flow rates needed for quantify pollutant loadings.

The RGA watershed currently has twelve NPDES permitted discharges in the jurisdictions of Utuado, Adjuntas and Jayuya municipalities. NPDES permits have been issued to water treatment plants and waste water treatment plants in the area. Included pollutants species were the total nitrates as nitrogen ($NO_3^- + NO_2^-$), TAM ($NH_3 + NH_4^+$) and TP as P.

Pollutant loadings were estimated based on the regulated pollutants concentrations and the average outflow at the outlet point of the system. A summary of the NPDES is provided in Tables 4.6 to 4.8 and Figure 4.8 illustrates the location of the twelve authorized discharges.

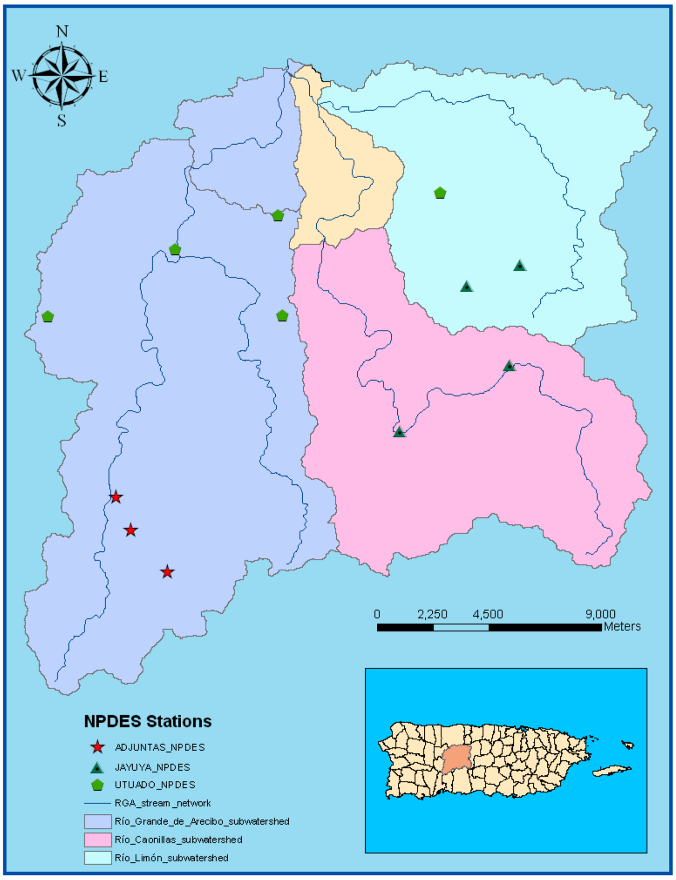


Figure 4.8. Río Grande de Arecibo NPDES

Table 4.6 Jayuya municipality NPDES Authorized discharges

NPDES ID	Facility Name	Maximum permitted concentrations			Average flow discharge	Average Annual Loads		
		Total Nitrates* (mg/l)	Total Ammonia* (mg/l)	Total Phosphorus (mg/l)	(MGD)	Total Nitrates (Kg/year)	Total Ammonia (Kg/year)	Total Phosphorus (Kg/year)
PR0026531	PRASA - JAYUYA WWTP (NEW)	10	1	1	0.53	7,322	732	732
PR0024121	PRASA JAYUYA URBANO	10	1	1	0.14	1,934	193	193
PR0025224	PRASA MAMEYES ARRIBA FILTER PL	---	---	---	---	---	---	---
PR0023132	SECOND UNIT MAMEYES SCHOOL	10	1	1	0.01	138	13.8	13.8
					TOTAL	**9,394**	**939**	**939**

Total Ammonia = $NH_3^+ + NH_4^+$; Total Nitrates = $NO_2^- + NO_3^-$

Table 4.7 Adjuntas municipalty NPDES Authorized discharges.

NPDES ID	Facility Name	Maximum permitted concentrations			Average flow discharge	Average Annual Loads		
		Total Nitrates (mg/l)	Total Ammonia (mg/l)	Total Phosphorus (mg/l)	(MGD)	Total Nitrates (Kg/year)	Total Ammonia (Kg/year)	Total Phosphorus (Kg/year)
PR0020214	PRASA ADJUNTAS STP	20	25	3	0.393	5,429	8,144	1,628
PR0025739	PRASA - ADJUNTAS NUEVA WTP	---	1	---	0.025	---	35	---
PR0022691	PRASA WTP ADJUNTAS	35	---	5	0.006	290	---	41
					TOTAL	**5,719**	**8,179**	**1,669**

Table 4.8 Utuado municipality NPDES Authorized discharges.

NPDES ID	Facility Name	Maximum permitted concentrations			Average flow discharge	Average Annual Loads		
		Total Nitrates (mg/l)	Total Ammonia (mg/l)	Total Phosphorus (mg/l)	(MGD)	Total Nitrates (Kg/year)	Total Ammonia (Kg/year)	Total Phosphorus (Kg/year)
PR0026271	PRASA - RONCADOR WTP	10	1	1	0.048	663	66.3	66.3
PR0020915	PRASA - UTUADO WWTP	14	25*	1	0.3225	4,456	8,911	446
PR0026255	PRASA - SABANA GRANDE WARD WTP	---	1	1	0.0045	---	6.3	6.3
PR0025208	PRASA MAMEYES ABAJO WTP	---	---	---	---	---	---	---
PR0024155	PRASA WTP UTUADO	10	1	1		1,450	145	145
					TOTAL	**6,569**	**9,128.6**	**664**

4.2.4 Model calibration and validation

Model calibration was achieved by the trial and error method, where an initial set of values for all parameters is utilized based on literature recommendations or technical notes provided by the model's authors. The second step is the adjustment of preliminary parameters values comparing simulated and observed data series. The process stops when adequate statistical indicators are obtained according with literature guidelines and no more parameter adjustments are needed.

Validation of data is a complementary process that tries to set a different time series with the same set of parameters used in the calibration. Refsgaard in 1997 defined the model validation as the process of demonstrating that a given site-specific model is capable of making "sufficiently accurate" simulations, although "sufficiently accurate" can vary based on project goals.

For hydrology, sediments, and water quality calibration, the corresponding streamflow, sediments and water quality data were obtained from USGS records for the entire simulation and validation periods. Additional data from Martínez compiled in 2006 were used as complementary data for water quality model validation.

Appendix B details the corresponding parameters for hydrology, hydraulics, sediments and water quality calibration and validation.

According to Moriasi in 2007, although the American Society of Civil Engineers (ASCE) in 1993 emphasized the need to clearly define model evaluation criteria, no commonly accepted guidance has been established, but specific statistics and performance ratings for their use have been developed and used for model evaluation. However, these performance ratings are model and project specific.

For the model presented here, performance evaluation, graphical and quantitative statistical indicators were utilized according to literature recommendations and guidelines given by HSPF developers. These statistics were used as the basis for the model calibration and validation process (Donigian, 1983).

Quantitative statistics selection includes considerations like the type of process to be calibrated (hydrology, sediments or water quality), quantity and quality of data and evaluation time step. Quantitative statistics includes the standard regression, dimensionless and error index classes (Moriasi et al., 2007). Among the standard regression, Pearson's correlation (r) and determination (R^2) coefficients were used. Those coefficients describe the degree of co-linearity between simulated and measured data. The correlation coefficient given by Equation 4.5 ranges from -1 to 1 and evaluate the degree of linear relationship between observed and simulated data. Similarly, R^2 describes the proportion of the variance in measured data explained by the model. R^2 ranges from 0 to 1 with higher values indicating less variance and typically values greater than 0.5 are considered acceptable. Limitations in both indicators turn around the oversensitive to high extreme values (outliers) and insensitive to additive and proportional differences between model predictions and measured data (Moriasi et al., 2007).

$$r = \frac{\sum_{i=1}^{n}(Y^{obs}{}_i - Y^{obs\_mean})(Y^{sim}{}_i - Y^{sim\_mean})}{\left[\sum_{i=1}^{n}(Y^{obs}{}_i - Y^{obs\_mean})^2\right]^{0.5}\left[\sum_{i=1}^{n}(Y^{sim}{}_i - Y^{sim\_mean})^2\right]^{0.5}} \tag{4.5}$$

where: $Y^{obs}{}_i$ = i^{th} observation for the constituent being evaluated, $Y^{sim}{}_i$ = i^{th} simulated value for the constituent being evaluated, Y^{obs_mean} = mean of observed data for the constituent being evaluated, Y^{sim_mean} = mean of simulated data for the constituent being evaluated and n = total number of observations.

The Nash-Sutcliffe efficiency (NSE) was used as a dimensionless statistic for model performance. The NSE indicator is a normalized statistic that determines the relative magnitude of the residual variance ("noise") compared to the measured data variance ("information") (Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. Equation 4.6 shows how to compute this indicator.

$$NSE = 1 - \left[\sum_{i=1}^{n}(Y^{obs}{}_i - Y^{sim}{}_i)^2 / \sum_{i=1}^{n}(Y^{obs} i - Y^{obs\_mean})^2\right] \tag{4.6}$$

where; $Y^{obs}{}_{i}$ = i^{th} observation for the constituent being evaluated, $Y^{sim}{}_{i}$ = i^{th} simulated value for the constituent being evaluated, Y^{obs_mean} = mean of observed data for the constituent being evaluated, and n = total number of observations.

NSE ranges between -∞ and 1.0 (1 inclusive) with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance. Whereas values ≤ 0.0 indicates that the mean observed value is a better predictor than the simulated value, which indicates unacceptable performance (Moriasi et al., 2007).

The third class of statistical indices utilized for model performance evaluation was the error index class, valuable quantitative statistics because they indicate error in the units or square units. The Root Mean Square Error ($RMSE$), the Mean Absolute Error (MAE) or the Mean Square Error (MSE) with a value of zero indicate a perfect fit between observed and simulated data. Equation 4.7 is presented and used to compute the $RMSE$.

$$RMSE = \sqrt{\sum_{i=1}^{n} \left(Y^{obs}{}_{i} - Y^{sim}{}_{i}\right)^{2}} \qquad (4.7)$$

4.3 HSPF SIMULATION RESULTS

In this section, the results obtained from ten years of continuous simulations (1995-2005) of the RGA watershed and its corresponding statistical analysis are presented and discussed. The simulation, calibration and validation of the model focus to obtain acceptable agreement among see observed and simulated values based on defined criteria or targets, maintaining realistic bounds of physically based parameters and non point loadings in the study area.

Water quality calibration was achieved following a sequence according to the analyzed constituent. For example, sediment associated pollutants like the Total Phosphorus (TP) requires a good calibration of hydrology and then sediment washoff. Likewise, Total Nitrogen (TN) is associated with flow requiring only a good hydrologic calibration.

In general, calibration is a hierarchical process beginning with hydrology calibration, followed by sediment erosion and sediment transport calibration and finally calibration of non point source loading rates and water quality constituents. Before TP and TN, water temperature and dissolved oxygen calibration was needed (Donigian, 2002).

Several sources of in-stream monitoring data were used to calibrate the water quality model. One of the most important data source is the historical data recording by the USGS stations at the RGA watershed. USGS stations included data are above Lago

Caonillas (50026025), Río Grande de Arecibo near Utuado (50025000) and near Adjuntas (50020500) and Río Limón (50027000).

Another data source comes from the data collected in the water year 2004-2005, in the investigation "Predicting sediment and nutrient loads in tropical watersheds in Puerto Rico". (Martínez, 2006). From September 2004 to September 2005 water quality data was collected, including TP, Dissolved Phosphorus (DP), Total Kjehdal Nitrogen (TKN), water temperature, etc.

In this chapter a detailed description of the calibration and validation procedures are presented along with the time series procured from external sources or gathered in this study.

4.3.1 Hydrology, sediment and water quality calibration guidelines

The calibration of the model was done by using a methodology called *trial and error* which consists of: 1) running the model with an initial set of physical parameters between realistic boundaries. This step allows the parameter evaluation in the model and then the refinement as a result of comparing simulated and observed values of interest. 2) Graphical comparison and statistical tests to assess model performance. 3) Adjust and refinement of initial values. Initial values were taken from literature and other studies using the same constituent simulation. 4) New iterations are necessary to find the optimum parameters values that adjust observed and simulated data based on statistical criteria.

Table 4.9 list general calibration/validation tolerances that have been provided by the HSPF developers over the past ten years using the *Percent Mean Error* (PME) statistic indicator.

Additional specific statistics and performance ratings have been used for model evaluation by Donigian et al., 1983; Gupta et al., 1999; Singh et al., 2004. In this study several statistics and specific performance ratings detailed in section 4.2.4 were used as a general guidance for model evaluation.

Table 4.9 General calibration and validation tolerances for HSPF applications based on the PME* (Donigian et al., 2000)

Constituent	Percent of difference between simulated and recorded values		
	Very good	Good	Fair
Hydrology/flow	<10	10-15	15-25
Sediment	<20	20-30	30-45
Water temperature	<7	8-12	13-18
Water quality	<15	15-25	25-35
Pesticide, toxics	<20	20-30	30-40

<, less than
* Difference between simulated and observed values.

4.3.2 Flow and sediments calibration and validation results

The HSPF model was calibrated and validated in monitoring stations with water quality data. The model was calibrated for hydrology and sediment (Suárez, 2005). A total of eight flow and sediment stations were calibrated and validated in the Suárez analysis, but only five of them were used in the water quality simulation. Table 4.10 shows the calibrated stations and its corresponding calibration periods.

Table 4.10 Flow and sediment stations calibration period

USGS Station	Calibration period	
	Initial	Final
USGS 50020500 Río Grande de Arecibo near Adjuntas	2000-10-01	2001-09-30
USGS 50024950 Río Grande de Arecibo below Utuado	1996-10-01 1999-10-01*	1998-09-30 2001-09-30*
USGS 50025155 Río Saliente at Coabey near Jayuya	1995-10-01 2000-10-01*	1998-09-30 2001-03-01*
USGS 50026025 Río Caonillas at Paso Palma	1995-10-01 1995-10-01*	1998-09-30 2000-02-29*
USGS 50027000 Río Limón above Lago Dos Bocas	2000-10-01	2001-09-30

* Corresponding to sediment calibration period

Figures 4.9 to 4.13 depicts the results obtained from the hydrology calibration in the five stations selected (Table 4.11).

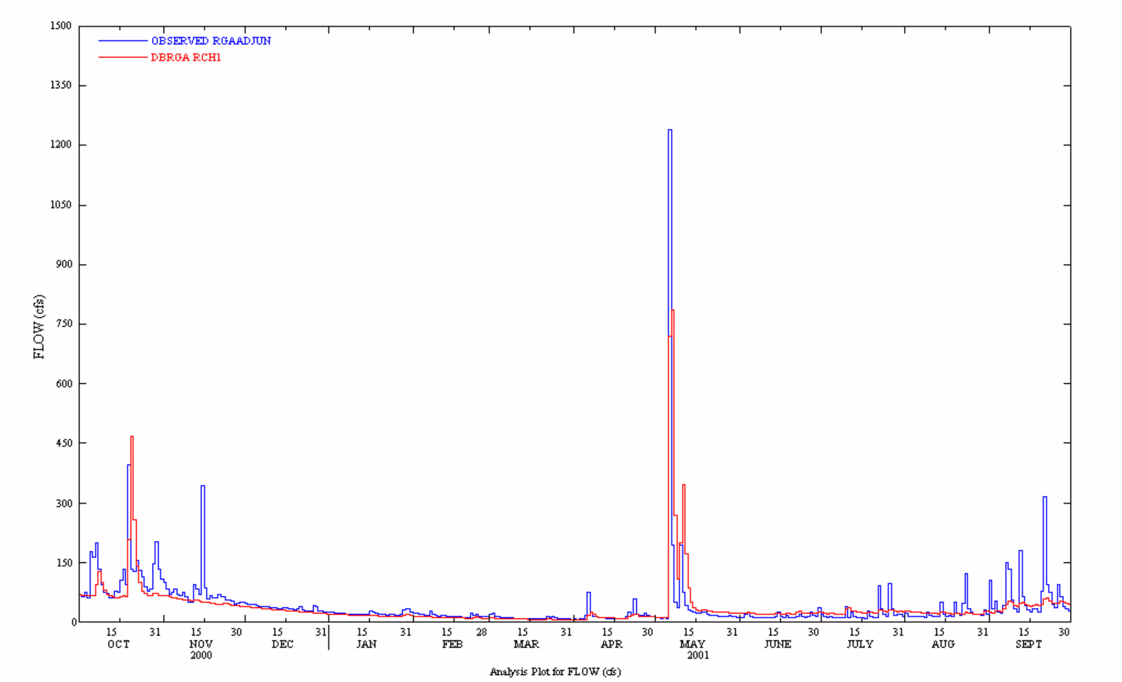


Figure 4.9 USGS 50020500 Río Grande de Arecibo near Adjuntas (Calibration period from October 2000 to September 2001)

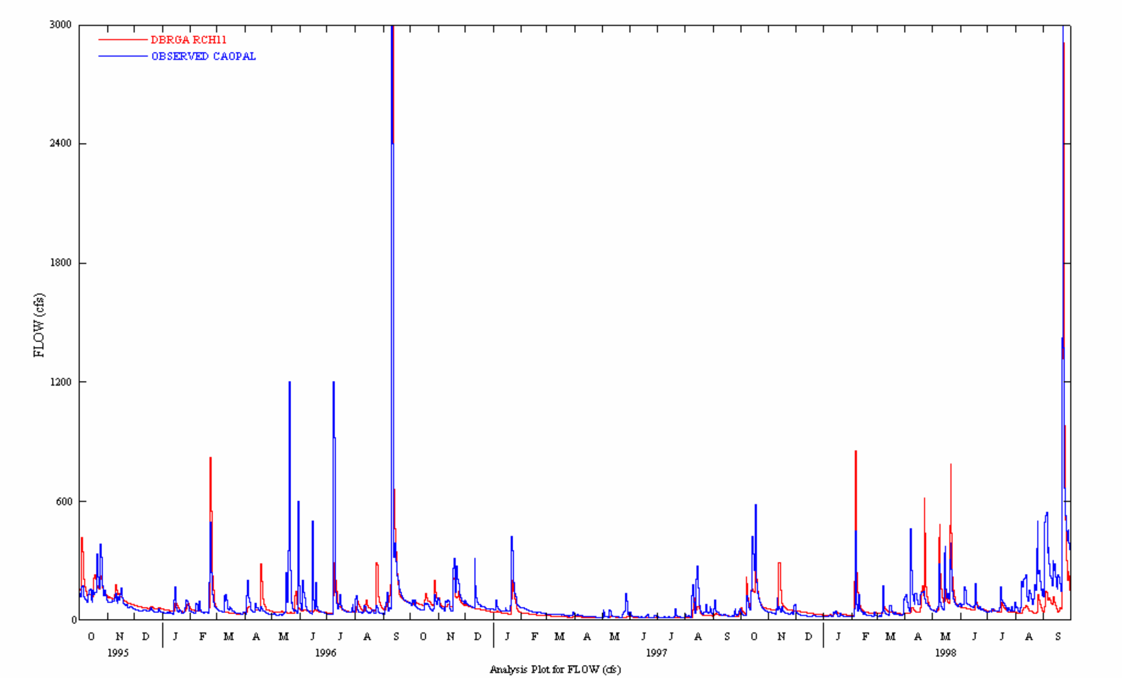


Figure 4.10 USGS 50026025 Río Caonillas at Paso Palma (Calibration period from October 1995 to September 1998)

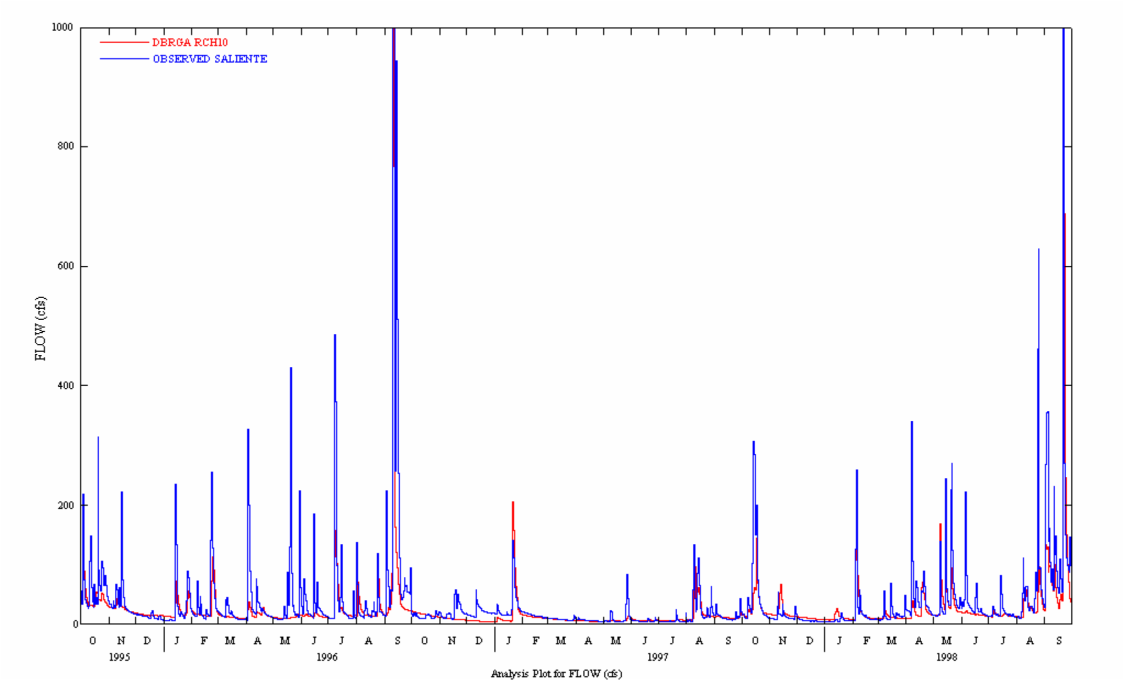


Figure 4.11 USGS 50025155 Río Saliente at Coabey near Jayuya (Calibration period from October 1995 to September 1998)

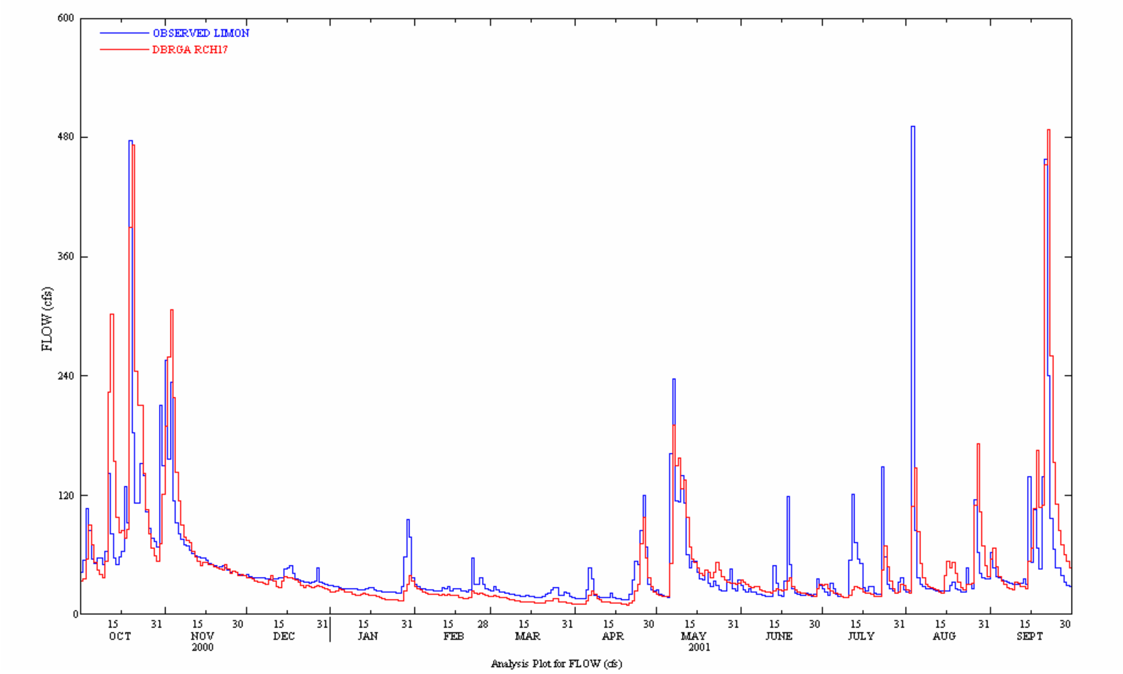


Figure 4.12 USGS 50027000 Río Limón above Lago Dos Bocas (Calibration period from October 2000 to September 2001)

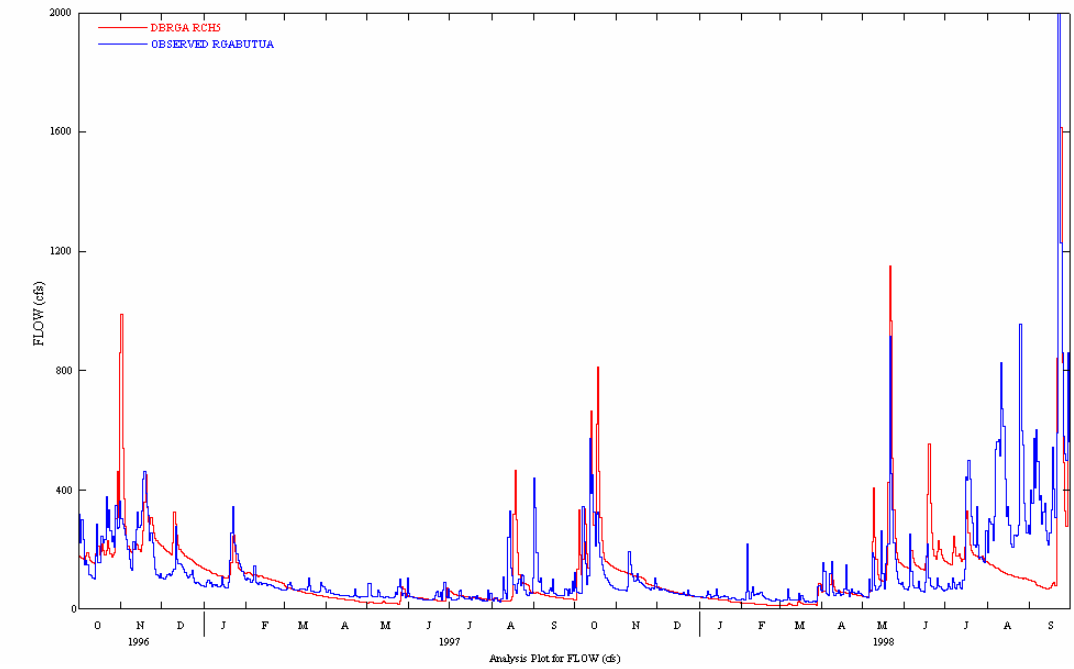


Figure 4.13 USGS 50024950 Río Grande de Arecibo below Utuado (Calibration period from October 1996 to September 1998)

Table 4.11 Statistical results for hydrologic calibration

USGS Station	Observed Mean Daily flow (m^3/s)	Simulated Mean Daily flow (m^3/s)	PME (%)	R	R2	NSE	RMSE (m^3/s)	MAE (m^3/s)
USGS 50020500 Río Grande de Arecibo near Adjuntas	1.17	1.04	-12.71	0.87	0.75	0.72	1.14	0.47
USGS 50024950 Río Grande de Arecibo below Utuado	4.26	3.87	-10.08	0.94	0.89	0.70	7.64	2.14
USGS 50025155 Río Saliente at Coabey near Jayuya	1.22	0.79	-53.40	0.64	0.41	0.10	4.13	0.74
USGS 50026025 Río Caonillas at Paso Palma	2.79	2.66	-4.72	0.95	0.91	0.90	4.56	1.26
USGS 50027000 Río Limón above Lago Dos Bocas	1.32	1.35	1.91	0.82	0.67	0.67	1.05	0.46

Results presented in Table 4.11 shows a good calibration based on statistical indicators and acceptable ranges published in the literature for hydrologic simulation. Determination and correlation coefficients (R^2 and R) showed high values in almost all the stations except in the Río Saliente station. Donigian et al., (2000) suggest using a value of R^2>0.70 or R>0.80 as a good fit indicator. This author stipulates that percent mean errors (PME) below 15% imply a good to very good calibration. In four of the five analyzed stations the criteria established by Donigian was met.

Nash-Sutcliffe efficiency (NSE) is a normalized statistic that determines the relative magnitude of the residual variance (“noise”) compared to the measured data variance (“information”) (Nash and Sutcliffe, 1970). NSE indicates how well the plot of observed versus simulated data fits the 1:1 line. NSE ranges between -∞ and 1.0 (1 inclusive) with NSE = 1 being the optimal value. Values between 0.0 and 1.0 are generally viewed as acceptable levels of performance (Moriasi et al, 2007). All the calibration stations met this criteria.

Sediment simulation and calibration follows the hydrologic calibration and precedes water quality analysis. The process is analogous, meaning that parameters were refined to find the best combinations that adjust observed and simulated concentrations.

Table 4.12 summarizes the statistical results obtained from the sediment calibration in the Río Grande de Arecibo watershed and its analyzed stations.

Table 4.12 Statistical results for suspended sediment concentration calibration

USGS Station	Observed Mean Daily flow (mg/l)	Simulated Mean Daily flow (mg/l)	PME (%)	R	R2	NSE	RMSE (mg/l)	MAE (mg/l)
USGS 50020500 Río Grande de Arecibo near Adjuntas	36.74	33.19	-10.70	0.46	0.21	-0.19	103.06	38.58
USGS 50024950 Río Grande de Arecibo below Utuado	187.73	193.79	3.13	0.73	0.53	0.48	392.71	160.13
USGS 50025155 Río Saliente at Coabey near Jayuya	25.90	21.51	-20.41	0.29	0.08	-1.54	64.62	24.70
USGS 50026025 Río Caonillas at Paso Palma	229.07	241.55	5.17	0.71	0.50	0.50	1,157.91	232.20
USGS 50027000 Río Limón above Lago Dos Bocas	46.27	49.99	7.44	0.35	0.12	-2.41	153.97	54.96

Calibration of parameters involved in sediment simulations are more uncertain than the hydrologic case due to less experience with sediment simulation in different regions of the country (Donigian, 2000).

Results of sediment calibration were fair. Based on HSPF developer performance ratings, correlation tests results shows that determination coefficients (R^2) ranges from 0.12 (a very low value) to 0.53 (fair fit), meaning in the first value a high variance in measured data explained by the model and in the second value an acceptable variance. In terms of R it range from 0.29 to 0.73, indicating a low degree of linear relationship between observed and simulated data.

For sediment simulation, obtained results of R and R^2 may reflect the oversensitivity of these statistics to extreme values. Nash-Sutcliffe efficiency (NSE) shows only in two stations, Río Grande de Arecibo near Adjuntas and Río Caonillas at Paso Palma a value inside the optimal range (0 to 1). Stations where NSE was inferior to 0, reflects that mean observed value is a better predictor than the simulated value.

Measured sediment concentrations from USGS are taken instantaneously. For this research purpose these values were utilized as representative of a daily value in order to compare with HSPF daily output results. This assumption may be reflected in the calibration statistic results for this specie. Additionally, some initial parameters values in RGA were unknown due to the lack of literature in areas with similar conditions, producing perhaps poor statistics in the calibration results.

Hydrologic and suspended sediments simulations were additionally validated in RGA with a different output data time period. Validation is a way of giving credibility to the model based on the ability of a single set of parameters to represent the entire range of observed data in a reasonable way. Table 4.13 summarizes the periods employed for hydrologic and sediment validation analysis.

Table 4.13 Flow and sediment stations validation periods

USGS Station	Validation period	
	Initial	Final
USGS 50020500 Río Grande de Arecibo near Adjuntas	2001-10-01	2002-09-30
USGS 50024950 Río Grande de Arecibo below Utuado	1999-10-01	2002-09-30
USGS 50025155 Río Saliente at Coabey near Jayuya	1998-10-01 2001-10-01*	2002-09-30 2002-09-30*
USGS 50026025 Río Caonillas at Paso Palma	1998-10-01 2000-03-01*	2002-09-30 2002-09-30*
USGS 50027000 Río Limón above Lago Dos Bocas	2001-10-01	2002-09-30

* Corresponding to sediment calibration period

Results from the hydrologic validation analysis shows that some of the statistical indicators are poor according with the guidelines given by Donigian et al. (2000). The R^2 varies from a value of 0.27 at RGA near Adjuntas to an acceptable value of 0.67 in Río Limón above Lago Dos Bocas station. According to literature recommendations, the *NSE* dimensionless statistic results are adequate because optimal values range between 0 and 1 in the five analyzed stations. Results from the validation process are summarized in Table 4.14 showing the effect of the scarcity of data in the one year validation period.

Table 4.14 Statistical results for hydrologic validation

USGS Station	Observed Mean Daily flow (m^3/s)	Simulated Mean Daily flow (m^3/s)	PME (%)	R	R2	NSE	RMSE (m^3/s)
USGS 50020500 Río Grande de Arecibo near Adjuntas	1.12	0.94	-18.86	0.52	0.27	0.26	1.17
USGS 50024950 Río Grande de Arecibo below Utuado	4.91	4.23	-16.01	0.62	0.39	0.12	5.31
USGS 50025155 Río Saliente at Coabey near Jayuya	0.84	0.86	3.28	0.75	0.56	0.32	0.34
USGS 50026025 Río Caonillas at Paso Palma	2.71	2.33	-16.43	0.79	0.62	0.58	2.18
USGS 50027000 Río Limón above Lago Dos Bocas	2.83	2.74	-3.28	0.82	0.67	0.45	3.68

According to the guidelines given in the literature the suspended sediments validation results were poor for the analyzed stations. The correlation coefficient (*r*) and consequently the determination coefficient showed values between 0.24 in Río Limón above Lago Dos Bocas and 0.75 in Río Grande de Arecibo below Utuado, meaning that this station obtained the higher determination coefficient with a value of 0.56. RGA below Utuado was the only station with an acceptable *NSE*, with a value of 0.30.

4.3.3 Water Temperature Simulation

Simulated stream water temperature was calibrated against observed instantaneous measurements from the four water quality USGS stations at RGA watershed. The water-temperature data was collected by USGS simultaneously with the nutrients data collection. Comparison of simulated hourly mean and observed instantaneous water temperature at the four stations shows a good correlation between simulated and observed water temperature. Percent mean error (PME) range between 0.36 and 3.46, meaning a *very good calibration* according with Donigian et al. (2000) guidelines (Table 4.9).

Adequate water temperature calibration results are the basis for a good water quality simulation and calibration due to tight relationship between the rate of chemical reactions and biological processes.

Figure 4.14 shows graphically the results obtained at the four stations. Percent Mean Errors (PME) are summarized in Table 4.15.

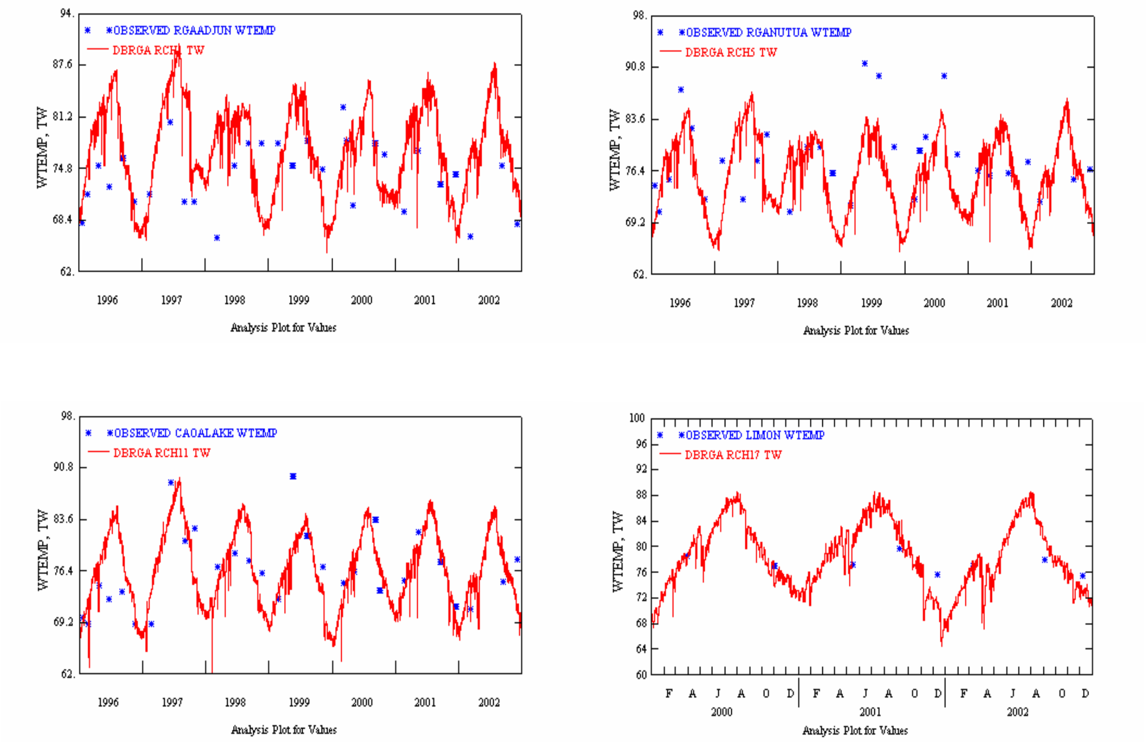


Figure 4.14 Simulated hourly mean and observed instantaneous water temperature at measurement stations (A) USGS 50020500, , (B) USGS 50025000, (C) USGS 50026050 and (C) USGS 50027000

Table 4.15 Water temperature calibration results

USGS Station	Observed Mean Daily Temperature (ºC)	Simulated Mean Daily Temperature (ºC)	PME (%)
USGS 50020500 Rio Grande de Arecibo near Adjuntas	23.31	25.02	3.46
USGS 50025000 Rio Grande de Arecibo near Utuado	25.59	24.36	2.84
USGS 50026050 Rio Caonillas above Lago Caonillas	24.68	24.73	0.36
USGS 50027000 Rio Limón above Lago Dos Bocas	25.16	25.77	1.40

4.3.4 Water Quality Simulation

The calibration and validation process in HSPF is a hierarchical methodology beginning with the hydrology, followed by soil erosion and sediment transport calibration and finally with the calibration of non point source loading rates and respective water quality constituents (Donigian, 2000).

The water quality simulation analysis comprises a ten-year continuous simulation period between 1995 and 2005, where parameters were evaluated under a variety of climatic, soil moisture and water quality conditions. A total of four USGS water quality stations were used for the calibration and validation of the results (See Figure 4.15).

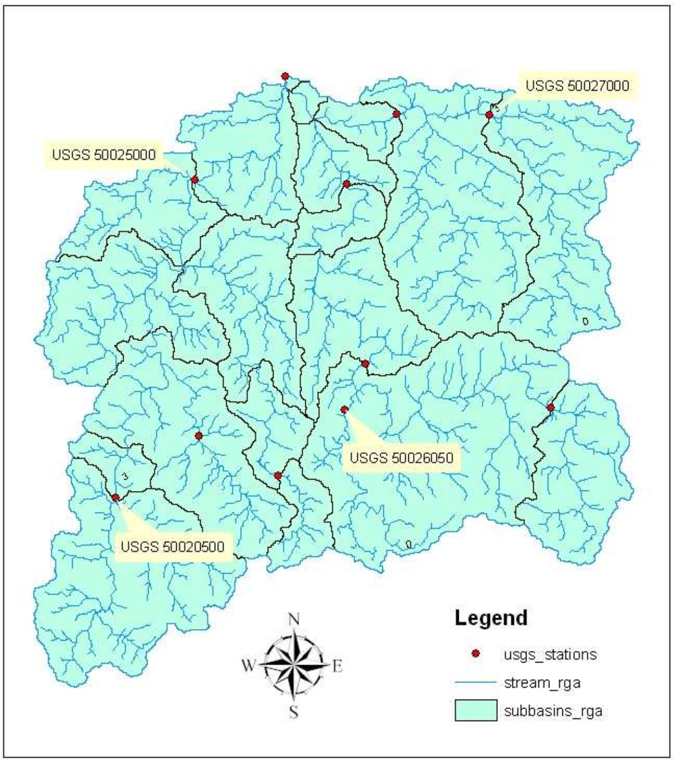


Figure 4.15 USGS water quality stations

USGS Stations tagged as USGS 50020500, USGS 5002700 and USGS 50024950 corresponds to the outlet point of the three main sub-watersheds of this study, Río Grande de Arecibo, Río Limón and Río Caonillas subwatersheds, respectively.

HSPF uses PQUAL and IQUAL modules to simulate constituents of the nitrogen cycle individually. Total nitrogen loads were calculated using pre-established relationship observations of nitrogen species by the selected USGS monitoring stations. The monitoring record expands between 1995- 2002. Individual simulated water quality constituents includes TAM ($NH_3 + NH_4^+$) as N, total nitrates ($NO_3^- + NO_2^-$) as N and TP as P.

4.3.4.1 Water quality calibration and validation

Water quality simulation includes the delivery from pervious and impervious land areas to stream reaches, the transport and chemical reactions in those reaches. Instream simulation depends on water temperature because it affects the saturation levels of dissolved oxygen (DO) and rates of chemical reactions in the water. Additionally to water temperature and previous to simulation of nitrogen and phosphorus species, the dissolved oxygen was simulated and compared with available data.

Several assumptions were made for the water quality model. Those include: (1-) land use in the area were simplified by seven general categories. (2-) Non point sources simulation was done using the PQUAL and IQUAL simplified approach form HSPF. (3-) conversion from nitrogen species to total nitrogen loads were done using specific local relations for the conversion. (4-) Instream sediment transport was limited to the three available equations in HSPF. 5-Export coefficients were associated to delivered loads in the stream reaches.

Tables 4.16 and 4.17 shows the period employed for the total nitrates and total phosphorus instream water quality calibration. Additionally to instream water quality constituents calibration, the non point loading rates defined as export coefficients were compared with values reported in the literature and used traditionally to assess nutrient export from these landuses. Although those values are highly variable due to variables such as local site conditions of slope, soil, topography and climate, the comparison is an important step before the instream water quality calibration. Export coefficients are detailed in the next section and compared with those values from literature.

Table 4.16 Calibration period for total nitrates simulation ($NO_3^- + NO_2^-$).

USGS Station number and site name	Calibration period	
	Start	End
USGS 50020500 Rio Grande de Arecibo near Adjuntas	1996/01/01	2000/12/31
USGS 50025000 Rio Grande de Arecibo near Utuado	1996/01/01	2000/12/31
USGS 50026050 Rio Caonillas above Lago Caonillas	1996/01/01	2000/12/31
USGS 50027000 Rio Limón above Lago Dos Bocas	2000/01/01	2002/12/31

Table 4.17 Calibration period for total phosphorus simulation (TP).

USGS Station number and site name	Calibration period	
	Start	End
USGS 50020500 Rio Grande de Arecibo near Adjuntas	1995/02/09	2002/12/31
USGS 50025000 Rio Grande de Arecibo near Utuado	1995/02/09	2002/12/31
USGS 50026050 Rio Caonillas above Lago Caonillas	1995/02/09	2000/12/31
USGS 50027000 Rio Limón above Lago Dos Bocas	2000/01/01	2003/12/31

The computer program GenScn, a graphical interface to HSPF, was the tool used to visualize and quantify the model evaluation performance.

Additionally to statistical analysis, a comparison between loads were used to complement the evaluation of the model's performance. Evaluating only instantaneous concentrations may result in larger apparent differences between observed and simulated values implying that simulation errors usually are larger for water-quality concentrations than for streamflow.

Initial parameters for land-use categories were associated to groundwater, interflow and superficial contributions. Initial parameters values are set-up depending on the simulated species and the corresponding association with sediments or flow.

The calibration of TP, a specie associated with sediment loads, begins after a satisfactory calibration of sediment wash off. Potency factors *POTFW* and *POTFS* were adjusted for the cited specie. For contaminants associated with overland flow like the nitrogen species, the calibration process was focused on the adjustment of parameters related to daily accumulation rates (*ACQOP*, Kg/ha/day), accumulation limits (*SQO* and *SQOLIM, Kg/ha*) and washoff parameters.

Contributions from groundwater and interflow include parameters like *AOQC* (mg/l) and *IOQC* (mg/l) respectively in a monthly step to reflect annual variations in the concentrations. Table 4.18 summarizes the calibration statistics for total nitrates simulation complemented with graphics results depicted in Figure 4.16.

Table 4.18 Statistical indicators for calibration period in total nitrate simulation.

USGS Station	Observed Mean Daily Concentration (mg/l)	Simulated Mean Daily Concentration (mg/l)	PME (%)	Ratio*	RMSE (mg/l)
USGS 50020500 Rio Grande de Arecibo near Adjuntas	1.09	1.01	7.59	0.93	0.3
USGS 50025000 Rio Grande de Arecibo near Utuado	1.19	0.79	35.6	0.66	0.53
USGS 50026050 Rio Caonillas above Lago Caonillas	0.9	0.72	14.91	0.80	0.31
USGS 50027000 Rio Limón above Lago Dos Bocas	1.07	0.92	15.11	0.86	0.38

* Ratios calculated from Simulated and Observed concentrations.

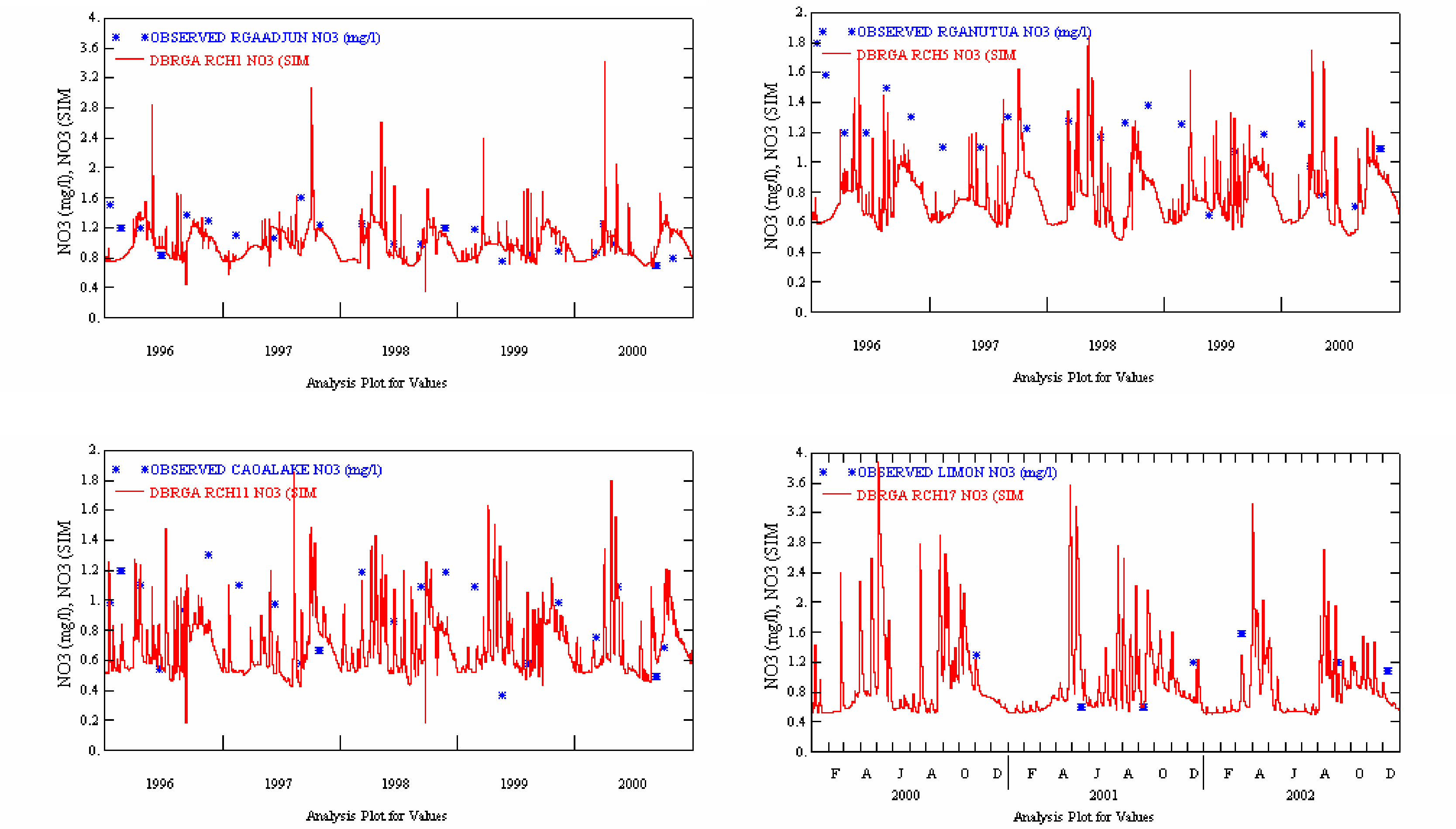


Figure 4.16 Total nitrates calibrated results for stations USGS 50020500, Rio Grande de Arecibo near Adjuntas; USGS 50025000, Rio Grande de Arecibo near Utuado, USGS 50026050; Rio Caonillas above Lago Caonillas and USGS 50027000, Rio Limón above Lago Dos Bocas

Statistical results for best-fit calibration of total nitrates show that PME was good for three of four water quality stations. Using the accepted tolerances given by Donigian et al. (2000), results fall in a *very good* calibration category. Only the USGS 50025000 station, RGA near Utuado was fair.

Referring to RMSE, results are low around 0.3. Once again, only the USGS 5002500 station reports a medium value of 0.53 according to the literature (Moriasi et. al., 2007).

Finally, the ratios between simulated and observed concentrations for the calibration period demonstrate that simulated values are generally within the twenty percent (20%) of observed values. Once again, the bigger difference was for the USGS 50025000 station with a ratio of 0.66, out of the cited boundaries.

For the TP calibration period, the results are depicted in Figures 4.17 and statistics for this nutrient are summarized in Table 4.19.

Percent mean errors in the water quality stations ranges between 13.90% and 29.24%. Comparing with the acceptable ranges reported in the literature, the total phosphorus calibration results are defined as “very good” in Río Caonillas and Río Limón and defined as “fair” results on the two analyzed RGA stations.

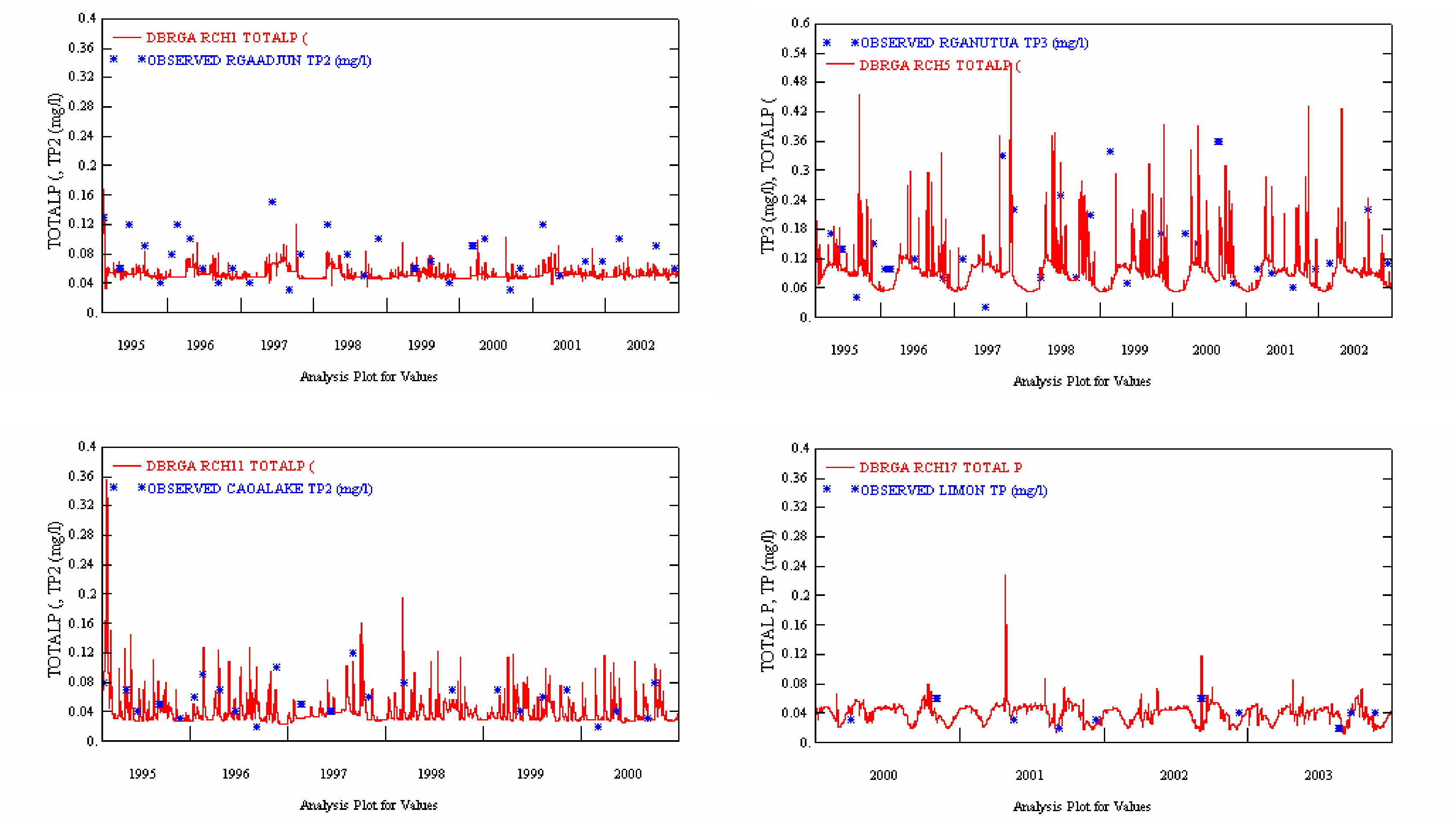


Figure 4.17 Total phosphorus calibrated results for stations USGS 50020500, Rio Grande de Arecibo near Adjuntas; USGS 50025000, Rio Grande de Arecibo near Utuado; USGS 50026050, Rio Caonillas above Lago Caonillas and USGS 50027000, Rio Limón above Lago Dos Bocas.

Table 4.19 Statistical indicators for calibration period in Total Phosphorus (TP) simulation.

USGS Station	Observed Mean Daily Concentration (mg/l)	Simulated Mean Daily Concentration (mg/l)	PME (%)	Ratio*	RMSE (mg/l)
USGS 50020500 Rio Grande de Arecibo near Adjuntas	0.08	0.05	28.19	0.63	0.04
USGS 50025000 Rio Grande de Arecibo near Utuado	0.14	0.10	29.24	0.71	0.10
USGS 50026050 Rio Caonillas above Lago Caonillas	0.06	0.04	12.85	0.67	0.03
USGS 50027000 Rio Limón above Lago Dos Bocas	0.04	0.04	-13.90	1.00	0.02

* Ratios calculated from Simulated and Observed concentrations.

Validation

The validation process, defined as an extension of the calibration, was conducted with water quality data for the period between January 2003 and July 2004 for total nitrates simulation and between January 2003 to December 2004 for TP. The validation purpose is to assure that the calibrated model properly assesses all the variables and conditions that can affect model's results.

Several approaches are available to validate a model but one of the most effective procedures is to split and use a portion of the available record of observed values for calibration. Once the model is calibrated and parameters are optimized, the next step is to run the model in the validation period and reassess the results statistically. Using this type of methodology, the obtained results are summarized in Tables 4.20 and 4.21

Table 4.20 Statistical indicators for validation period in Nitrate (NO_3^-) simulation.

USGS Station	Observed Mean Daily Concentration (mg/l)	Simulated Mean Daily Concentration (mg/l)	PME (%)	Ratio*	RMSE (mg/l)
USGS 50020500 Rio Grande de Arecibo near Adjuntas	0.75	0.98	-25.88	1.31	0.32
USGS 50025000 Rio Grande de Arecibo near Utuado	1	0.78	20.31	0.78	0.38
USGS 50026050 Rio Caonillas above Lago Caonillas	0.78	0.71	5.49	0.91	0.37
USGS 50027000 Rio Limón above Lago Dos Bocas	0.74	0.88	9.32	1.19	0.34

* Ratios calculated from Simulated and Observed concentrations.

Table 4.21 Statistical indicators for validation period in Total Phosphorus (TP) simulation.

USGS Station	Observed Mean Daily Concentration (mg/l)	Simulated Mean Daily Concentration (mg/l)	PME (%)	Ratio*	RMSE (mg/l)
USGS 50020500 Rio Grande de Arecibo near Adjuntas	0.07	0.05	28.5	0.71	0.04
USGS 50025000 Rio Grande de Arecibo near Utuado	0.10	0.10	11.97	1.00	0.04
USGS 50026050 Rio Caonillas above Lago Caonillas	0.06	0.04	23.19	0.67	0.02
USGS 50027000 Rio Limón above Lago Dos Bocas	0.05	0.04	19.93	0.80	0.02

* Ratios calculated from Simulated and Observed concentrations.

According to the results obtained from the validation process period, the model performance in the four water quality stations was acceptable for total nitrates and TP (See Table 4.9).

Percent mean errors (PME) for TN validation were below the twenty five percent suggested by Donigian et al. (2000) as *good* performance of the model. With respect to the ratios of mean simulated and mean observed values, the results shows ratios between the 20% of observed data, meaning that those ratios are mostly between 0.8 and 1.2 except for USGS 50020500 with a value of 1.3.

TP validation results from Table 4.21 indicate that with respect to PME all the stations except USGS 50020500 falls in the defined as *good* tolerance validation according to Donigian guidelines. Station USGS 50020500 has a PME around 28% meaning a fair validation for this station (greater than 25%).

4.3.5 Total nutrients annual loads

Based on the results from the calibrated and validated water quality model, the total annual loads from each sub-watershed were computed. HSPF and more specifically the modules PQUAL and IQUAL simulate the total nitrates and total ammonia nitrogen species individually. In order to compute the total nitrogen annual loads from the individual simulated species, a pre-established relationship based on observations of nitrogen species by the selected USGS monitoring stations was developed. The USGS monitoring record expands from the 1995 to 2002.

The nitrogen species relationship allows the conversion from one nitrogen specie to another form at the four USGS stations analyzed in the Río Grande de Arecibo watershed. These relationships apply only to the study area and can not be generalized or transfer to other locations. Table 4.22 shows the above mentioned relationships where TAM refers to total ammonia, ON refers to organic nitrogen fraction and TKN refers to Total Kjeldahl Nitrogen defined as the sum of ON plus TAM.

Total nitrogen (TN) is defined as the sum of TKN plus the total nitrates and can be given by the Equation 4.8:

$$TN = NH_3 + NH_4^+ + ON + NO_2^- + NO_3^- \qquad (4.8)$$

$$TN = TAM + ON + NO_2^- + NO_3^-$$

$$TN = TKN + NO_2^- + NO_3^-$$

Table 4.22 Nitrogen relationships between species at Río Grande de Arecibo watershed

Station USGS	n*	% (TAM/TN)	% (ON/TN)	% (TKN/TN)	% (NO_3^- /TN)***
USGS 50020500 Río Grande de Arecibo near Adjuntas	40	3.29	18.22	21.51	78.49
USGS 50025000 Río Grande de Arecibo near Utuado	38	4.03	24.69	28.72	71.28
USGS 50026050 Río Caonillas above Lago Caonillas	39	2.39	25.82	28.21	71.79
USGS 50027000 Río Limón above Lago Dos Bocas	11**	1.43	21.13	22.56	77.44

* Total number of data (start year 1995: last year 2004).
** Station USGS 50027000; data begin in the 2000 year and finish in 2004.
***RGA show insignificant values of nitrites with respect to nitrates, meaning that total nitrates correspond to NO_3^-

Total nitrogen annual loads and the total phosphorus annual loads are reported for the ten-year simulation period in which different hydro-meteorological conditions were considered and reflected in the calculated loadings. One of the main temporal variables reflected in the annual loadings is the precipitation in the area and still more important the associated flow at each monitoring station.

Results are summarized in Tables 4.23 and 4.24 reflecting the dry and wet conditions in the annual loadings. The station USGS 50020500 is not included because the USGS 50025000 is on the same reach but downstream near Lake Dos Bocas. Values in parenthesis refer to general yield or export coefficients by sub-watershed and it will be broken down by land use in the next section.

In addition, a linear regression analysis was performed using the results from the previous tables to analyze the relation between annual loadings and mean daily flow for each year and subwatershed. Results are presented in Figure 4.18 and 4.19 and respective equations detailed in Tables 4.25 and 4.26 respectively for all the water quality stations.

Results showed an excellent fit adjusting the relationship between annual loadings and mean daily annual flow with R^2 values between 0.94 and 0.97 corresponding to total nitrogen and between 0.92 and 0.99 for total phosphorus.

Obtained regressions constitute a useful tool to predict loads at the RGA watershed for different time periods. The ten-year annual loadings record allows the user to obtain confidence in the results because they are derived from a set of different conditions in the study area.

Table 4.23 Total Nitrogen Annual Loads at Lago Dos Bocas, Río Grande de Arecibo.

USGS STATION	AREA (Ha)	Total Nitrogen Annual Loads (Kg) and Nitrogen Yield (Kg/Ha-yr)									
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
50025000	20,829	186,896 (9.0)	75,897 (3.6)	249,735 (12.0)	262,130 (12.6)	175,821 (8.4)	130,211 (6.3)	170,279 (8.2)	197,890 (9.5)	221,820 (10.6)	293,444 (14.1)
50026050	12,338	90,193 (7.3)	43,212 (3.5)	134,432 (10.9)	122,410 (9.9)	85,270 (6.9)	65,367 (5.3)	70,363 (5.7)	84,767 (6.8)	110,698 (8.9)	144,787 (11.7)
50027000	9,974	62,732 (6.3)	7,804 (0.8)	78,991 (7.9)	53,441 (5.4)	77,805 (7.8)	77,643 (7.8)	96,700 (9.7)	106,873 (10.7)	151,702 (15.2)	171,439 (17.2)
TOTAL		339,837 (7.7)	126,920 (2.9)	463,181 (10.5)	438,005 (9.9)	338,911 (7.7)	273,232 (6.2)	337,356 (7.6)	389,546 (8.8)	484,239 (11.0)	609,696 (13.8)

*Values in parenthesis represent the Yield (Kg/Ha-yr)

Table 4.24 Total Phosphorus Annual Loads at Lago Dos Bocas, Río Grande de Arecibo.

USGS STATION	AREA (Ha)	Total Phosphorus Annual Loads (Kg) and Phosphorous Yield (Kg/Ha-yr)									
		1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
50025000	20,829	16,197 (0.8)	7,812 (0.4)	33,249 (1.6)	27,870 (1.3)	18,845 (0.9)	15,303 (0.7)	14,644 (0.7)	21,082 (1.0)	23,329 (1.1)	32,822 (1.6)
50026050	12,338	4,250 (0.3)	1,823 (0.1)	6,870 (0.6)	5,018 (0.4)	3,478 (0.3)	3,008 (0.2)	2,592 (0.2)	3,692 (0.3)	4,603 (0.4)	5,531 (0.4)
50027000	9,974	2,169 (0.2)	294 (0.0)	2,731 (0.3)	1,672 (0.2)	2,175 (0.2)	2,488 (0.2)	3,004 (0.3)	3,001 (0.3)	3,598 (0.4)	5,523 (0.6)
TOTAL		22,618 (0.5)	9,930 (0.2)	42,852 (1.0)	34,562 (0.8)	24,499 (0.6)	20,800 (0.5)	20,241 (0.5)	27,777 (0.6)	31,532 (0.7)	43,878 (1.0)

*Values in parenthesis represent the Yield (Kg/Ha-yr)

Table 4.25 Linear regression analysis between mean annual daily flow and total annual nitrogen loadings

Station	Linear regression equation	R^2
50025000	TN_Annual_Load (Kg) = 1020.8*Qmadf (m3/s)+ 5220.6	0.97
50026050	TN_Annual_Load (Kg) = 29032*Qmadf (m3/s) + 11031	0.94
50027000	TN_Annual_Load (Kg) = 36591*Qmadf (m3/s) + 14575	0.94

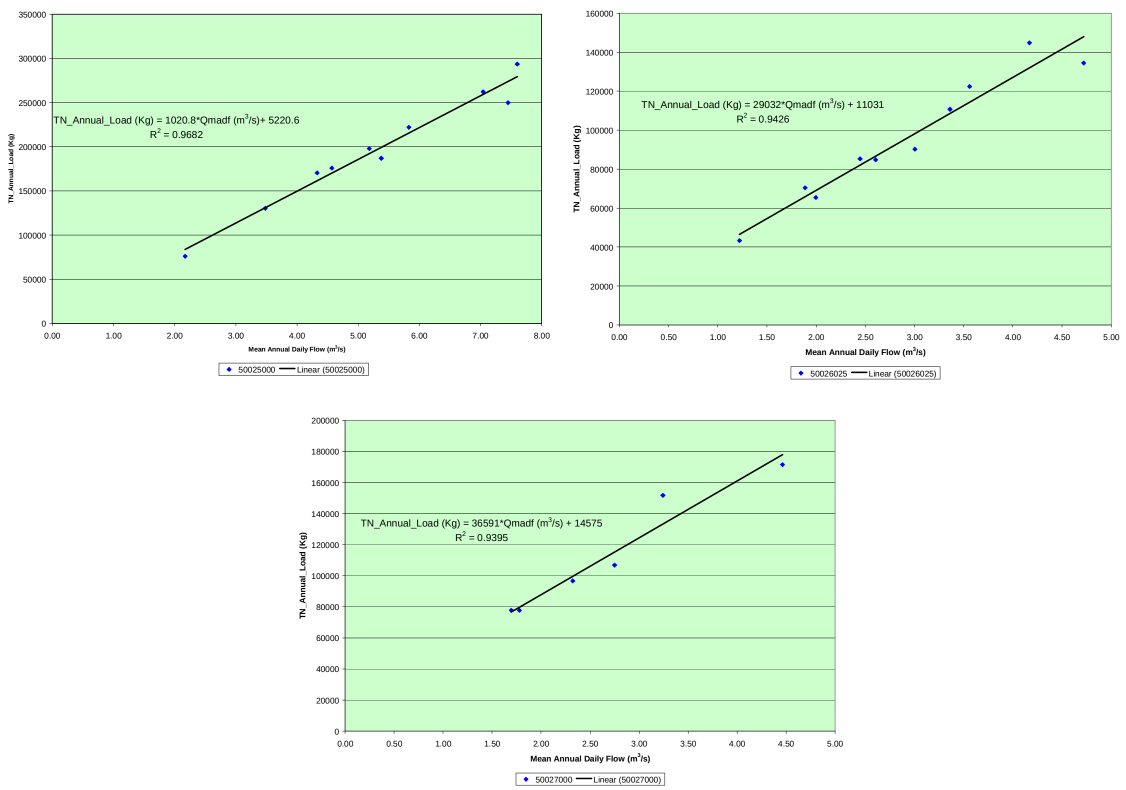


Figure 4.18 Mean annual daily flow vs total nitrogen annual loads at measurement stations (A) USGS 50020500, (C) USGS 50026050 and (C) USGS 50027000

Table 4.26 Linear regression analysis between mean annual daily flow and total annual phosphorus loadings

Station	Linear regression equation	R^2
50025000	TP_Annual_Load (Kg) = 4519*Qmadf (m3/s) - 2854.9	0.92
50026050	TP_Annual_Load (Kg) = 1371.5*Qmadf (m3/s) + 112.61	0.99
50027000	TP_Annual_Load (Kg) = 1120.5*Qmadf (m3/s)+ 263.02	0.95

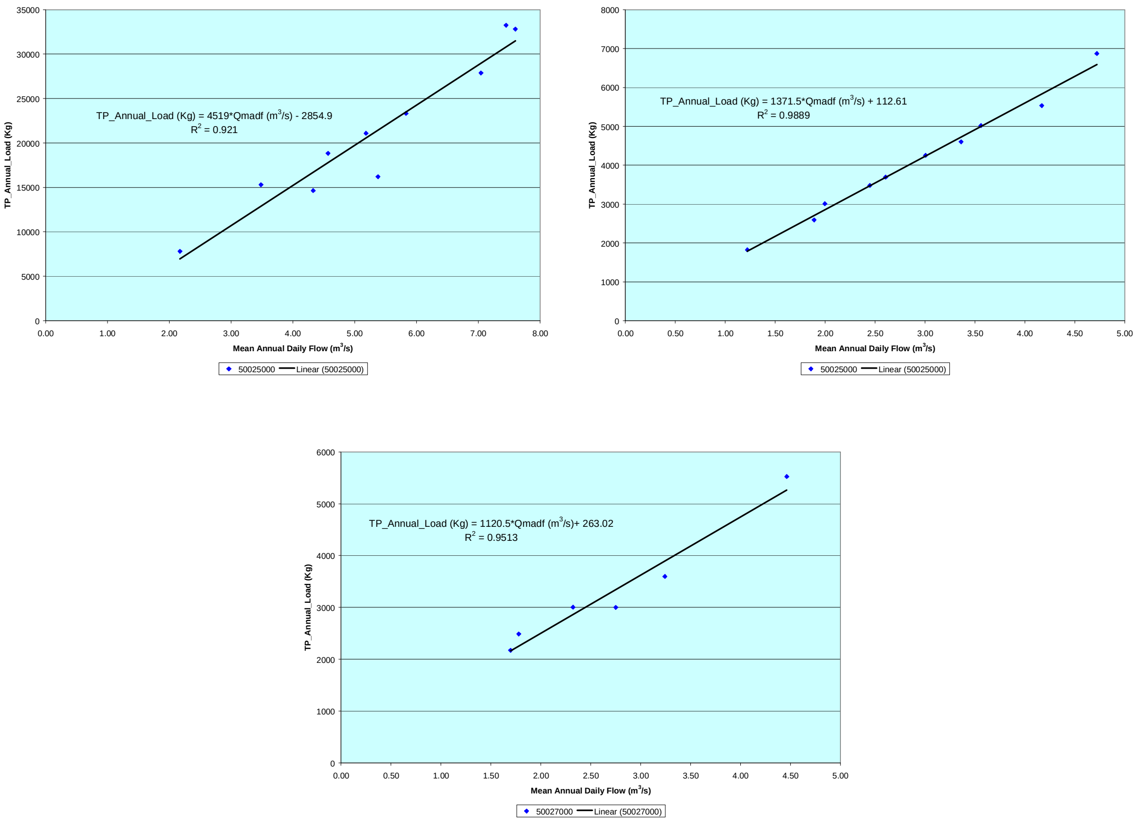


Figure 4.19 Mean annual daily flow vs total phosphorus annual loads at measurement stations (A) USGS 50020500, (C) USGS 50026050 and (C) USGS 50027000

4.3.6 Export coefficients by land use

This section presents the nutrients export coefficients detailed by land use from the HSPF modeling results. The export coefficients are the main input for the uncertainty multi-objective optimization approach that is one of the main objectives of this investigation and is discussed in Chapter V of this dissertation. The export coefficients presented in this investigation are the first attempt to measure and model nutrient export coefficients in Puerto Rico using a continuous simulation approach. Previous studies in Puerto Rico reported export coefficients ranges but only for a limited number of land uses and do not take into account the watershed context analysis (Ortiz-Zayas, 2006; Ramos-Ginés, 1997; McDowell, 1994).

Studies in the island and other latitudes are mainly based on sampling at the site and post-analysis using statistical or mathematical techniques. Most techniques include regression analysis or sampling events integration to generate loadings estimation for an established period in a short term period.

The results reported in this study were generated using a hydrologic, sediment and water quality long term continuous simulation (1996-2005), calibrated and validated with field measured data and considering the most important inputs and parameters from a physical view of the system.

Export coefficients are very useful indicators that allow predicting the possible yield of nutrients or sediments reaching receiving water bodies. Those values are the combination of a lot of site specific conditions and variables at the subwatershed level including hydro metereological, topographic, land use management practices and physical characteristics.

Results are presented individually for each subwatershed at the Río Grande de Arecibo watershed and compared with the reported literature ranges around the world and more specifically for tropical and subtropical regions. Some values from local Puerto Rico studies were evaluated.

Tables 4.27 and 4.28 summarize the obtained export coefficients. For multi-objective optimization approach purposes, those ranges were separated into export coefficients for wet years (includes extreme storm events like hurricanes), and export coefficients for normal hydrological conditions years.

Table 4.27 Total nitrogen export coefficients by sub-watershed.

Land Use	Sub-watershed		
	Río Grande de* Arecibo (Kg/Ha*yr)	Río Caonillas* (Kg/Ha*yr)	Río Limón** (Kg/Ha*yr)
Urban	6.82 – 14.91	6.12 – 13.08	8.53 – 14.63
Pasture	9.53 – 31.65	6.86 – 34.10	11.33 – 33.10
Agriculture	14.07 – 41.13	5.63 – 39.74	21.65 – 41.06
Forestland	2.02 – 5.41	1.64 – 6.15	3.12 – 6.72
Rangeland	2.12 – 5.56	2.25 – 7.158	3.63 - 5.90
Mean Annual Daily Flow (m^3/s)	2.17 – 7.60	1.22 – 4.72	1.70 – 4.46

* Results correspond to 1996-2005 period.
** Results correspond to 2000-2005 period.

Table 4.28 Total phosphorus export coefficients by sub-watershed.

Land Use	Sub-watershed		
	Río Grande de* Arecibo (Kg/Ha*yr)	Río Caonillas* (Kg/Ha*yr)	Río Limón** (Kg/Ha*yr)
Urban	2.94 – 4.65	1.39 – 4.15	0.66 – 3.06
Pasture	1.18 – 3.10	0.18 – 2.07	0.14 – 1.88
Agriculture	1.16 -3.91	0.32 – 2.24	0.37 – 1.92
Forestland	0.16 – 0.47	0.05 – 0.36	0.06 – 0.33
Rangeland	0.17 – 0.52	0.06 – 0.22	0.08 – 0.49
Mean Annual Daily Flow (m^3/s)	2.17 – 7.60	1.22 – 4.72	1.70 – 4.46

* Results correspond to 1996-2005 period.
** Results correspond to 2000-2005 period.

Obtained export coefficients were compared with those reported in the literature, especially for tropical or sub-tropical watersheds. In this sense works from New Zealand and properly Puerto Rico were considered. Differences can be associated to local conditions at each study area. Additionally, works from United States of America were taken into account obtaining a considerable set of ranges to compare with values obtained in this investigation. All the available sources are summarized in Tables 4.29 and 4.30 for total nitrogen and total phosphorus species respectively.

Table 4.29 Río Grande de Arecibo land use export coefficients and literature comparison (Total nitrogen)

Land Use	This study	Total nitrogen export coefficients (Kg/ha*yr)							
		Puerto Rico and New Zealand				United States of America			
		Ramos - Ginés Puerto Rico (1998)	Ortiz-Zayas Puerto Rico (2006)	McDowell and Asbury Puerto Rico (1994)	Quinn & Stroud New Zeland (2002)	USEPA (1982)	Beaulac & Rechow (1982)	Donigian et al. (1990)	Omernick (1976)*
Agriculture	**5.6 - 41.1**	6.9 – 8.6	26.9 – 39.7	------	6.76 (Mixed agriculture)	9.0 – 20.2	2.5 – 41.5	5.6 – 78.4	4.2 – 38.0
Urban	**6.1-14.9**	6.6 – 17.1	4.8 - 33.0	------	------	4.5 - 11.2	1.6 – 38.5	5.6 – 28	2.0 – 17.0
Pasture	**6.9 - 34.1**	------	------	------	10.0 – 35.3	2.2 – 6.7	2.0 – 30.8	1.7 – 7.8	----
Forest	**1.6 – 6.7**	2.7	------	4.4 – 9.8	2.1 – 3.7	0.6 – 2.2	1.6 – 6.5	0.2 – 5.6	----
Rangeland	**2.1 – 7.2**	------	------	------	------	------	------	------	------

Table 4.30 Río Grande de Arecibo land use export coefficients and literature comparison (Total phosphorus)

Land Use	This study	Total phosphorus export coefficients (Kg/ha*yr)							
		Puerto Rico and New Zealand			United States of America				
		Ramos - Ginés Puerto Rico (1998)	McDowell and Asbury Puerto Rico (1994)	Quinn & Stroud New Zeland (2002)	USEPA (1982)	Beaulac & Rechow (1982)	Donigian et al. (1990)	Frink (1991)*	Ott et. al (1990)
Agriculture	**0.3 – 3.9**	1.5 – 2.0	------	1.33 (Mixed agriculture)	0.3 – 5.0	0.1 – 3.3	0.6 – 5.6	0.4 – 0.7	1.9 – 2.5
Urban	**0.7 - 4.7**	2.6 – 7.1	------	------	0.03 – 2.5	1.1 – 2.2	0.6 – 3.4	1.5 – 1.9	0.7 – 0.8
Pasture	**0.1 – 3.1**	------	------	1.16 – 3.24	0.3 – 0.6	0.01 – 4.9	0.1 – 1.0		
Forest	**0.05 – 0.5**	0.4	4.4 – 9.8	0.58	0.01 – 0.9	0.01 – 0.9	0.06 – 0.3	0.07 – 0.1	0.03 – 0.05
Rangeland	**0.06 – 0.5**	------	------	------	------	------	------	------	------

RGA watershed has some characteristics like hydro-meteorological and physical conditions, topography, land use distribution, soils classes and agricultural practices that are similar to the found in other places at the island. This implies that obtained export coefficients intervals could be used in other locations of Puerto Rico with similar conditions to RGA.

According with literature, nutrients export coefficients show low values for land uses like forest and rangeland. Agricultural and urban areas report the larger annual yield values, representing the most problematic areas in the water quality pollution process.

Reported ranges for Puerto Rico in urban and agricultural activities are different because study conditions were not the same with respect to conditions in this study. Ortiz-Zayas et al. (2006), report 32.9 Kg/ha-yr for urban total nitrogen export coefficient at the Río Piedras watershed. This value is greater than the reported in this study because the Río Piedras watershed belongs to the San Juan metropolitan area (SJMA), the most densely populated area in the island.

For Río Grande de Loíza watershed, the land use and urban influences are similar to those founded at RGA watershed. For this reason urban export coefficients falls in similar ranges for both areas. Río Grande de Loíza reported an upper boundary value of 16.9 Kg/ha-yr compared with 14.9 Kg/ha-yr in RGA watershed.

In the agricultural case, export coefficients reported by Ortiz Zayas et al. (2006) in the Río Grande de Añasco compares well with those reported in this investigation. The reason is associated to similar local conditions at both areas, where milk production and meat cattle are the predominant agricultural activities. For the Río Grande de Añasco, the upper boundary of TN export coefficient was 39.7 Kg/ha-yr compared with 41.1 Kg/ha-yr of this study, reflecting the above mentioned similar conditions.

For TP, obtained land use export coefficients interval shows similar upper boundaries with those reported in tropical and sub tropical areas. RGA forest land use compares well in the upper limit (0.5 Kg TP/ Ha*yr) with respect to Ramos-Ginés (1998) value (0.4 Kg TP/ Ha*yr) and respect to the value reported by Quinn and Stroud in New Zealand (0.58 Kg TP/ Ha*yr).

For agriculture, the upper limit of the interval reported by Ramos-Ginés fall around the mid value of the interval from RGA watershed (2 Kg TP/ ha*yr) and for Pasture land use the upper limit of RGA is close to the upper limit reported by Quinn and Stroud.

Finally, RGA intervals show some similarities with reported values for temperate areas at the United States of America. TP export ranges from USEPA agency and those reported by Beaulac and Rechow (1980) are similar for agriculture and forest land uses. Urban interval reported by Donigian (1990) is similar with the obtained in RGA watershed with values between 0.6 and 3.4 against 0.7 and 4.7 Kg TP/ ha*yr respectively.

Summarizing, RGA watershed reports similar land use nutrients export coefficients with those from literature, differing in the wide of the interval obtained for RGA due to the extended simulation that considers a lot of possible combinations in the input parameters and thus reflected in the output. Additionally to the nutrients export coefficients, the MOLP discussed in Chapter VI includes sediment export coefficients for the same RGA watershed reported by Suárez (2005).

4.4 SUMMARY AND CONCLUSIONS

The development of a water quality model based on hydrologic and sediment simulation constitutes a robust base for the development of a methodology to find the future optimal land use growth combination considering environmental and socio-economic factors at the watershed level.

Additionally, the watershed simulation methodology presented here is robust and heavily based on the best science available to support local and federal agencies in the development of TMDL's for lakes and rivers listed as impaired waters (303d. list) by the USEPA and the local PREQB.

HSPF was selected as the water quality model, designed to support watershed based analysis and TMDL development. This model is a process-based, lumped and continuous developed under the USEPA sponsorship.

Reasons to HSPF selection in this research were:

1. HSPF is a process based continuous hydrological model which has been successfully applied in the same study area in Puerto Rico (Díaz, 2004; Suárez 2005).
2. The model is endorsed by the USEPA for TMDL development.
3. The research group has acquired significant experience using the model.
4. The input data for the model is available in Puerto Rico.

The results from the ten year water quality simulation allowed finding the land use export coefficients utilized as the input for the multi-objective optimization approach that will be discussed in Chapter V of this document. One of the main advantages of the long term simulation is the consideration of different conditions at the watershed level reflected in the obtained export coefficients ranges.

Additional benefits from the continuous calibrated and validated simulation include the analysis of hypothetical scenarios with different conditions at the analyzed watershed. It allows the evaluation of the watershed behavior under possible future conditions as well as to provide a planning tool for regulatory environmental agencies in Puerto Rico to use and develop better management programs.

Specifically, with respect to the water quality model simulation, some recommendations and conclusions in this research are:

1- Previously to water quality simulation, the hydrological and sediments calibration and validation plays a crucial role in the results.

2- It is very important to evaluate all the parameters in the model and determine those that need to be calibrated. Additionally, a sensitivity analysis allows the user to focuses the efforts on the most sensitive parameters (See Appendix B).

3- In addition to the utilized PQUAL and IQUAL, the Agricultural-Chemical module (AGCHEM) could be incorporated to the model in the future for a more detailed agricultural land use simulation. The incorporation will depend on the modeling purpose and the available of extensive data required for this module.

4- Results from calibration and validation periods were good according with the literature suggested guidelines and statistical parameters. Hydrologic and sediment calibration results allow a solid base for nutrients simulation. Water quality model performance evaluation was in agreement with available data and general criteria for this kind of constituents. Scarcity of water quality data to calibrate a model tends to limit the results and model evaluation.

5- Appendix B summarizes all the parameters and bold the most sensitive parameters for the hydrologic, sediments and water quality simulation at RGA watershed.

6- Previous studies using HSPF at the RGA watershed evaluated the most sensitive parameters associated to hydrology and sediments using a local and global sensitivity analysis methodology (Díaz, 2004; Suárez 2005). For the hydrology component, parameters associated to infiltration, percolation and interflow defined by LZSN, INFILT, INFFEXP, INFILD, UZSN, INTFW and IRC were the most sensitive. For soil erosion and sediment simulation, the most sensitive parameters were JSER, KGER, JGER, associated to wash-off erosion and gully erosion. Additionally, parameters associated to sediment transport in the main channel including KSAND, EXPSND, TAUCS y M were sensitive for the simulation model.

7- For nutrient species associated with overland flow, the adjustment of parameters was focused on the ACQOP, SQOLIM and WSQOP defined as the rate of accumulation and surface runoff as well as the maximum storage for each constituent respectively.

8- Associated to the calculated sediment loadings in the Dos Bocas reservoir and complemented with historical trends, the accelerated sedimentation has been considered a problem in the study area for water supply capacity. In terms of nutrients and using the time of residence of the Lake Dos Bocas (22 times for year of renovation) and the respective volume (16E6 m^3), actual conditions help to mitigate the eutrophication problem due to the relative short contact time of water entering the lake. This does not mean eutrophication is not a problem at the reservoir but it will be worst with a greater storage volume.

CHAPTER V

MULTI-OBJECTIVE OPTIMIZATION APPROACH FOR LAND USE OPTIMAL DEVELOPMENT

5.1 ABSTRACT

Chapter V applies a multi-objective optimization linear programming (MOLP) approach considering uncertainties associated with decision variables (land use export coefficients, Table 4.27 and 4.28), for the evaluation of multiple scenarios to obtain sustainable strategies for optimal land use increase and distribution in the RGA watershed. The studied scenarios consider several factors including environmental, physical, social and economical factors as part of the decision making process. This approach is one of the components together with a GIS model for the land allocation system developed in this research. The advantage of the multi-objective optimization approach is to optimize independent objectives at the same time. The objective functions lie in the need to address the environmental goals in order to meet the water quality standards imposed by the USEPA and the PREQB agencies, regarding nutrient loadings of total phosphorus (TP), total nitrogen (TN) and total sediments (TS).

5.2 INTRODUCTION

Multi-objective optimization linear programming (MOLP) approach deals with several independent objectives and tries to solve them simultaneously. In such situations, it may be impossible to find a single solution that optimizes the conflicting objectives. Instead, a compromise solution based on the relative importance of each objective is searched and simultaneously optimized for the conflicting objectives. A Pareto optimal solution is a commonly used term in multi-objective optimization and refers to solutions equally good with respect to others (Deb, 2001).

A Pareto optimal set of solution is such that when we go from any one point to another in the set, at least one objective function improves and at least one other worsens (Yee et al., 2003). Neither solution dominates over each other. All the sets of decision variables on the Pareto front are equally good and are expected to provide flexibility for the decision maker. Normally, the decision about “what the best answer is” corresponds to the so-called decision maker (Coello, 1999).

Classical and evolutionary algorithms are two main groups of solution methods for handling MOLP problems. Classical methods have been around for at least the past forty years. During those years numerous algorithms were developed by researchers. Although the origins remount to the late 1950s, the evolutionary algorithms started to receive significant attention during the last decade.

In water resources problems as well as in many modeling situations, it is unreasonable to assume that the coefficients or functions in optimization problems are deterministically fixed values. Most real-world situations are characterized by limited to no data. Often, data is difficult to obtain, relies on estimates and is subject to changes. As a result, these combinations create uncertainty in the analyzed system and therefore deterministic optimization techniques are not sufficient to model uncertainties sources associated with variation in model parameters.

Several methods have been used to tackle uncertainty in optimization problems. Some of the methods used are the fuzzy multiobjective optimization, stochastic multiobjective optimization and multiobjective linear programming with interval coefficents. In the fuzzy multiobjective optimization method, it is important to define a so called *membership function* that simulates a possibilistic distribution in variable coefficients. In the stochastic method a probability distribution is needed and in the linear programming with interval coeffcients method only a range of variation for each parameter is needed.

5.2.1 Multi-Objective Optimization Applied to Water Resources

In water resources multi-objective optimization and system planning, researchers have focused on the goal that pursues the sustainable land development, water resources conservation, and water quality management by using deterministic multi-objective programming techniques (Chang *et al.*, 1995). Goicoechea and Duckstein (1976) illustrated the use of multi-objective programming models in a watershed land management project without considering environmental factors. Van and Nijkamp (1976) presented a multi-objective decision model for optimizing regional development, environmental quality control and industrial land use. Das and Haimes (1979), applied multi-objective optimization techniques in a river basin planning project. Two broad based planning objectives considered in their project were: economic development and environmental quality. Both impacts of point and nonpoint source pollutants on water quality were evaluated in various land management scenarios. Ridgley and Giambelluca (1992) applied a water balance simulation model for calculating groundwater recharge as it varies with land use in a multi-objective programming framework.

Beck stated that the random character of the natural processes governing water resources, the estimation errors in parameters of water quality models, and the vagueness of planning objectives and constraints are all possible sources of uncertainty (Beck, 1987).

Chang et al. (1995;1997), incorporated the uncertainty in the analysis using a fuzzy multi-objective approach for the evaluation of sustainable management strategies of optimal land development in the analyzed reservoir watershed. The obtained results demonstrated how imprecise information in such a system can be quantified by specific membership functions in a fuzzy multi-objective analytical framework.

Wang and Huang (2003) uses Inexact-fuzzy multio-bjective optimization approach (IFMOP) to solve a problem in Lake Erhai basin, China. Findings of this research responds to questions like *what should I do?* and *how do I do it?* in land use planning process.

5.3 METHODOLOGY

Multiple scenarios were evaluated to obtain sustainable strategies for optimal land use growth in the RGA watershed using a Multi-objective Linear Programming Approach (MOLP). Two different algorithms in combination with several hypothetical scenarios were used as solution methods, reflecting spatial, socio-economic, physical, and political factors.

5.3.1 Multi-objective Optimization Solution Methods

Two differents methods were used to solve the land use planning scenarios. The first method used was based on the Goal Programming method developed by Charnes et al. (1955), specifically the weigthed goal programming method. The second method used was the Goal Attainment method used by Gembicki and Haimes (1975). This implies the construction of a set of goal values for the objective functions.

It is well known that uncertainty plays an important role in optimization problems, therefore based on the results from the water quality simulation in HSPF, the land use export coeffcients intervals obtained were introduced into the MOLP analysis to reflect the stochastic nature of the problem. Land use export coeffcients intervals responded to the results from a ten years continuous simulation (1995-2005) using HSPF. Outputs from HSPF reflected the variability of the response to the number of parameters in the model and the different uncertainties in the export coefficients. Factors like sub-watershed physical charateristics (slope, area); hydrometereological behavior (rain spatial and temporal distribution) were reflected in the export coefficients intervals from a calibrated hydrologic, sediments, and water quality model.

The optimization model developed in this research is robust because it included the uncertainties and consequently the stochasticity of the landuse allocation system analysed in this project. Optimization results reflects the inherent uncertainty associated to the land use planning and decision making process giving to it the fortress and soundness required to support their implementation.

5.3.1.1 Goal Attainment algorithm description

The use of a multi-objective optimization approach is of some concerns because it minimizes a set of objectives simultaneously. One formulation for this problem which was implemented in this research is the goal attainment problem from Gembicki (1975).

The optimization strategy of Goal Attainment method allows the objectives $F(X) = [f_1(X),\ f_2(X),\ ....,\ f_m(X)]^T$, to be under or over-achieved according to the preset design goals $\left[f_1^*, .f_2^*, ... f_m^*\right]^T$. The preference information is the vector of weight coefficients $\left[w_1, .w_2, ... w_m\right]^T$. For a multiple-objective optimization problem, the standard goal attainment formulation is given by:

$$\text{Minimize} \quad \gamma;$$
$$\text{where } \gamma \in \Re$$

subject to:

$$f_i(X) - w_i * \gamma \leq f_i^*; \ \forall \ i = 1, ..., m$$

where the term $w_i * \gamma$ introduces an element of slackness so that hard constraints, $f_i(X) \leq f_i^*$ are avoid. The weighting vector, ***W***, enables the designer to express a measure of the relative tradeoffs between the objectives. For instance, setting the weighting vector W equal to the initial goals indicates that the same percentage under- or overachievement of the goals, F^*, is achieved. Also, incorporates hard constraints into the design by setting a particular weighting factor to zero (i.e., $w_i = 0$) is possible using this method.

The goal attainment method is a power tool to find the best compromise solution in multiobjective problems and it is not subject to convexity limitations. It provides a convenient intuitive interpretation of the problem design, which are solvable using standard optimization procedures.

A geometrically illustration of the goal attainment method is presented in the Figure 5.1 for a two dimensional problem, whose equations are given by:

$$\text{Minimize} \quad \gamma$$

$$; \text{where } \gamma \in \Re$$

such that:

$$f_1(X) - w_1 * \gamma \leq f_1^*$$

$$f_2(X) - w_2 * \gamma \leq f_2^*$$

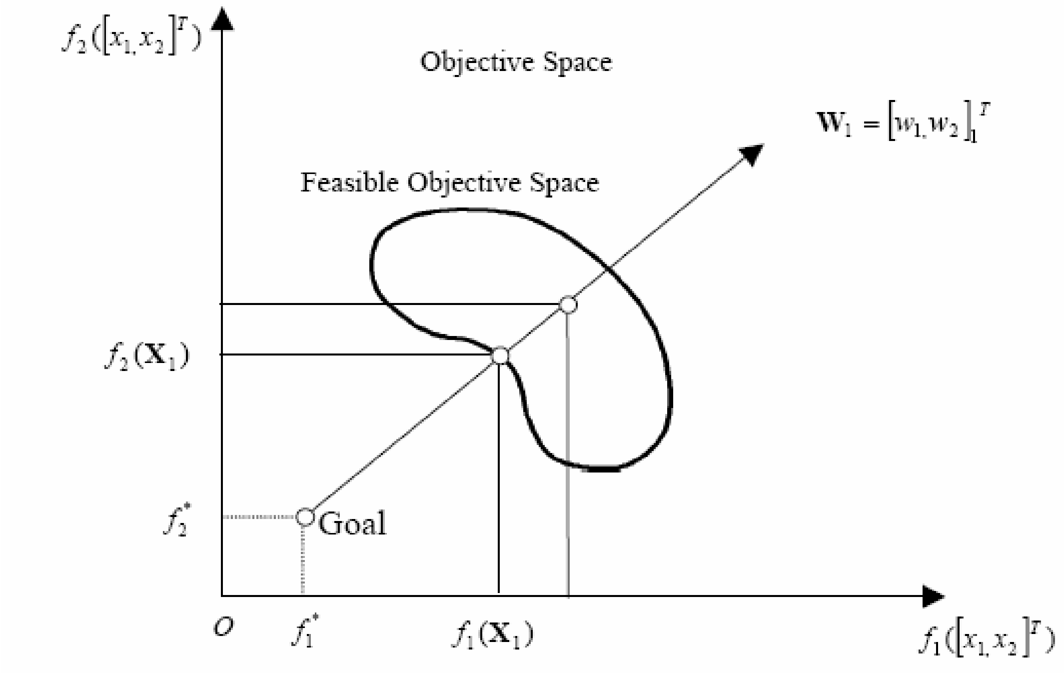


Figure 5.1 Goal attainment geometrically two dimensions illustration (From MATLAB User's Manual)

Specification of the goals, $[f_1^*, f_2^*]$ defines the goal point, **"Goal"**. The weighting vector $[w_1, w_2]$, defines the direction of search from **"Goal"** to the feasible objective space. During the optimization γ is varied, which changes the size of the feasible region.

The MATLAB software, version 7 from MathWorks was utilized to solve the goal attainment problem using the *fgoalattain* function.

Although the problem to solve in this research is a linear programming approach, the goal attainment method has the advantage that it can be posed as a nonlinear programming problem and solved by a Sequential Quadratic Progamming (SQP) method.

5.3.1.2 Goal Programming algorithm description

Goal programming was first introduced in an application of a single-objective linear programming problem by Charnes et al. (1955). However, goal programming gained popularity after the work of Ignizio (1976), Lee (1972), and various others (Deb, 2001).

This method can be thought of as an extension or generalization of linear programming to handle multiple, normally conflicting objective measures and where a compromise solution instead of a single solution is looked for, based on the relative importance of each objective. Each of these measures is given a goal or target value to be achieved. Unwanted deviations from this set of target values are then minimized in an achievement function. This can be a vector or a weighted sum dependent on the goal programming variant used.

Conceptually, the goal programming works as follows:

$$\text{goal} \quad \left(f(x) = t\right),$$

$$x \in S; \qquad \text{with } S \text{ the feasible search region}$$

This problem has two possible cases. The first one is when the target value t is smaller than the optimal objective value $f(x^*)$, meaning that no feasible solution exists to attain the goal exactly. The objective of goal programming is then to find that solution which will minimize the deviation d between the achievement of the goal and the aspiration target t. In this case the solution is still x^* and the overestimate is $d = f(x^*) - t$.

The second case is when the target t is larger than the maximum feasible cost $f_{\max}$, the solution of the goal programming problem is x which makes the objective value exactly equal to t. Although this solution may not be the optimal solution of the constrained $f(x)$, this solution is the outcome of the above goal program (Deb, 2001).

Although the above conceptual example is for a single function, the concept in a multi-objective optimization problem can be applied in the same way.

Weighted Goal Programming

To solve a multi-objective optimization problem using this method, a composite objective function with deviations from each of M objectives is used. Mathematically, we have:

$$\text{Minimize } \sum_{j=1}^{M} \left(\alpha_j \rho_j + \beta_j \eta_j \right),$$

$$\text{Subject to } f_j(x) - \rho_j + \eta_j = t_j, \qquad j = 1,2,\ldots, M$$

$$x \in S$$

$$\eta_j, \rho_j \geq 0, \qquad j = 1,2,\ldots, M$$

Where the α_j and β_j are weighting factors for positive and negative deviations of the $j-$th objective. For less-than-equal-to type goals, the parameter β_j is zero and for the greather-than-equal-to type goals, the α_j is zero.

In the Goal Programming method two classes of restrictions are considered; the system constraints and the goal constraints.

5.3.1.3 Interface for uncertainty analysis consideration

Both methods described above are deterministic and do not consider the inherently uncertainty associated to real world situations. In this sense, the sustainable land development problem associated to water resources conservation and water quality is a characterized problem to have uncertainty in almost all the process. To address this uncertainty, a methodology that considers uncertainty in the decision variables coeffcients of a MOLP is used.

In order to consider the uncertainty nature of the problem, the obtained land use export coefficients intervals from a ten years water quality simulation were used as the decision variables coefficients inputs in the MOLP model. This analysis allows considering multiple random samples in those decision variables to generate multiple runs and determine the optimal solution of the conflictive objectives. Equation 5.1 defines the MOLP problem with the associated uncertainty in the decision variables coefficients.

$$Min\ [f_1(X),\ f_2(X),...,\ f_n(X)]^T \tag{5.1}$$

where:

$$X = x_1,\ x_2,...,x_n$$

and subject to:

$$\sum_{j=1}^{n}\left[a_{ij}^L,\ a_{ij}^U\right]x_j \le 0$$
$$\sum_{j=1}^{n}\left[b_{ij}^L,\ b_{ij}^U\right]x_j = 0$$
$$x_j \ge 0,\quad j = 1,...,n$$

where $f_n(X)$ is the *n*-th objective function, $\sum_{j=1}^{n}\left[a_{ij}^L,\ a_{ij}^U\right]x_j \le 0$ and $\sum_{j=1}^{n}\left[b_{ij}^L,\ b_{ij}^U\right]x_j = 0$ are the inequality and equality constraints, respectively, X is the vector of optimization or decision variables and the intervals in the constraints reflects the incorporated uncertainty in the decision variables coeffcients. The solution to the above problem is a set of Pareto points.

RGA land use export coefficients incorporate uncertainty due to considered variables in the water quality simulation. Hydro-meteorological variables like precipitation, wind speed, solar radiation, evapotranspiration, and air temperature were used along the simulation period. The physical characteristics of each subwatershed such as elevation, slope, areas, land use, and soils classification, and are incorporated in those coefficients reflecting multiple possible combinations in the analyzed system (watershed).

To construct the multiple runs a custom made interface was created between Microsoft EXCEL and MATLAB or LINGO software depending on the used solution method. The interface allows setting up a specific scenario from a work sheet in Excel. The land use export coefficients intervals are used to create a random sample of decision variables coefficients used as input in the multi-objective optimization models and load it into the respective software.

The interface allows the user to create an infinite number of automatically runs, necessary to evaluate the system and determine the best solution for land development. Also this interface allows running automatically once the EXCEL worksheet is set up.

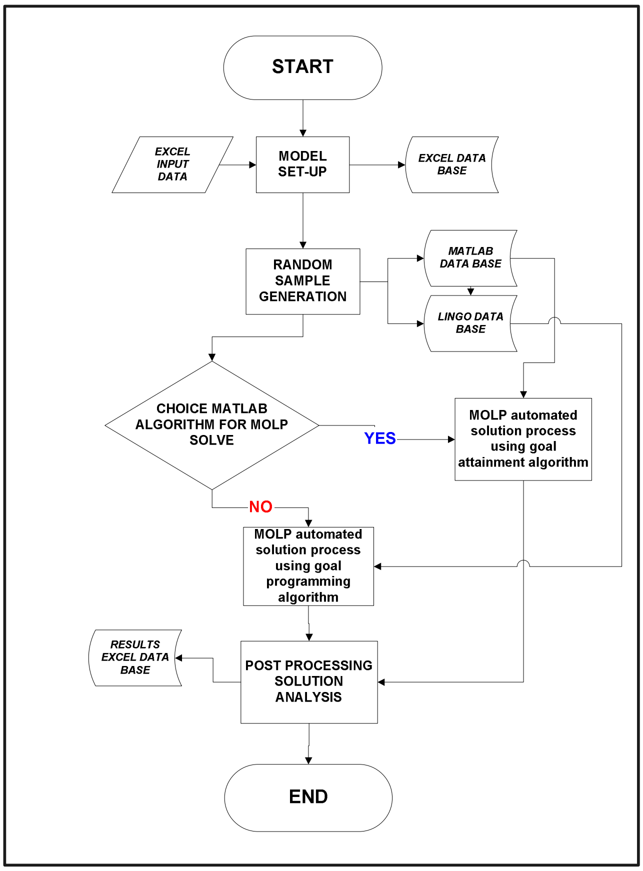


Figure 5.2. MOLP solution interface

5.3.2 Optimization Scenarios

The optimization model was solved under several scenarios with different environmental, social and economical conditions. In order to reflect interregional and spatial characteristics in the study area, the RGA watershed was divided into three sub-areas or sub-watersheds (Río Caonillas, Río Limón and Río Grande de Arecibo) corresponding to three municipalities at the region (Adjuntas, Jayuya and Utuado).

Scenarios take into account different combinations in the land use growth priority as consequence of historical information and future projections about tendencies in the land use growth pattern. For this, a detailed compilation of social characteristics in the study area, economic sectors inside each municipality tied to the subbasins as well as forecasting from local, state, and federal agencies in Puerto Rico were used. Appendix F summarizes all compiled information used to construct the scenarios in this research including the interviews to experts in the socio-economic field in Puerto Rico.

The higher priority in the scenarios is water quality, meaning that the economic development is not admissible at the expense of a dilapidated environmental condition (surface water contamination). Nevertheless the socio-economic aspects are inherent in a decision making analysis, especially sustainable growth of land use where local, government and federal policies play a determinant role in the decision making process that includes guidelines which need to be followed in land use planning (Minh, 2002).

Summing up, the model considers forest conservation, soil loss targets (sediment loss objectives), water quality objectives (Nitrogen, Phosphorus loss objectives), and socio-economic characteristics subject to:

- Land availability constraints,
- Forest conservation constraints,
- Soil loss constraints,
- Water quality constraints.
- Agricultural growth constraints.
- Urban development constraints.

It find the best land use combination according with the proposed goals. Also, physical characteristics are important to land allocation based on the optimum land use values.

The study time horizon is until the year 2025, where a regional land use development would affect the water quality and natural resources. Scenarios are based on two different water quality criteria detailed in the following section.

The scenarios considered in this study take into account a sufficiently long simulation period for a good implementation of the optimization results. As of today, Lago Dos Bocas has an eutrophication water quality problem and is necessary a short term solution, but in the long term a good implementation will allow the compliance with proposed water quality standards. A detailed description of the scenarios is presented in the next section.

All the scenarios consider as a high priority the preservation of the forest cover by not allowing any reduction in this land use. In a different way, a conversion from Rangeland or Barrenland to more productive land uses like the urban development or agriculture expansion is allowed. The low economic value of those land types allow decision maker to use them as wildcards.

5.3.2.1 Scenarios description

A total of six possible scenarios are detailed in this section for each sub watershed in the study area, meaning a total of 18 mathematical models to evaluate. Scenarios were codified as Scenario 1, 2 and 3 for those with an environmental goal based on the proposed nutrients water quality regulation submitted by the University of Puerto Rico using the National Nutrient Criteria Program guidelines from the USEPA (Martínez et al., 2006). For those scenarios with an environmental goal based on the actual regulation imposed by the Puerto Rico Water Quality Board (PREQB, 2003) the code was Scenario 11, 12 and 13. Both regulations are discussed and explained in the next section.

Fundamentals for the first group scenarios (Scenarios 1 to 3) are the same for the second one (Scenarios 11 to 13), with the difference focused in the water quality target depending on the regulation used. That is the reason to explain only the fundamentals for the first group.

Results from the optimization model show the suggested ranges in land use changes by sub-watershed at the end of the planning year 2025. These results were implemented according to a predetermined creation in a GIS model presented in the final stage of this research. Following is a description of the results obtained by scenarios considered in the study:

Scenario 1; Priority: Urban and Agriculture land use growth

This scenario combines the Urban or built-up development as well as Agricultural growth giving the same priority for both of them. Urban and agriculture correspond to the main socio-economic activities in the region and Scenario 1 considers a well-grounded hypothetical development in both activities. Also, is real to consider that economic growth due to the agriculture activity increment will produce one imminent urban development effect.

As cited above, forest conservation is a priority in all the scenarios and no trade-off with this land use is permissible. Forest land use growth is set-up in the model to oscillate between 1 to 3% according to the actual Puerto Rico state policies in incrementing those areas (Herencia Cien Mil, 2005).

All created scenarios are hypothetical but based on future possible projections. The main idea is to evaluate the behavior in the trade-off between the existent land use in the area according to priorities in the growth of the main sectors.

Pasture is considered a part of the agricultural activity, meaning that some of the possible growth in agriculture will be assigned to Pasture land use.

Finally, rangeland and barrenland are the land use available areas to be converted in Agriculture or Urban. In the final step of this research, a GIS model will allow to evaluate if the land use conversion obtained from the multiobjective optimization analysis is feasible or not in a spatial and physical context.

Scenario 2; Priority: Urban land use growth

Urban land use growth is the priority in this scenario, supposing that agriculture can grow but at low rates with respect to urban. In the construction of hypothetical scenarios, the main idea is to determine multiple possible growth patterns in the area in compliance of water quality criteria in rivers and consequently reservoirs. Scenario 2 gives the priority to urban development to find the maximum possible increment in this land use.

Scenario 2 is formulated as a less ambitious scenario in terms of agriculture growth. It may reflect the actual situation in the agriculture condition of the region, where this economic activity does not have too many incentives.

Scenario 3; Priority: Agriculture land use growth

In this scenario, agriculture growth is the main priority and urban areas are set up to grow too but in at a much lower rate that those in Scenario 2.

Agriculture activity in the study region needs to be activated to secure food security for the future of the country. Based on actual trends, researchers of the world foresee this topic as a priority in the countries of the world (FAO, 1996). Alimentary security will be a hot topic in the next 25 years, the time horizon of this study and is the reason to evaluate how much the agriculture land use can grow in the future according to the existent conditions in the study area.

The results from the above scenarios will allow determining the maximum possible growth in agricultural activities for the next 25 years in the region. Table 5.1 summarizes a description for the three hypothetical scenarios used to asses the land use planning problem with the MOLP approach.

Table 5.1 Land use planning scenarios

Code	Scenario priority	Scenario description
1 and 11	Urban or built-up and Agriculture	This scenario considers the urban and agricultural growth with the same priority.
2 and 12	Urban or built-up	Urban growth is the priority in the land use assignment. Agriculture growth is allowed but with a lower rate.
3 and 13	Agriculture	Agriculture growth is the priority for land use growth in this scenario. Urban growth is allowed but with a lower rate.

5.3.3 Model Formulation

A mathematical formulation was developed to solve the optimization problem for all the scenarios described before. The scenarios are translated to mathematical expressions incorporating all the information related to water quality targets according to the proposed or existing environmental regulations, constraints about the system including the total area of the system, the actual distribution of the land use and the functions to be minimized in terms of sediment loads and nutrients.

5.3.3.1 Water quality targets

Two water quality standards were considered in the analysis: a) the existing water quality standards by the PREQB (2003) and the USEPA, and b) a proposed new water quality standard developed by the University of Puerto Rico for nutrient standards (Martínez et al., 2006). Differences between quality standards lie in the maximum allowed concentrations for nutrient species in surface waters classified as SD by the PREQB (2003).

Findings from the University of Puerto Rico research allows to conclude that some of the actual water quality criteria imposed by the PREQB need to be reviewed and modified to assure the water quality minimum levels. This is the reason why both criteria are included in the analysis in order to determine implementing differences between them. Table 5.2 summarizes the actual and proposed criteria for nutrients and sediments maximum allowed concentrations. Associated to maximum concentrations this table shows the maximum annual loads for each sub watershed.

Table 5.2 Maximum regulated loads in Río Grande de Arecibo watershed

Station#-Subwatershed	Total Nitrogen* (Kg/year)		Total Phosphorus** (Kg/year)		Total Sediments+ (Kg/year)
	Actual criterion(1) (1 mg/l)	Proposed criterion (2) (1.025 mg/l)	Actual criterion (3) (1 mg/l)	Proposed criterion (4) (0.05 mg/l)	Actual and proposed criterion(5)
50025000-RGA	3,932,983	136,655	166,652	6,667	3,352
50026025-Caonillas	3,820,967	74,921	91,411	3,655	1,400
50026025-Limón	4,659,919	54,667	66,665	2,667	952

(1) Standard for Total Ammonia (PREQB, 2003)
(2) Proposed standard for Total Nitrogen (Martínez et al., 2006)
(3) Standard for Total Phosphorus (PREQB, 2003)
(4) Proposed standard for Total Phosphorus (Martínez et al., 2006)
(5) Criterion is not available for total sediments. Instead, it was based on historical trends about maximum watershed export under normal conditions (no storm events) (Sóler, 2001a).

5.3.3.2 Existing land use distribution in the study area

Existing land use distribution represents the starting point for land use conversions in the future and is one of the inputs in the mathematical construction of the proposed scenarios. Table 5.3 shows the existing land use distribution in the three sub-watersheds.

Table 5.3 Existing land use distribution (Square kilometers and percentage by subwatershed).

Land Use	Subwatershed			Lago Caonillas	Lago Dos Bocas
	RGA	Caonillas	Limón		
Urban	8.84 (4.7)	2.84 (2.29)	1.65 (1.8)		
Pasture	0.11 (0.1)	1.81 (1.46)	1.02 (1.1)		
Agriculture	12.86 (6.9)	6.43 (5.19)	6.95 (7.4)		
Forest	146.53 (78.6)	81.56 (65.83)	76.3 (81.2)	2.83*	2.57*
Rangeland	17.13 (9.2)	29.71 (23.98)	7.85 (8.36)		
Barren land	0.60 (0.3)	0.68 (0.55)	0.11 (0.12)		
Water	0.35 (0.2)	0.87 (0.70)	0.14 (0.14)		
Total	**186.31**	**123.80**	**93.86**	**2.83**	**2.57**

* Superficial area for reservoirs inside RGA watershed.

5.3.4 Mathematical model

The mathematical model assembling is the final step before running the optimization models associated to the above mentioned scenarios. These models represent the translation to the mathematical language used in the different multi-objective optimization approaches. The next sections describe the different components of the mathematical models as well as the construction of the respective scenarios.

5.3.4.1 Decision variables

Five categories of land uses corresponding to the 99% of total land use in the watershed were used as the decision variables in the multi-objective optimization analysis.

The five decision variables are:

$X_1 =$ The optimal area reserved for forest conservation.

$X_2 =$ The optimal area allowed for agricultural development.

$X_3 =$ The optimal area assigned for urban development.

$X_4 =$ The optimal area reserved for pastures growth.

$X_5 =$ The optimal area reserved for range land (not improved pasture land).

5.3.4.2 Objective functions

As mentioned above, the water quality achievement is the highest priority in this optimization analysis. It implies that water quality standards and respective maximum permissible loads need to be considered as a constraint of the system as well as the objective functions to be minimized in the system.

Three objectives functions related to water quality impacts and total discharges of Nitrogen (TN), Phosphorus (TP) and Sediment yield from soil erosion (TS) were proposed.

The three objective functions are:

$Z_1 =$ The objective function of total phosphorus discharge (TP);
$Z_2 =$ The objective function of total nitrogen discharge (TN).
$Z_3 =$ The objective function of total discharge of sediment yield, (TS).

5.3.4.3 Constraints

Two different types of constraints were incorporated in the mathematical model. The first type consists of system constraints regarding to the actual land use and minimal areas needed for optimal land management and development. The second type are goal constraints, they provide a measure of the assimilative capacity to different pollution impacts (maximum permissible loads) reaching the water body. Constraints described above are defined as the system constraints and goal constraints respectively in a MOLP model.

Description of each of the ten restrictions considered in the final problem formulation, are as follows:

Restriction 1 The maximum area allowed for developing various land use programs oscillates in the three studied sub basins areas between 9,386 ha and 18,596 ha, which is equal to the watershed area minus the surface area of the associated reservoir.

Restriction 2 Due to the reserved area of forest. Actually this area oscillates in the three sub basins between 66% and 81% of the total area of each one.

Restriction 3 Associated to the minimum existent agriculture area. Actually this area oscillates between the 5.2% and the 7.4% of the total area of each sub basin.

Restriction 4 Associated to urban development. In RGA watershed, the urban area oscillates between the 1.8% in Limón sub basin and 4.8% in the RGA sub watershed.

Restriction 5 Minimum area assigned to controlled pastures.

Restriction 6 Minimum area assigned to rangeland.

Restriction 7 This restriction is associated with the PREQB standards in use and the proposed new water quality criteria submitted to the USEPA agency. The restriction is a function of the maximum permitted loads value of total phosphorus (TP) in water body receptors (See Table 5.2).

Restriction 8 Similar to Restriction 7, this restriction is associated with the maximum permitted value of total nitrogen loads (TN) in water body receptors (See Table 5.2).

Restriction 9 Associated to the maximum total sediment yield (TS) amount in. (See Table 5.1). For each watershed the maximum allowed sediment yield loads associated to soil erosion were computed using the results from Suárez (2005) and the USGS bathymetric results in 2007.

Restriction 10 The non-negative constraints, $\vec{X} \geq 0$; $[x_1, x_2, x_3, x_4, x_5] \geq 0$

Associated with the above constraints, each one of the evaluated scenarios has additional constraints according with the land use growth priority promulgated in the scenarios description.

5.3.5 Final mathematical models

A total of six different mathematical models were constructed considering the characteristics of each sub-watershed and the water quality targets. Scenarios 1 to 3 has the same basis comparing with Scenarios 11 to 13 differing only in the water quality goals associated to the existing and proposed water quality standards.

The final mathematical models assembling for each subwatershed is detailed, where the uncertainty associated to land use export coefficient intervals is considered, giving to each model the inexact nature condition in this type of decision analysis.

Río Grande de Arecibo Model

The final mathematical model in RGA sub-watershed is as follow:

$$Min\ \ Z_1(x) = C_{11}X_1 + C_{12}X_2 + C_{13}X_3 + C_{14}X_4 + C_{15}X_5$$

$$Min\ \ Z_2(x) = C_{21}X_1 + C_{22}X_2 + C_{23}X_3 + C_{24}X_4 + C_{25}X_5$$

$$Min\ \ Z_3(x) = C_{31}X_1 + C_{32}X_2 + C_{33}X_3 + C_{34}X_4 + C_{35}X_5$$

where C_{ij} are the land use export coefficients given by a characteristic uniform distribution described by a lower and upper limit and showed in Table 5.4 .

Table 5.4 Nutrients and sediments yield land use export coefficients; RGA sub-watershed

Land Use(j)	Total Phosphorus (TP) (C_{1j}) (Kg/Ha*yr)	Total Nitrogen (TN) (C_{2j}) (Kg/Ha*yr)	Total Sediment Yield (TS) (C_{3j}) (Kg/Ha*yr)
Urban	2.94 – 4.65	6.82 – 14.91	14.58 – 789.23
Pasture	1.18 – 3.10	9.53 – 31.65	9.76 – 37.56
Agriculture	1.16 -3.91	14.07 – 41.13	182.85 – 1,390.17
Forestland	0.16 – 0.47	2.02 – 5.41	0.74 – 52.14
Rangeland	0.17 – 0.52	2.12 – 5.56	0.86 – 59.55

The objective functions are subject to:

1- $X_1 + X_2 + X_3 + X_4 + X_5 + X_6 = 18{,}596\ ha$

2- $X_1 \geq 14{,}653\ ha$

3- $X_2 \geq 1{,}286\ ha$

4- $X_3 \geq 884\ ha$

5- $X_4 \geq 12\ ha$

6- $X_5 \geq 1{,}713\ ha$

7- $C_{11}X_1 + C_{12}X_2 + C_{13}X_3 + C_{14}X_4 + C_{15}X_5 \leq Environmental\ TP\ goal$

8- $C_{21}X_1 + C_{22}X_2 + C_{23}X_3 + C_{24}X_4 + C_{25}X_5 \leq Environmental\ TN\ goal$

9- $C_{31}X_1 + C_{32}X_2 + C_{33}X_3 + C_{34}X_4 + C_{35}X_5 \leq Environmental\ TSS\ goal$

10- $X_1,\ X_2,\ X_3,\ X_4,\ X_5 \geq 0$

Río Caonillas sub-watershed

The final mathematical model in Río Caonillas sub-watershed is as follow:

$$Min\ \ Z_1(x) = C_{11}X_1 + C_{12}X_2 + C_{13}X_3 + C_{14}X_4 + C_{15}X_5$$

$$Min\ \ Z_2(x) = C_{21}X_1 + C_{22}X_2 + C_{23}X_3 + C_{24}X_4 + C_{25}X_5$$

$$Min\ \ Z_3(x) = C_{31}X_1 + C_{32}X_2 + C_{33}X_3 + C_{34}X_4 + C_{35}X_5$$

where C_{ij} are land use export coefficients given by a characteristic uniform distribution described by a lower and upper limit and showed in Table 5.5.

Table 5.5 Nutrients and sediments yield land use export coefficients; Caonillas sub-watershed.

Land Use(j)	Total Phosphorus (TP) (C_{1j}) (Kg/Ha*yr)	Total Nitrogen (TN) (C_{2j}) (Kg/Ha*yr)	Total Sediment Yield (TS) (C_{3j}) (Kg/Ha*yr)
Urban	1.39 – 4.15	6.12 – 13.08	20.90 – 61.53
Pasture	0.18 – 2.07	6.86 – 34.10	24.71 – 87.47
Agriculture	0.32 – 2.24	5.63 – 39.74	336.05 – 1,279.96
Forestland	0.05 – 0.36	1.64 – 6.15	3.51 – 11.61
Rangeland	0.06 – 0.22	2.25 – 7.158	7.56 – 24.59

The objective functions are subject to:

1- $X_1 + X_2 + X_3 + X_4 + X_5 + X_6 = 12{,}302\ ha$

2- $X_1 \geq 8{,}156\ ha$

3- $X_2 \geq 643\ ha$

4- $X_3 \geq 284\ ha$

5- $X_4 \geq 181\ ha$

6- $X_5 \geq 2{,}377\ ha$

7- $C_{11}X_1 + C_{12}X_2 + C_{13}X_3 + C_{14}X_4 + C_{15}X_5 \leq Environmental\ TP\ goal$

8- $C_{21}X_1 + C_{22}X_2 + C_{23}X_3 + C_{24}X_4 + C_{25}X_5 \leq Environmental\ TN\ goal$

9- $C_{31}X_1 + C_{32}X_2 + C_{33}X_3 + C_{34}X_4 + C_{35}X_5 \leq Environmental\ TSS\ goal$

10- $X_1,\ X_2,\ X_3,\ X_4,\ X_5 \geq 0$

Río Limón sub-watershed

The final mathematical model in Río Limón sub-watershed is as follow:

$$Min\ \ Z_1(x) = C_{11}X_1 + C_{12}X_2 + C_{13}X_3 + C_{14}X_4 + C_{15}X_5$$
$$Min\ \ Z_2(x) = C_{21}X_1 + C_{22}X_2 + C_{23}X_3 + C_{24}X_4 + C_{25}X_5$$
$$Min\ \ Z_3(x) = C_{31}X_1 + C_{32}X_2 + C_{33}X_3 + C_{34}X_4 + C_{35}X_5$$

where C_{ij} are land use export coefficients given by a characteristic uniform distribution described by a lower and upper limit and showed in Table 5.6.

Table 5.6 Nutrients and sediments yield land use export coefficients; Limón sub-watershed

Land Use(j)	Total Phosphorus (TP) (C_{1j}) (Kg/Ha*yr)	Total Nitrogen (TN) (C_{2j}) (Kg/Ha*yr)	Total Sediment Yield (TS) (C_{3j}) (Kg/Ha*yr)
Urban	0.66 – 3.06	8.53 – 14.63	32.62 – 49.91
Pasture	0.14 – 1.88	11.33 – 33.10	0.49 – 115.39
Agriculture	0.37 – 1.92	21.65 – 41.06	1.48 – 451.69
Forestland	0.06 – 0.33	3.12 – 6.72	0.003 – 11.12
Rangeland	0.08 – 0.49	3.63 - 5.90	2.10 – 25.20

The objective functions are subject to:

1- $X_1 + X_2 + X_3 + X_4 + X_5 + X_6 = 9{,}386\ ha$

2- $X_1 \geq 7{,}627\ ha$

3- $X_2 \geq 695\ ha$

4- $X_3 \geq 165\ ha$

5- $X_4 \geq 102\ ha$

6- $X_5 \geq 628\ ha$

7- $C_{11}X_1 + C_{12}X_2 + C_{13}X_3 + C_{14}X_4 + C_{15}X_5 \leq Environmental\ TP\ \ goal$

8- $C_{21}X_1 + C_{22}X_2 + C_{23}X_3 + C_{24}X_4 + C_{25}X_5 \leq Environmental\ TN\ \ goal$

9- $C_{31}X_1 + C_{32}X_2 + C_{33}X_3 + C_{34}X_4 + C_{35}X_5 \leq Environmental\ TSS\ \ goal$

10- $X_1,\ X_2,\ X_3,\ X_4,\ X_5 \geq 0$

5.4 RESULTS

This section presents the results of the multi-objective optimization approach containing a total of six different scenarios to evaluate and detailed previously. The results are summarized by scenario and a final comparison between all is discussed. Additionally, the results are divided by solution method reflected in the lower and upper boundary of the solution interval. According to this interval a mid value will be used as input in the GIS land allocation model, the final stage of the research. Appendix D shows the unprocessed results including all the statistics, results by solution method, goal achievement and the optimal land use export coefficients interval.

5.4.1 Scenario 1; Urban and Agriculture growth priority

This scenario evaluates the optimal land use growth in the 2025 planning year for an equally probable development in the urban or built-up and in the agriculture economic activity at the three main sub-watersheds of RGA watershed. For Scenarios 1 to 3 the environmental goal falls in the proposed water quality standard (Martínez et. al, 2006).

For analysis purposes and considering a conservationist approach, the forest land is set-up to allow a minimal growth but never a decrease on it. Rangeland and Barreland were used as the available land use for the trade off to more profitable activities. Table 5.7 and 5.8 summarizes the results for the Scenario 1.

Table 5.7 Land uses optimization values summarize (Scenario 1)

Sub-watershed	Land Use	2005	2025			
		Actual Value (Ha)	Lower Bound (Ha)	Upper Bound (Ha)	Interval (Ha)	Mid. Value (Ha)
RGA	Forest	14,653.1	14,689.4	14,699.2	9.8	14,694.3
	Agriculture	1,286.3	1,363.5	1,416.6	53.1	1,390.1
	Urban	883.7	948.8	978.4	29.6	963.6
	Pasture	11.7	35.8	78.5	42.7	57.2
	Rangeland	1,713.3	1,452.4	1,482.7	30.3	1,467.6
CAONILLAS	Forest	8,155.7	8,159.6	8,160.1	0.5	8,159.9
	Agriculture	643	710.8	733.1	22.3	721.9
	Urban	283.7	409.1	414.8	5.7	411.9
	Pasture	180.9	197.3	198.3	1.0	197.9
	Rangeland	2,970.9	2,762.5	2,792.2	29.7	2777.4
LIMON	Forest	7,627.0	7,676.7	7,682.5	5.8	7,679.6
	Agriculture	694.7	728	763.4	35.4	745.7
	Urban	165.2	174.8	187.9	13.1	181.35
	Pasture	102.3	104.7	110.9	6.2	107.8
	Rangeland	784.9	654.6	676.3	21.7	665.45

Table 5.8 Land use probable conversion based on mean optimization modeling output. Scenario 1 (Forest conservation + agriculture and urban growth)

Land use	Sub-watershed land conversion (Ha)			**TOTAL (Ha)**
	RGA	Caonillas	Limon	
Forest	38.3 (0.26%)	4.1 (0.05%)	52.5 (0.69%)	94.9
Agriculture	104.0 (8.09%)	78.9 (12.28%)	50.9 (7.34%)	233.8
Urban	79.6 (9.00%)	128.2 (45.20%)	16.1 (9.76%)	223.9
Pasture	45.4 (388.3%)	16.9 (9.33%)	5.51 (5.4%)	67.8
Rangeland	245.4 (-14.33%)	193.6 (-6.52%)	119.42 (-15.2%)	558.4
Barrenland	24.5 (-40.8%)	34.1 (-50.1%)	5.6 (-50.9%)	
Water	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0

*Negative values means a decrease in the land use tradeoff.

Results from Scenario 1 show a well proportionate growth in urban or built-up and agriculture activities for RGA and Limón sub watersheds ranging from 8% to 9% in the first case and from 7.3% and 9.8% for the second case.

For Caonillas sub-watershed, the estimated housing demand in 2025 year is around of 150 Ha according with the projections of the Land Use Plan. Obtained result for Caonillas, allows concluding about the accordance between growth expectations and optimal obtained value. In conclusion, the result explains the big growth in the urban activity with a 45.2 % against a 12.3% in the agriculture for this sub watershed.

For the three sub watersheds, forest land use growth is under a 0.5% meaning a minimal increasing percentage in those areas but considerable in magnitude due to the high percent of this land use with respect to the entire distribution.

Originally, pasture at RGA sub watershed has a value tending to zero. This explains the high optimized value for pasture land use growth at RGA watershed, where a minimal increment in the optimal values produces a considerable increment in the relative percent.

5.4.2 Scenario 2; Urban growth priority

Scenario 2 searches for the maximum possible growth in the urban areas taking into account the land use projections based on the Land Use Plan demand of municipalities in the area. Scenario 2 considers the agriculture growth but not as the higher priority in the land use assignment solution.

All the scenarios in this chapter are formulated to evaluate different hypothetical combinations between the two main economic activities, considering the uncertainty in the future growth pattern.

Associated municipalities to the three main sub watersheds are the Jayuya municipality for Caonillas sub watershed; Adjuntas and Utuado for RGA sub watershed and Ciales for Limón sub watershed. The first two sub watersheds are the most urbanized areas meaning a higher possible growth with respect to Limón case, the lower urbanized area.

Results for this scenario are summarized in Tables 5.9 and 5.10.

Table 5.9 Land uses optimization values (Scenario 2)

Sub-watershed	Land Use	2005	2025			
		Actual Value (Ha)	Lower Bound (Ha)	Upper Bound (Ha)	Interval (Ha)	Mid. Value (Ha)
RGA	Forest	14,653.1	14,690.35	14,700.00	9.65	14,695.18
	Agriculture	1,286.3	1,325.04	1,338.94	13.9	1,331.99
	Urban	883.7	1,003.68	1,067.22	63.54	1,035.45
	Pasture	11.7	13.60	17.02	3.42	15.31
	Rangeland	1,713.3	1,476.36	1,512.99	36.63	1,494.675
CAONILLAS	Forest	8,155.7	8,159.72	8,160.00	0.28	8,159.86
	Agriculture	643	669.49	669.64	0.15	669.565
	Urban	283.7	409.55	417.07	7.52	413.31
	Pasture	180.9	188.40	188.47	0.07	188.435
	Rangeland	2,970.9	2,833.68	2,841.70	8.02	2,837.69
LIMON	Forest	7,627.0	7,682.37	7,695.15	12.78	7,688.76
	Agriculture	694.7	720.53	721.04	0.51	720.785
	Urban	165.2	205.06	205.72	0.66	205.39
	Pasture	102.3	105.77	106.14	0.37	105.955
	Rangeland	784.9	653.07	664.70	11.63	658.885

Table 5.10 Land use probable conversion based on mean optimization modeling output. SCENARIO 2 (Forest conservation + urban growth priority)

Land use	Sub-watershed land conversion (Ha)			**TOTAL (Ha)**
	RGA	Caonillas	Limón	
Forest	42.2 (0.29%)	4.2 (0.05%)	61.7 (0.81%)	108.1
Agriculture	46.0 (3.58%)	26.6 (4.1%)	26.1 (3.75%)	98.7
Urban	151.5 (17.1%)	129.6 (45.68%)	40.2 (24.31%)	321.3
Pasture	3.6 (30.8%)	7.5 (4.2%)	3.6 (3.54%)	14.7
Rangeland	218.3 (-12.8%)	133.2 (-4.48%)	126.0 (-16.05%)	477.5
Barrenland	25.0 (-41.7%)	34.7 (-51.0%)	5.6 (-50.9%)	
Water	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0

*Negative values means a decrease in the land use tradeoff.

Results from the Scenario 2 were in agreement with the expected hypothesis, meaning a higher urban development with respect to agriculture activity. Urban growth range between 17% to 46% approximately with respect to an agriculture growth around 4% in all sub-watersheds. Pasture land use maintains the tendency of Scenario 1 for RGA sub watershed, with approximately same extension but with the higher percent increment with respect to Caonillas and Limón .

Solutions obtained from all the evaluated scenarios are in agreement with water quality goals, meaning that an optimal solution implies underachievement of nutrients and sediment maximum allowed loadings. This is important to note because environmental quality is regard as the highest priority in the analysis.

5.4.3 Scenario 3; Agriculture growth priority

This scenario evaluates the maximum possible growth of the agriculture economic activity based on the available projections until the 2025 year, the planning study year. Urban growth in this scenario has a low priority. Results from this scenario are summarized in Tables 5.11 and 5.12.

Table 5.11 Land uses optimization values summarize (Scenario 3)

Sub-watershed	Land Use	2005 Actual Value (Ha)	2025 Lower Bound (Ha)	Upper Bound (Ha)	Interval (Ha)	Mid. Value (Ha)
RGA	Forest	14,653.1	14,691.42	14,699.90	8.48	14,695.66
	Agriculture	1,286.3	1,392.52	1,470.44	77.92	1,431.48
	Urban	883.7	949.02	952.23	3.21	950.625
	Pasture	11.7	10.24	16.68	6.44	13.46
	Rangeland	1,713.3	1,451.46	1,511.29	59.83	1,481.375
CAONILLAS	Forest	8,155.7	8,159.98	8,160.00	0.02	8,159.99
	Agriculture	643	756.48	763.92	7.44	760.2
	Urban	283.7	307.85	308.80	0.95	308.325
	Pasture	180.9	188.38	188.45	0.07	188.415
	Rangeland	2,970.9	2,848.71	2,855.16	6.45	2,851.935
LIMON	Forest	7,627.0	7,677.18	7,680.13	2.95	7,678.655
	Agriculture	694.7	732.40	771.85	39.45	752.125
	Urban	165.2	171.86	180.52	8.66	176.19
	Pasture	102.3	103.39	106.34	2.95	104.865
	Rangeland	784.9	655.75	680.01	24.26	667.88

Table 5.12 Land use probable conversion based on mean optimization modeling output. SCENARIO 3 (Forest conservation + agriculture growth priority)

Land use	Sub-watershed land conversion (Ha)			**TOTAL (Ha)**
	RGA	Caonillas	Limon	
Forest	42.7 (0.29%)	4.3 (0.05%)	51.6 (0.68%)	98.6
Agriculture	145.5 (11.31%)	117.2 (18.23%)	57.4 (8.26%)	320.1
Urban	66.7 (7.54%)	24.6 (8.68%)	11.0 (6.63%)	102.3
Pasture	1.8 (15.0%)	7.5 (4.2%)	2.5 (2.48%)	11.8
Rangeland	231.6 (-13.5%)	119.0 (-4.00%)	117.0 (-14.91%)	467.6
Barrenland	25.1 (-41.8%)	34.6 (-50.9%)	5.5 (-50.0%)	
Water	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0

Results from Scenario 3 show a similar tendency comparing with the obtained in the Scenario 1. Both scenarios are influenced by the high values contained in the agricultural land use export coefficients intervals, giving considerable influence in the optimal mathematical solution.

For scenario 3, the agriculture expansion would be able to attain an upper limit around 10% for RGA and Limón sub-watersheds. In Caonillas, this maximum agriculture growth corresponds to 18.2%. Those projections in growth rates are in accordance with the expectations at the study area from local and federal programs like “*Resiembra*” and “*Siembras Nuevas*”, activated since the year 2000 by the Puerto Rico Department of Agriculture.

5.4.4 Summary of results for Scenarios 1 to 3

These scenarios were developed using a solid data base compilation of social, economic, historical and actual conditions of the study area that included drafted plans by the municipalities within. Additional information used in the analysis were Land Use Plans ("*Planes de ordenamiento territorial*") for municipalities within RGA watershed, historical socio-economic tendencies in population, urban growth and economic activities. Finally, interviews with experts in the research topic were considered to complement the above data in the scenarios formulation.

Figures 5.3 to 5.5 compare the obtained results from the three above analyzed scenarios by sub-watershed. Additionally to the two main prioritized economic activities, the comparison of the results allowed to visualize the effect in the remaining land uses, especially in the wildcards (Rangeland and Barrenland) as well as the forest land use.

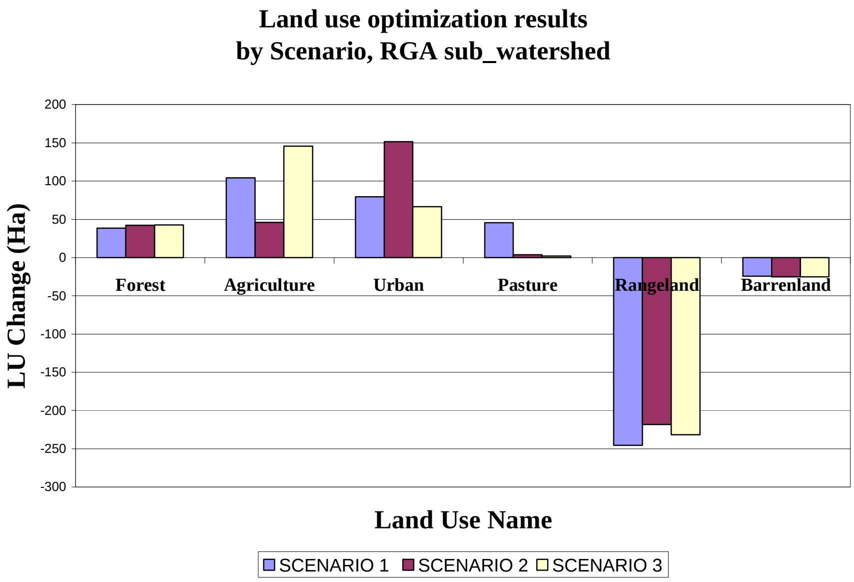


Figure 5.3 MOLP scenarios results (RGA sub-watershed)

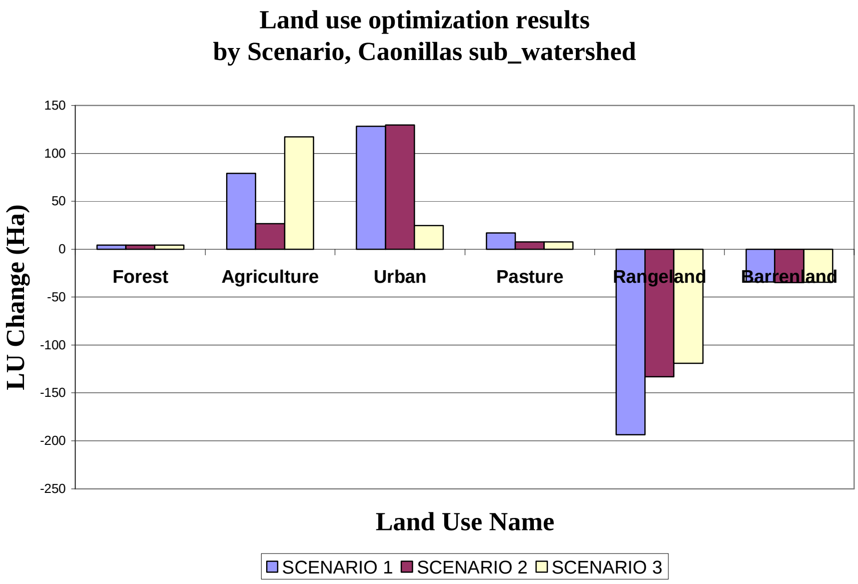


Figure 5.4 MOLP scenarios results (Caonillas sub-watershed)

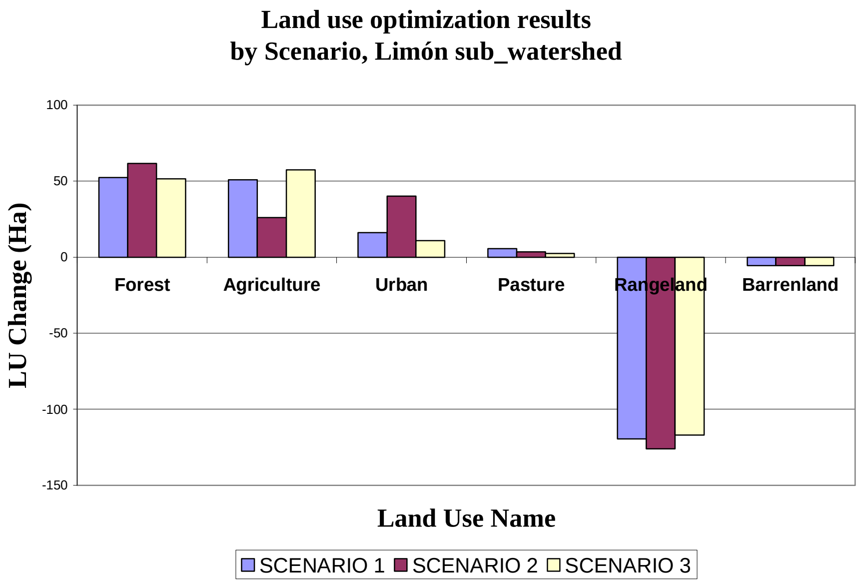


Figure 5.5 MOLP scenarios results (Limón sub-watershed)

Results from scenario 1 to 3 shows some similar tendencies in the land use growth pattern for the three analyzed sub watersheds. For scenarios where the priority in the land use growth pattern was a combination of agriculture and urban, the results show an assignment preference for the agriculture economic activity rather than the urban, translated in a major expansion of these areas. This effect is associated with some of the variables in the land use decision making process. In particular, the land use export coefficients play a determinant role in the mathematical land use optimization model.

In particular, for RGA sub-watershed, Scenario 2 shows that the urban built-up can reach up to 151.5 Ha representing an increment of 17% with respect to the actual urban distribution inside this sub-watershed. According to historical trends in the municipalities of Adjuntas and Utuado that belongs to RGA sub-watershed, a growth projection of 125 Ha is expected in this urban sector. In this case, the simulation results overestimate urban area development when compared to expected projections for this sector.

As stated above, projections for all the scenarios are based on historical municipalities trends and socio-economic indicators as well as Territorial Order Plans that compile the available information to planning the growth pattern at the area. Therefore, comparison between optimization results and projections are used only to evaluate the potential growth of a specific land use.

Hypothetical scenarios can give to the decision making process a range of possible combination values for the land-use development based on the optimal mathematical results. As in the above case, results for a particular land use could be greater than expected projections. Likewise, to maintain a balance in the system an optimal land use result could be lower than expected projection.

For Scenarios 1 and 3, RGA results show similar percent change in the urban and agriculture growth. Forestlands areas could grow at a maximum percent change of 0.29% meaning an increment with respect to the actual forest land use of 38 Ha.

With respect to the Caonillas sub-watershed, the obtained results for scenarios 1 and 2 show the maximum urban growth around 45% of existing area. Comparing this value with the actual surface area of 284 Ha, Caonillas sub-watershed could see a total urban area of 400 Ha by year 2025. Agriculture maximum growth is expected to increase by 22% without impact in the water quality.

Scenario 3 in this sub-watershed reflects the maximum agriculture growth around the 23% complemented with an approximately 9% in the urban areas.

The Jayuya municipality and the government of Puerto Rico acquired 83 Ha in September 2007 through the *"Herencia Cien Mil"* program. Considering this recent increment in high ecological forest areas at Caonillas sub-watershed, a minimal projected growth in the Caonillas sub-watershed around 0.1% was considered.

Finally, the results between scenarios at the Limón sub-watershed are analyzed. In this case for Scenario 2 with the higher urban priority, a maximum 24% increment could de achieved complemented with a 7% increment in agriculture economic activity.

Scenarios 1 and 3 show similar well balanced results between the two higher growth priorities in the analysis. At these conditions urban could grow at a maximum of 10%. Agriculture will grow at a maximum of 8%.

Limón sub-watershed has the higher increment in forest areas with respect to RGA and Caonillas sub-watersheds. A projected increment of 50 Ha could be achieved in those scenarios.

5.4.5 Scenarios 11 to 13

Scenarios 11 to 13 differ from 1 to 3 in the water quality standards used as environmental goals for the multi-objective optimization model. Scenarios 11 to 13 used the actual water quality standards given by the PREQB (2003) for nutrients in Puerto Rico.

Table 5.2 summarizes the associated loadings to these maximum nutrients and sediment concentrations incorporated in the analysis for the three additional scenarios. Actual regulation in Puerto Rico tends to be more conservative than the proposed allowing greater loadings to be discharge in water bodies.

Incorporation of scenarios with different water quality standards corresponds to different possibilities in the land use assignment process. This allow to the land use decision making process to obtain multiple feasible options to be implemented in the future. Also, comparing both regulation results allow concluding about different growth patterns in the RGA watershed.

5.4.6 Scenario 11; Urban and Agriculture growth priority

This scenario is very similar to Scenario 1, evaluating the optimal land use growth in the 2025 planning year for an equally probable development in the urban and increase in the agriculture activity at the three main sub-watersheds inside the RGA watershed. The main difference between Scenario 1 and 11 is the environmental goal. As stated before, the existing water quality standards by the PREQB are incorporated in this research. Table 5.13 and 5.14 summarizes the results for the Scenario 11.

Table 5.13 Land uses optimization values summarize (Scenario 11)

Sub-watershed	Land Use	2005 Actual Value (Ha)	2025 Lower Bound (Ha)	2025 Upper Bound (Ha)	2025 Interval (Ha)	2025 Mid. Value (Ha)
RGA	Forest	14,653.1	14,700.0	14,700.0	0.0	14,700.0
	Agriculture	1,286.3	1,389.3	1,469.8	80.5	1,429.6
	Urban	883.7	989.8	1,010.7	20.9	1,000.3
	Pasture	11.7	19.9	19.9	0.0	19.9
	Rangeland	1,713.3	1,371.4	1,472.8	101.4	1,422.1
CAONILLAS	Forest	8,155.7	8,160.0	8,160.0	0.0	8,160.0
	Agriculture	643	734.1	734.1	0.0	734.1
	Urban	283.7	430.5	430.5	0.0	430.5
	Pasture	180.9	198.4	198.4	0.0	198.4
	Rangeland	2,970.9	2,745.9	2,745.9	0.0	2,745.9
LIMON	Forest	7,627.0	7,671.7	7,685.2	13.5	7,678.5
	Agriculture	694.7	737.3	787.6	50.3	762.5
	Urban	165.2	164.7	189.4	24.7	177.1
	Pasture	102.3	102.4	111.6	9.2	107.0
	Rangeland	784.9	626.7	670.5	43.8	648.6

Table 5.14 Land use probable conversion based on mean optimization modeling output. SCENARIO 11 (Forest conservation + agriculture and urban growth)

Land use	Sub-watershed land conversion (Ha)			**TOTAL**
	RGA	Caonillas	Limon	**(Ha)**
Forest	47.0 (0.32%)	4.3 (0.05%)	58.1 (0.76%)	109.4
Agriculture	143.6 (11.2%)	91.1 (14.2%)	67.7 (9.7%)	302.4
Urban	116.3 (13.2%)	146.8 (51.8%)	11.8 (7.2%)	274.9
Pasture	8.2 (69.9%)	17.5 (9.7%)	4.7 (4.6%)	30.4
Rangeland	290.9 (-17.0%)	225.0 (-7.6%)	136.2 (-17.4%)	652.1
Barrenland	24.2 (-40.3%)	34.7 (-51.0%)	6.1 (-55.5%)	
Water	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0

*Negative values means a decrease in the land use tradeoff.

Result from Scenario 11 shows a balance between the urban growth and agriculture land uses in RGA and Limón watersheds in accordance with the statements of this scenario formulation, where these both economic activities were prioritized. Instead, for the Caonillas watershed, a large urban growth as compared with agriculture land use was obtained.

Scenario 11 shows higher land use areas for urban and agriculture growth when compared with the results obtained for Scenario 1. This is due to the higher numerical values for nutrient and sediments concentrations of the existing water quality standard.

In order to maintain a balance in the system, the Rangeland wildcard tends to show a higher reduction with respect to scenario 1. Rangeland reduction oscillates between 8% and 17% in RGA watershed for this scenario.

5.4.7 Scenario 12; Urban growth priority

This scenario was researched to determine possible differences in the land use distribution with respect to scenario 2, as a result of the changes in water quality standards. The priority in this Scenario 12 is urban expansion. Agricultural expansion is limited and has a low priority.

Scenarios constructed under actual regulation have loose conditions in terms of maximum allowable loadings reaching the water bodies. This condition implies a higher growth pattern comparing with conditions for scenarios 1 to 3.

Under these conditions, scenarios 11 to 13 are more restricted by physical characteristics rather than loadings. Maximum land use conversion obeys to physical constraints in terms of available land use areas for future expansion, where the total area at each sub watershed can not be exceeded from its actual condition. Tables 5.15 and 5.16 summarize the results for this scenario.

Table 5.15 Land uses optimization values summarize (Scenario 12). Urban expansion has high priority.

Sub-watershed	Land Use	2005 Actual Value (Ha)	2025 Lower Bound (Ha)	2025 Upper Bound (Ha)	2025 Interval (Ha)	2025 Mid. Value (Ha)
RGA	Forest	14,653.1	14,700.0	14,700.0	0.0	14,700.0
	Agriculture	1,286.3	1,341.6	1,341.6	0.0	1,341.6
	Urban	883.7	1,056.9	1,141.9	85.0	1,099.4
	Pasture	11.7	17.9	17.9	0.0	17.9
	Rangeland	1,713.3	1,370.5	1,455.4	84.9	1,413.0
CAONILLAS	Forest	8,155.7	8,160.0	8,160.0	0.0	8,160.0
	Agriculture	643	669.6	669.6	0.0	669.6
	Urban	283.7	430.5	430.5	0.0	430.5
	Pasture	180.9	188.5	188.5	0.0	188.5
	Rangeland	2,970.9	2,820.3	2,820.3	0.0	2,820.3
LIMON	Forest	7,627.0	7,686.3	7,700.0	13.7	7,693.2
	Agriculture	694.7	727.4	727.6	0.2	727.5
	Urban	165.2	213.7	213.8	0.1	213.8
	Pasture	102.3	106.6	106.7	0.1	106.7
	Rangeland	784.9	632.3	646.2	13.9	639.3

Table 5.16 Land use probable conversion based on mean optimization modeling output. SCENARIO 12 (Forest conservation + urban growth priority)

Land use	Sub-watershed land conversion (Ha)			**TOTAL (Ha)**
	RGA	Caonillas	Limon	
Forest	47.0 (0.32%)	4.3 (0.05%)	66.0 (0.87%)	117.3
Agriculture	55.6 (4.3%)	26.6 (4.1%)	32.8 (4.7%)	115.0
Urban	215.4 (24.4%)	146.8 (51.8%)	48.6 (29.4%)	410.8
Pasture	6.2 (52.9%)	7.6 (4.2%)	4.3 (4.2%)	18.1
Rangeland	300.1 (-17.5%)	150.6 (-5.1%)	145.6 (-18.6%)	596.3
Barrenland	24.1 (-40.2%)	34.7 (-51.0%)	6.1 (-55.5%)	
Water	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0

*Negative values means a decrease in the land use tradeoff.

The results from scenario 12 suggest that the Caonillas sub watershed is the most feasible region in terms of urban development. For RGA and Limón sub-watersheds, the increment in urban areas was around the 25 to 30%, respectively. Agriculture growth was around 4%. In the Caonillas sub-watershed urban growth was 52 %, agricultural growth was 4%.

For this scenario, urban growth was achieved at the expense of all other land use types for all the sub-watersheds. Rangeland conversion rate oscillates from a minimum value of 5% in Caonillas sub watershed and around 18% for the remaining two sub areas.

Forestland growth at Limón sub watershed has the higher increment with 66 Ha against 47 Ha for RGA and only 4.3 Ha for Caonillas.

5.4.8 Scenario 13; Agriculture growth priority

Scenarios 3 and 13 investigates maximum growth in agricultural land use in the area using existing water quality standards (Scenario 3) and proposed water quality standards (Scenario 13). It is expected that some urban development will occur as a result of increase in agricultural activities in the study area. Urban growth was assigned a lower priority in these scenarios.

Scenarios 3 and 13 have its foundation on an expected reactivation of the agriculture economic activity in order to accomplish with world requirements to guarantee provisioning of food. Both scenarios evaluate the maximum possible growth for agriculture in the 2025 year.

Forest land use is to be maintained at least at the current cover level, meaning that decrease is not allowable for it. Tables 5.17 and 5.18 summarize the results from this scenario.

Table 5.17 Land uses optimization values summarize for Agriculture in the study area (Scenario 13)

Sub-watershed	Land Use	2005	2025			
		Actual Value (Ha)	Lower Bound (Ha)	Upper Bound (Ha)	Interval (Ha)	Mid. Value (Ha)
RGA	Forest	14,653.1	14,700	14,700	0.0	14,700.0
	Agriculture	1,286.3	1,402.3	1,533.4	131.1	1,467.9
	Urban	883.7	965.9	965.9	0.0	965.9
	Pasture	11.7	10.9	17.9	7.0	14.4
	Rangeland	1,713.3	1,316.5	1,485.7	169.2	1,401.1
CAONILLAS	Forest	8,155.7	8,160.0	8,160.0	0.0	8,160.0
	Agriculture	643	765.8	765.8	0.0	765.8
	Urban	283.7	309.5	309.5	0.0	309.5
	Pasture	180.9	188.5	188.5	0.0	188.5
	Rangeland	2,970.9	2,845.1	2,845.1	0.0	2,845.1
LIMON	Forest	7,627.0	7,676.1	7,696.4	20.3	7,686.3
	Agriculture	694.7	741.6	789.7	48.1	765.7
	Urban	165.2	164.7	181.4	16.7	173.1
	Pasture	102.3	102.2	106.7	4.5	104.5
	Rangeland	784.9	627.1	674.9	47.8	651.0

Table 5.18 Land use probable conversion based on mean optimization modeling output. SCENARIO 13 (Forest conservation + agriculture growth priority)

Land use	Sub-watershed land conversion (Ha)			**TOTAL (Ha)**
	RGA	Caonillas	Limon	
Forest	47.0 (0.32%)	4.3 (0.05%)	59.1 (0.78%)	110.4
Agriculture	181.8 (14.1%)	122.8 (19.1%)	70.9 (10.2%)	375.5
Urban	81.9 (9.3%)	25.8 (9.1%)	7.8 (4.7%)	115.5
Pasture	2.7 (23.2%)	7.6 (4.2%)	2.1 (2.1%)	12.4
Rangeland	289.4 (-16.9%)	125.8 (-4.2%)	133.9 (-17.1%)	549.1
Barrenland	24.0 (-40.0%)	34.7 (-51.0%)	6.0 (-54.5%)	
Water	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0

*Negative values means a decrease in the land use tradeoff.

Results from Scenario 13 shows that agriculture land could increase by 19% and urban 9% for the Caonillas watershed. RGA and Limón watersheds show increases of 14% and 10% for agriculture as well as 9% and 4.7% for urban, respectively.

Pasture land areas has the maximum potential growth of 23% for RGA sub-watershed; Limón and Caonillas in pasture are 2 and 4%, respectively. RGA considerable percent change in pasture area is due to the existing low acreage in this land use in RGA.

As in the two previous scenarios, Caonillas show the lowest forestland increment with only 4.3 Ha versus 47 Ha and 59 Ha for RGA and Limón.

5.4.9 Summary of results for Scenarios 11 to 13

One of the main differences between both set of evaluated scenarios is the achievement of the environmental goals. This difference was introduced in the numerical nutrients and sediments maximum allowed loadings at the rivers and consequently the reservoirs. Results considering the actual regulation show a very significant underachievement in the environmental goals with respect to the results obtained considering the new more restricted and proposed regulation.

Figures 5.6 to 5.8 compare the obtained results from the three above analyzed scenarios by sub-watershed. Additionally to the two main prioritized economic activities, the comparison of the results allowed to visualize the effect in the remaining land uses, especially in the wildcards (Rangeland and Barrenland) as well as the forest land use.

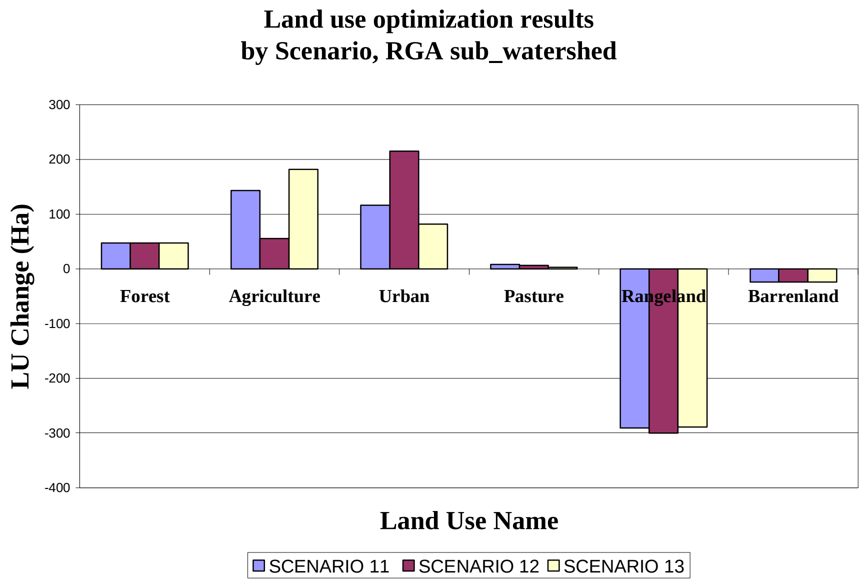


Figure 5.6 MOLP scenarios results (RGA sub-watershed)

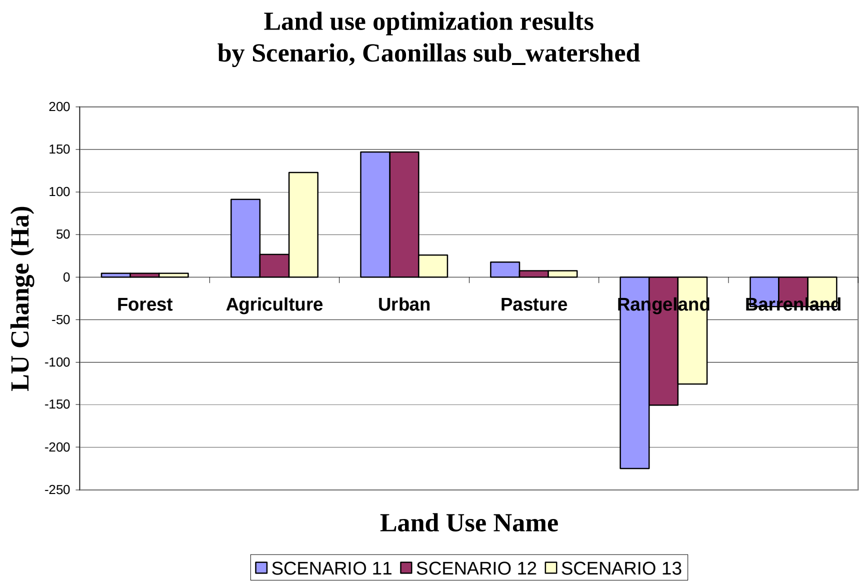


Figure 5.7 MOLP scenarios results (Caonillas sub-watershed)

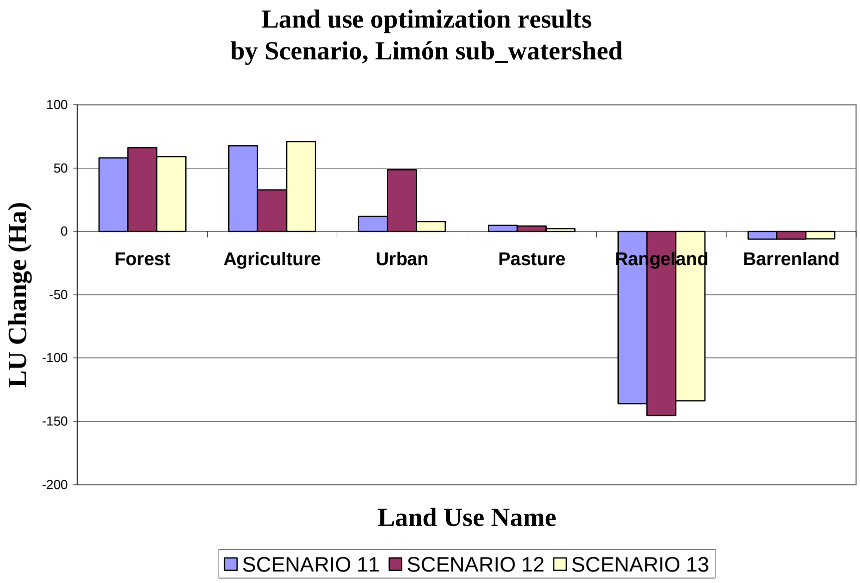


Figure 5.8 MOLP scenarios results (Limón sub-watershed)

Results from scenarios 11 to 13 reflect the effect of difference in environmental goals comparing with results from scenarios 1 to 3. In general, tendencies in growth pattern are similar for each scenario and main differences turns around the maximum optimal growth reached in land use.

Actual regulation in Puerto Rico allows higher loadings in water bodies receptors for the nutrients analyzed in the MOLP problem. This is the reason for a major growth potential in evaluated scenarios 11 to 13 where looser environmental targets allows a major expansion in the prioritized to grow land uses.

In the same way, wildcards like rangeland and barren land defined as lower profitable land uses tends to decrease in a major proportion with respect to scenarios 1 to 3. Balance in the system is the reason of a major wildcard trade off.

In particular, results for scenario 12 in RGA sub watershed represent the maximum expansion in urban areas with an increment of 24.4% with respect to the actual area. This result is greater than expectations until 2025 year according with state and municipal projections to this planning year.

In the scenarios 11 and 13, the results show a preference to agriculture growth rather than urban or built-up in RGA sub watershed. For scenario 11 the agriculture expansion can achieve an increment of 143 Ha against 116 Ha for urban development. Therefore for scenario13 agriculture could grow around 182 Ha versus 82 Ha for urban growth.

For Caonillas sub watershed the results show for urban land use the same optimization value for scenarios 11 and 12 with a growth of 146.8 Ha associated to an increment in percentage of 51.8%. For agriculture the scenario 13 results has the major possible expansion in this sub watershed with 122.8 Ha (19.1 % of increment).

Finally, for scenarios 11 and 13 Limón sub watershed obtained almost the same growth increment in agriculture land use with around 70 Ha. Scenario 12 results represent the higher possible growth of urban areas in this sub watershed with 48.6 Ha (29.4% of increment).

5.5 SUMMARY AND CONCLUSIONS

A Multi-objective Linear Programming (MOLP) approach was incorporated in this research in order to be used as a mathematical tool for the evaluation of a series of hypothetical scenarios searching for the optimal land use combination for the year 2025, the planning year. Scenarios formulation evaluated hypothetic cases to see the behavior of the main economic activities under possible combinations and get an idea about the potential growth of those strongest activities in the area like the agriculture and urban in accordance with environmental water quality targets, the highest priority in the analysis.

A solid social and economic research about the historical tendencies and data of the municipalities inside the RGA watershed, complemented with interviews with experts in the land use planning area, agriculture economic activity and local, state, and federal agencies were considered in the models formulation and utilized as an indicator to evaluate the results to come up, associated with possible future conditions in the area.

The MOLP methodology uses the results from a ten-years water quality simulation model to incorporate the nutrients and sediments land use export coefficients summarized in an interval and introducing the inherent uncertainty in this type of nature process.

One of the main contributions of the proposed methodology is the incorporation of the uncertainty associated to the model decision variables giving from the export coefficients associated to each land use type analyzed in this research. The 1,000 random runs give the fortress to the MOLP model, producing more realistic results compared with a deterministic formulation where a unique solution is available instead of multiple optimal possible combinations.

To run the scenarios an interface was created to link the two applications software that finds the solution to the optimization problem. The interface links to MATLAB for the goal attainment solution algorithm and links to LINGO for the goal programming solution algorithm. The interface allows the user to set-up multiple runs as required by the user for system evaluation and automation of the process.

Two kinds of environmental regulations were considered in the analysis; a) existing water quality standard guarded by the PREQB; and b) a new proposed water quality standard submitted to both local and federal agencies for review and approval.

A total of 1,000 random runs were executed combined with a six different scenarios producing an extensive data base of results to be analyzed and considered in the final results for each scenario.

Specific conclusions about the optimization scenarios results are the followings:

- Difference between scenarios according to the environmental water quality targets were reflected in the results. Greater growth and trade off in the land use assignment could be allowed in those scenarios with more flexible water quality criteria (Scenarios 11 to 13).

- The results from Scenarios 11 to 13 that considers the actual water quality regulation as target given by the PREQB, reflects a greater underachievement in the environmental goals comparing with the results from a more restricted regulation in water quality targets (Scenarios 1 to 3). This is a consequence in the looseness of actual water quality standards in Puerto Rico (See Appendix D).
- The wildcards land uses including the rangeland and barren land and defined as lower profitable land uses, tends to decrease in a major proportion for Scenarios 11 to 13 with respect to scenarios 1 to 3. Balance in the system is the reason of a major wildcard trade off due to the potential growth of more rentable land uses (urban and agriculture) obtained in Scenarios 11 to 13.
- The Forest areas in the MOLP results tend to be incremented in a percent around 1% as maximum. No decrease in this land use is allowed.

CHAPTER VI

LAND USE ALLOCATION SYSTEM

6.1 ABSTRACT

This chapter presents the development of a Geographical Information System (GIS) utilized together with the MOLP approach, to define the basis for a land use allocation system analysis. The GIS recommends specific land use locations based on several spatial constraints like distance to rivers, available infrastructure, preference land use conversion, etc. The GIS model provides a tool for decision makers in the land use planning and decision making process regarding to spatially land allocation.

6.2 INTRODUCTION

Geographic Information System (GIS) is a concept based on an organized collection of computer hardware, software, geographic data and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information. In simplified terms is a computer system capable of holding and using data describing places on the earth's surface.

GIS design includes different processes; planning stage, design and implementing of the system and consists of several activities like feasibility analysis, requirements determination, conceptual and detailed database design, and hardware and software selection. GIS analysts have been interested in the past years in developing system design techniques, some of them adopted from software engineering, including the software "life-cycle model" (Boehm, 1981). Specific GIS life-cycle models have been developed for GIS (Calkins, 1982; Tomlinson 1994; Calkins, 1998).

GIS design methodologies currently in use do not treat the database design problem and therefore errors in database design can still occur and can be very costly. More attention needs to be paid to geographic database design. Specific tools reflecting the special characteristics of spatial data need to be developed to support the database design portion of the GIS design process. The building of the database for a GIS is frequently the most expensive; consuming as much as 80% of the total GIS project cost (Dickinson and Calkins, 1989).

The entity-relationship (E-R) modeling technique by Chen (1976), is one of the many specific database design techniques developed and one of the most effective over a wide range of application areas. The next section shows the theoretical background of this technique and the conceptual modeling principles.

Conceptual Modeling and Data Base Design

The GIS data base design is the planning stage where the contents of the intended database are identified and described. Usually this stage is divided in three major activities; the conceptual data modeling, the logical data base design and the physical model design. Table 6.1 explains in detail those activities:

Table 6.1 Activities description in the database planning stage.

Activity	Description
Conceptual data modeling	Identify data content and describe data at an abstract, or conceptual, level.
Logical database design	translation of the conceptual database model into the data model of a specific software system;
Physical database design	representation of the logical data model in the scheme of the software.

The conceptual data modeling responds to the question “what the GIS model must do?” and the logical and physical models respond to “how the GIS will be implemented?”. It is important to remember that the database planning is the most important activity in the GIS development. It begins with the identification of the needed data and goes on to cover several other activities collectively termed the data life cycle mentioned before. Another activity includes identification of data in the needs assessment, inclusion of the data in the data model, creation of the metadata, collection and entry into the database, updating and maintenance, and, finally, retained according to the appropriate record retention schedule (Calkins, 1998).

The GIS developed in this research complements the results from the MOLP mathematical optimization approach. The main purpose is to identify potential areas to locate specific land use recommended ranges from the MOLP model subject to spatial constraints at the study area including: existing land use, conversion preference, topography constraints, access to services and, distance to water bodies.

6.3 METHODOLOGY

Integration of the results obtained from the multi-objective optimization approach with the GIS model development allows the creation of a land allocation system considering environmental, socio-economic and physical factors in the RGA watershed and the respective main sub-watersheds.

Multi-objective optimization results recommend the ranges of available growth at the end of the planning period (2025). This phase can be considered as an abstract numerical framework to find the best land use combination in several socio-economical scenarios. Abstract means that the numerical optimization results do not consider the spatial characteristics and constraints at the study area. Rather ignores the location of the landuse within the watershed. The proposed GIS model solves this problem when used as a complementary tool to assign those optimal values.

GIS land allocation model uses the multi-objective results and try to find the best strategy for implementing them in a spatial framework. Some factors are useful to implement the optimization results among them the actual existing land use, land use potential and conversion preferences. Scenarios were focused in the forest, agricultural and urban land uses as the main priority in terms of growth. Rangeland and barrenland were used as wildcards for land use trade off. The next section describes the conceptual, logical and physical models used as the basis for the GIS design.

6.3.1 Geographical Information System Design (GIS)

The GIS design was based on available literature and is a combination of two main approaches; the software engineering and, more specifically, the life-cycle model approach that take into account several steps including the planning step (analysis and requirements), testing, development (codification) operation and use. The second one is the structured design approach that uses three major activities; the conceptual, logical and the physical model design. Both approaches were used because they have a common sequence in the GIS development.

Figure 6.1 shows the combination of both methodologies used for the GIS design and implementing. The next section is a detailed description about the conceptual, logical and physical models construction in this research.

6.3.1.1 Conceptual Model

Resources

The first step to construct a conceptual model is to identify all the available resources, among themselves, the thematic and cartographic information data, technical support like software, hardware and, human resources. Also a very clear idea of the model purpose is necessary in this planning stage.

Geographical information containing thematic and cartographic data was obtained from federal and state agencies including the U.S Geological Survey (USGS), Junta de Planificación de Puerto Rico, U.S. Department of Agriculture (USDA), National Resource Conservation Service (NRCS) and private consultants. Additionally, some data was processed in this research generating new layers needed in the GIS model development. The geographic data used in this study is public domain and it is easily obtainable from government agencies.

ArcInfo, Version 9.2 from ESRI was the available software for physical model codification and hardware including high capacity computers were employed for GIS model design. Other resources like Trimble Global Positioning System (GPS) and Nokia Total Station were available.

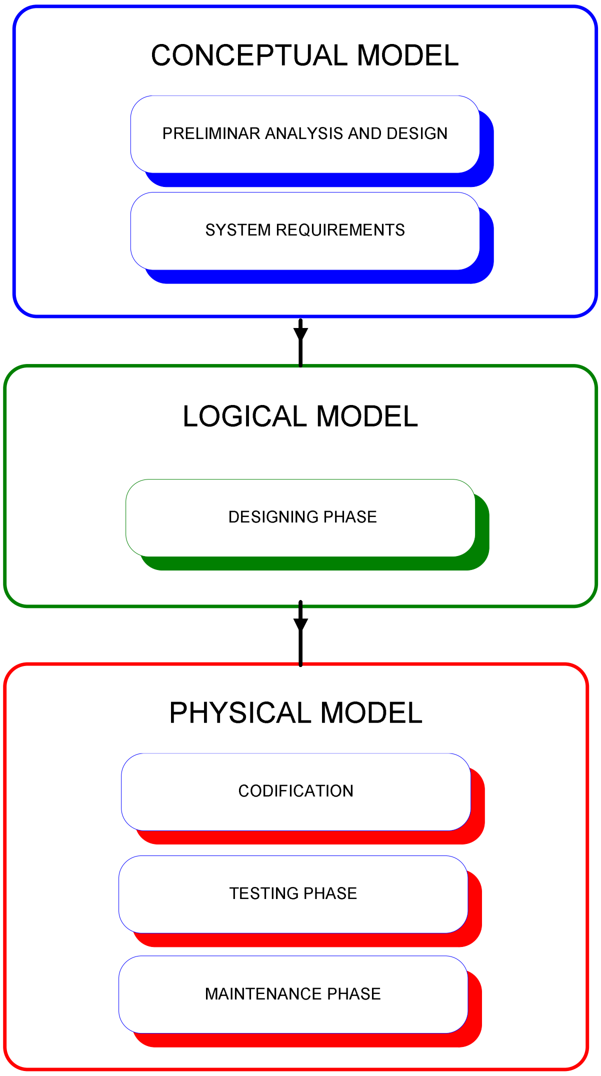
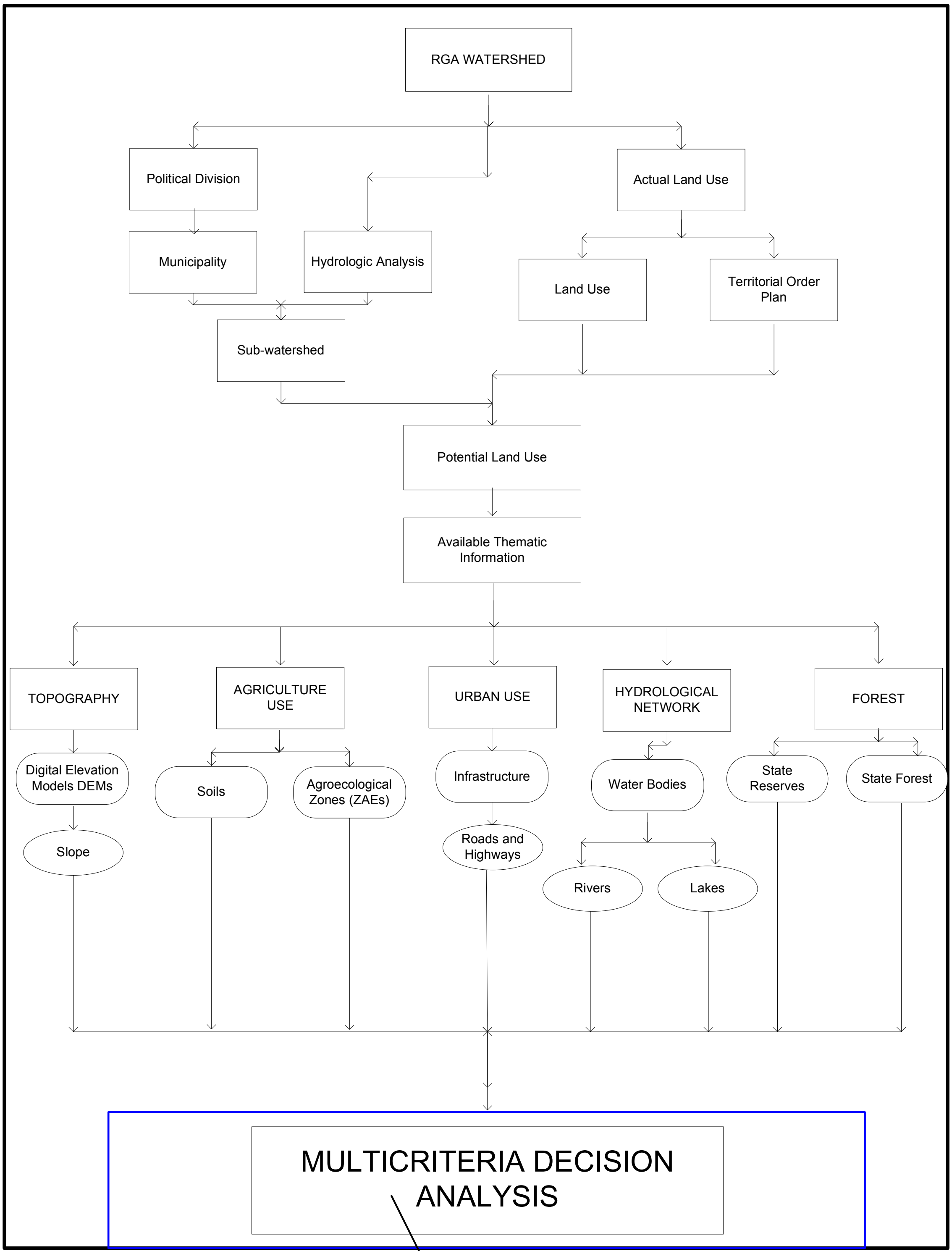


Figure 6.1 GIS combined methodology

Limitations

There were conflicts with geographic coordinates system projections for each data source. Also some of the layers and thematic data required pre-processing before it can be used adequately in the model.

The conceptual model flow chart, depicted in Figure 6.2 is a representation of the proposed conceptual model. Figure 6.2 presents two main stages; the first one summarizing all the thematic information needed in the model development including municipal boundaries, municipal territorial order plans, hydrological information, topography, soils and land use description among them. The second stage is the decision criteria analysis based on multiple criteria to obtain the best optimal combination for land use conversion in the watershed, the main objective of the GIS model.



RGA WATERSHED
Political Division
Actual Land Use
Municipality
Hydrologic Analysis
Land Use
Territorial Order Plan
Sub-watershed
Potential Land Use
Available Thematic Information
TOPOGRAPHY
AGRICULTURE USE
URBAN USE
HYDROLOGICAL NETWORK
FOREST
Digital Elevation Models DEMs
Soils
Agroecological Zones (ZAEs)
Infrastructure
Water Bodies
State Reserves
State Forest
Slope
Roads and Highways
Rivers
Lakes
MULTICRITERIA DECISION ANALYSIS

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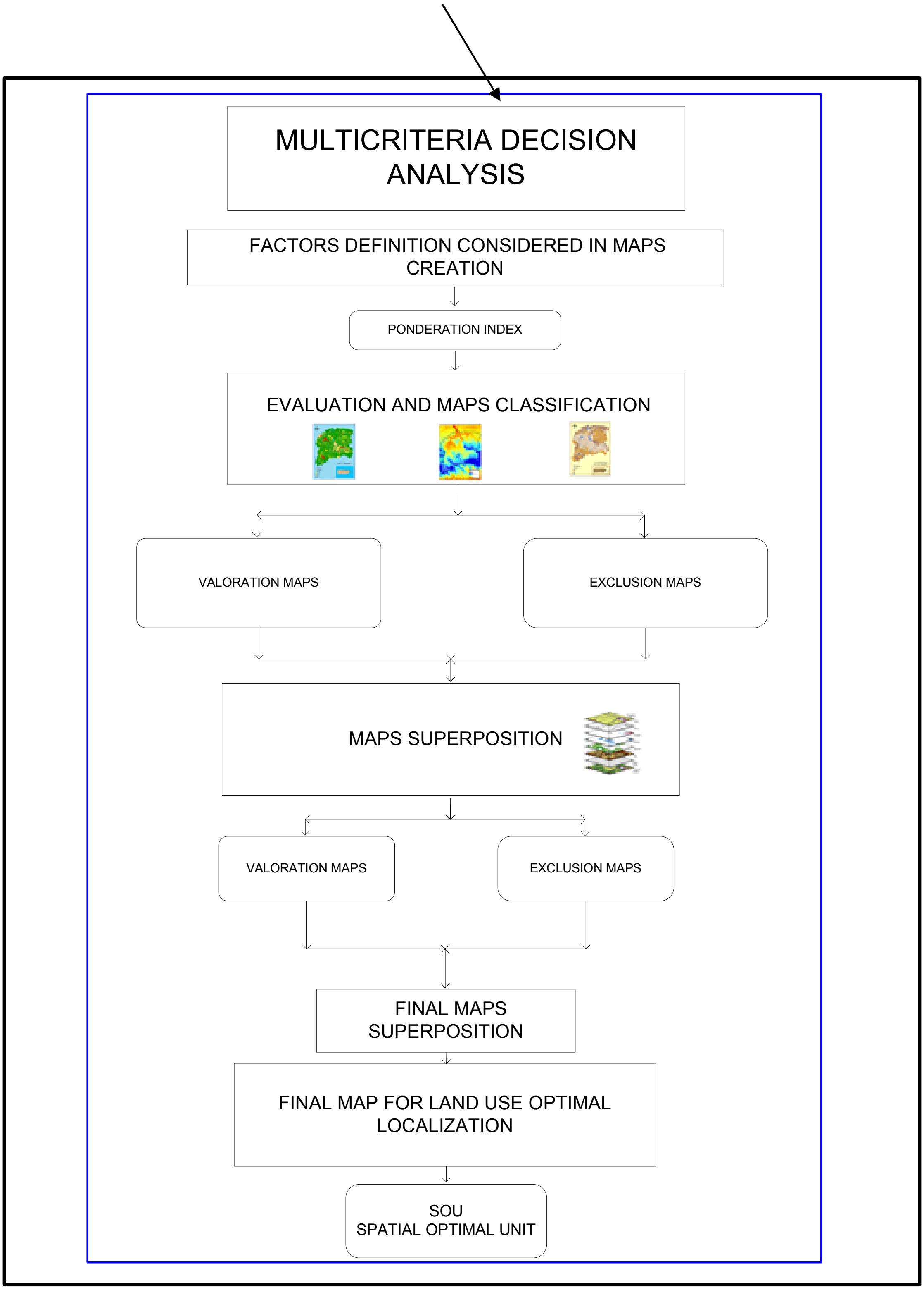


Figure 6.2 Conceptual Model for RGA watershed GIS Land allocation

6.3.1.2 Logical Model

Once the conceptual model is completed, the logical model becomes the second stage. The logical model component includes the information about the layers utilized, data base entities and respective attributes and the process analysis known as cartographic model.

Considering the GIS model development as a spatial tool to support in the decision analysis and based on the previous results obtained in the numerical multi-objective optimization, this section describes the individual steps to create a logical model from previous conceptual model.

Identification of all the spatial objects is the first step to construct a logical model. Those spatial objects constitute the information layers utilized in the GIS model prototype. Table 6.2 lists the spatial objects used, the respective layers, the data type file and the source associated to each layer. This data constitutes the database used in the model design and is the starting point to create a relational database between entities and its respective attributes.

Table 6.2 Layers for logical model

Spatial Object	Layer	Source
Land Use Records	*landuse.shp*	Junta de Planificación de Puerto Rico (1977), CSA Group (2000)
Hydrologic layers	*stream.shp , rivers_buffer.shp, subbasins.shp, rga_border.shp, floodplains.shp*	Preprocessed using Watershed Modeling System (WMS) 7.0 and Arc View 9.2
Hydro meteorological and water quality stations	*hidrom_sta.shp, wq_sta.shp*	U.S.Geological Survey and preprocessed in ArcView 9.2
Political Records	*counties.shp, barrios.shp*	U.S Census
Roads System	*roads.shp, roads_buffer.shp*	Junta de Planificación de Puerto Rico (2008)
Natural Features	*soils.shp,*	USDA, NRCS
Topography	*Digital Elevation Models* (DEMs)	MapMart

Entity Relational Data Base

Of the many specific database design techniques developed, the entity-relationship (E-R) modeling technique (Chen, 1976), has gained popularity and is extremely effective over a wide range of application areas. This technique is used here and it responds to the relation between the entities and the respective attributes.

The entity relational database was created using the format given in Table 6.3. This format allows constructing a data dictionary containing all the necessary information about the entities in the GIS model, the relation between layers, and the respective associated attributes.

Table 6.3.Data dictionary format

ENTITY <Entity name>				
Layer (s): <name of layer>			Info_Table: <name of table>	
Description: <description>				
Project Coordinate System: <Projection+datum>			Data_type: <raster or shapefile>	
ATTRIBUTES LIST				
Name	Description	Type	Indexed	Condition
<attribute 1>	<description 1>	<type 1>	<in 1>	<ob 1>
<attribute 2>	<description 2>	<type 2>	<in 2>	<ob 2>
…	…	…	…	…

Table 6.4 summarizes all the data included in the entity relational database for the GIS development for the RGA watershed and Appendix E shows the detailed data dictionary using the above format.

Table 6.4. Entity relational data base summary

Category	Entity (Attributes)	Spatial Object
Land Use Records	*Land Use(ID, LU_Code, LU_OPT_COD)*	Polygon
Hydrologic Records	*Stream (ARCID,SNAME)*	Polyline
	Rivers buffer (Id, Buff_river)	Polygon
	Lakes	Polygon
	Subbasins(DRAINTYPE, BASINID, MEANELEV)	Polygon
Political Records	*Counties boundaries*	Polygon
Roads System	*Roads_buffer(Id,Buffer_Op)*	Polygon
Natural Features	*Soils (Musym,Comment, Hyd_group, ZAE, ZAE_OPT_CO)*	Polygon
	Flood Plain	Polygon
	Land Use(LU_CODE, LU_OPT_COD)	Polygon
Topography	*Digital Elevation Models* (DEMs)	Raster
	Slope calculation	Raster

Cartographic Model

Interaction and operations between layers and maps, simulating a decision analysis process is the essence in a cartographic model. Map algebra is an example of this concept, implying a specific language to make the process. In cartographic modeling all the procedures are based on the interaction between layers or maps to generate a new map added to the existing initial data base.

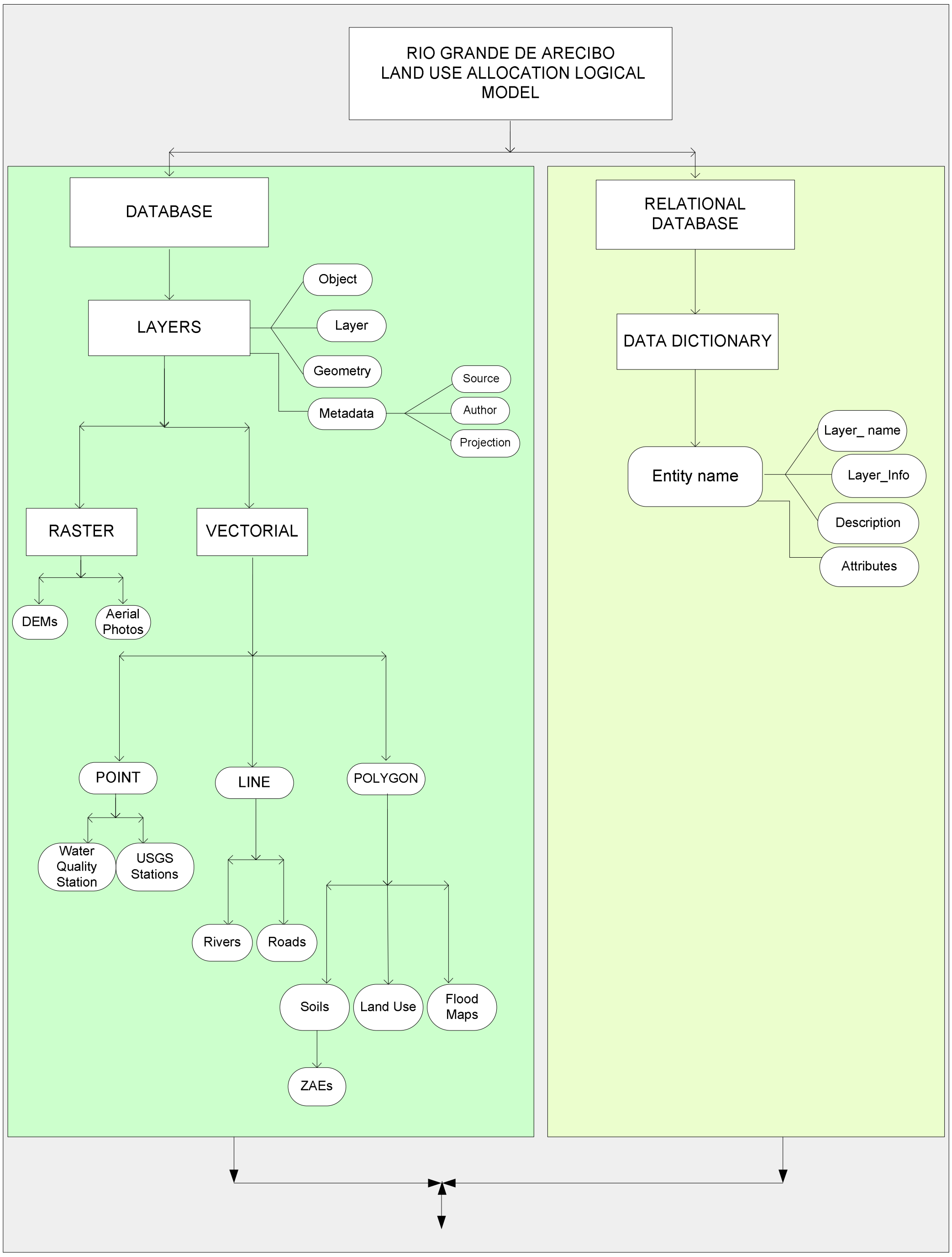
Operations and data analysis

One of the most important strongholds in the GIS modeling is the capacity to analyze using specific tools the data base information. This allows creating new information to solve the land use allocation spatial problem. The most employed operations in the interactions between the entities are summarized in Table 6.5.

Table 6.5 Common used operations in the GIS development

Operation	Description
Data handling	✓ Projections and transformations ✓ Attributes reclassification ✓ Scale transformations
Intersect	✓ Polyline to polygon ✓ Polygon to polygon
Union	✓ Polyline to polygon ✓ Polygon to polygon
Buffers	✓ In polylines
Digital elevation models analysis	✓ Deriving slope
Measures	✓ Area calcualtions

The main activities in the logical model described before are depicted in Figure 6.3. Once the conceptual and the logical model were done, the final major activity is the physical model codification.



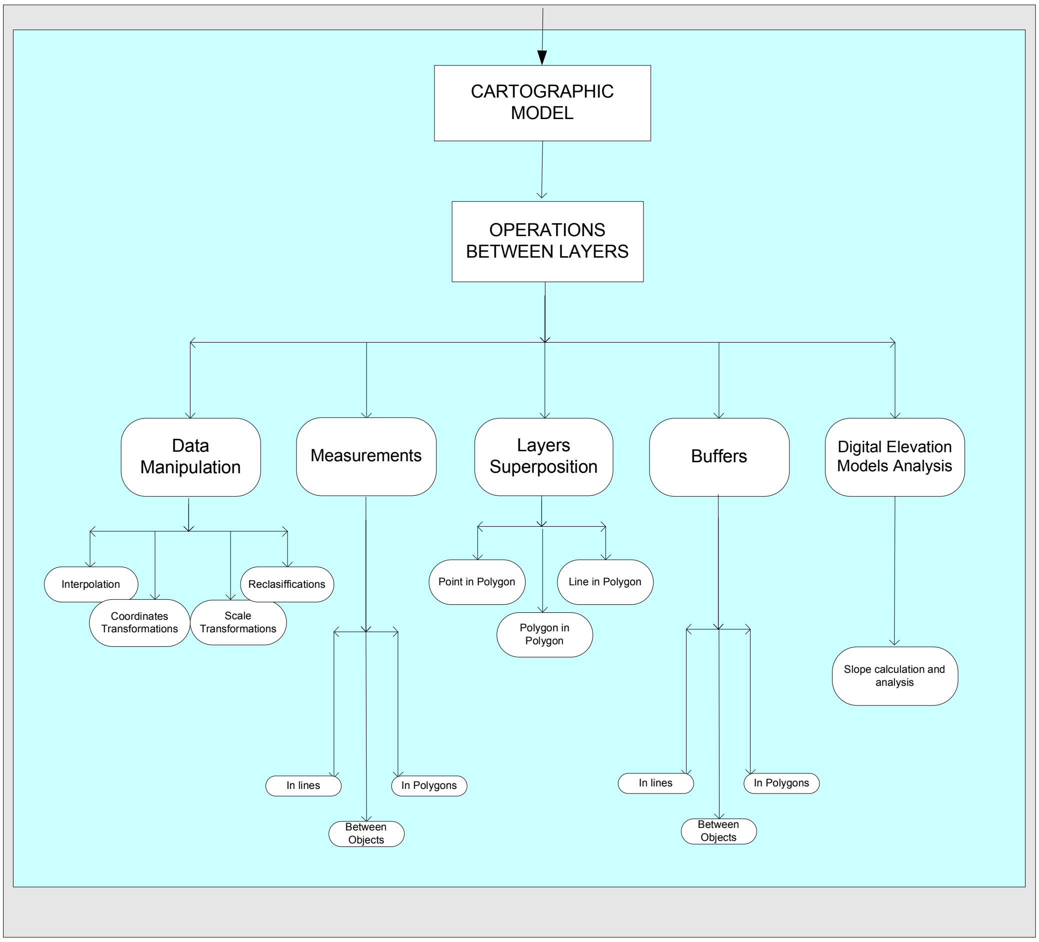


Figure 6.3 Logical Model for RGA watershed GIS Land allocation

6.3.1.3 Physical Model

Physical model design represents the transformation from the data model to the schema of the utilized software and it represents the final step in the GIS design analysis, previous to implementing the land allocation system. In the physical model all the available data is transformed into a same language to be used as the model data base.

The physical model design consists of several steps, including:

- Geographical Information Pre-processing.
- Relation between thematic information and all the layers and covers in the ARC View software.
- Model construction (Using the model builder tool in ARC Info)

The GIS model was developed using the Model Builder tool, from ArcInfo, in order to automate the process. Model construction using this tool is detailed in the next section.

Geographical Information Pre-processing

All the needed data was preprocessed according to the final model requirements, revised and located on a folder for model implementation purpose. These data included: the input data and the model output data.

Preprocess includes operations such as add a column to reclassify a code according to the multicriteria decision analysis objectives. For example, the land use coverage requires reclassifying the rangeland and barrenland uses as an optimal land use for conversion to urban and agriculture. For this purpose a column is added and a boolean code with 0 and 1 reclassify the existing land use codes giving a code equal to 1 for those two land uses and code equal to zero for the remaining. Table 6.7 summarizes all the realized preprocessing before the model codification.

Table 6.7 Preprocessing operations for Geographical Information

Layer	Preprocessing operation
landuse.shp	Add a column with a new Boolean code for Rangeland and Barrenland with code=1 and code=0 for the remaining land uses. The new column name is LU_OPT_COD in the *landuse.dbf* table.
soils.shp	Add a column with a new Boolean code=1 for Agro-ecological zones (ZAEs) classified as Edtl. Edtle, Edtlg, Edtlo and Emh categories and code=0 for the remaining categories. The new column name is ZAE_OPT_CO in the *soils.dbf* table.
stream.shp	Create a buffer for the *stream.shp* layer. The new layer called *rivers_buff.shp* has an area around the existing rivers network. For multicriteria analysis a new column named Buff_river is added in this buffer with a code=1
roads.shp	Create a buffer for the *roads.shp* layer. The new layer called *roads_buffer.shp* has an especified area around the existing roads network. For multicriteria analysis a new column named Buffer_op is added in this buffer with a code=1
Digital Elevation Model (DEMs)	A Mosaic is created with all the Digital Elevation Models (DEMs) contained in the watershed and clipped with the RGA border coordinates.

Additionally to preprocessing operations, a revision of all the data was done to avoid topological errors in the existing layers. All the data has the format needed in ArcView and it consists of vectorial (points, polylines and polygons) and raster information data. The next section is a detailed description of the physical codified model in model builder tool, based on the land use allocation procedure goals.

Model builder design and model assumptions

Model builder was used as a tool for the physical model codification based on conceptual and logical model. Using this tool, a spatial model is represented as a diagram that looks like a flowchart. It has nodes that represent each component of the spatial process. Figures in the model has a unique meaning, rectangles represent the input data, ovals represent functions that process the input data and rounded rectangles represent the output data that is created when the model run. Nodes are connected by arrows showing the sequence in the process (See Figure 6.4).

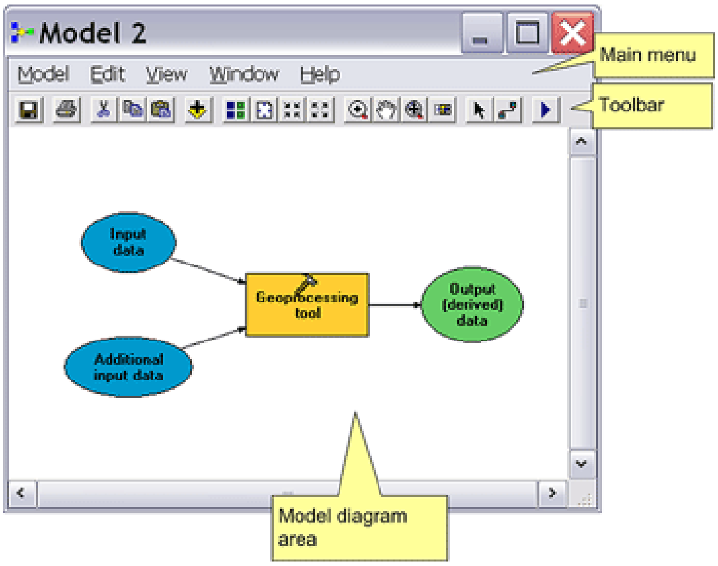


Figure 6.4 Model builder Application (from ArcView 9.2, ESRI)

Two physical models using Model Builder were created and used as the basis for implementing the results of the land allocation analysis. The first model was developed to identify the potential areas available for conversion to Urban or built-up land use and the second model search for optimal areas to be converted to Agriculture.

Since the physical models are the basis for the land allocation system, an overview of this analysis and a detailed description of both models and how they work are presented.

6.3.1.4 GIS Land allocation procedure

Once the conceptual, logical and physical models are developed, the land allocation implementation depends on the decision makers priorities. In this research, scenarios and the respective results from the multi-objective optimization approach were utilized as recommended ranges for the GIS model and land allocation implementing. In this sense the priorities goes on the need to convert the unutilized land uses like the rangeland and barrenland into urban and agriculture (main socio-economic activities at the area), taking into account spatial constraints not considered in the mathematical optimization analysis. This procedure allows defining a land use planning system based on numerical results and physical-spatial constraints considerations without risking the environmental goals.

The land allocation analysis use the physical models created with the Model Builder tool to evaluate multiples scenarios giving flexibility to the decision maker analysis. Adjustments or different criteria can be introduced in the developed models for multiple combinations analysis.

A fundament for land allocation considers that growth in a particular land use will grow adjacent to existing same category land use. This makes sense from a management point of view because two of three municipalities in the study area are governed by Land Use

Territorial Plans that try to produce an orderly development. As an example, new urban areas tends to develop near existing urban areas because of the presence of several factors such as infrastructure (roads, treatment plants, recreational parks), services (schools, hospitals, commerce). These factors are utilized as one advantage in the land allocation assigning.

Summarizing, the land allocation methodology is based on three stages as follows:

1. Preliminary Stage: Analysis and evaluation of the independent results from the Agriculture and Urban physical models. This stage allows searching for "*Potential land use*" areas available for conversion to urban or agriculture uses.
2. Land allocation stage 1: Previous results from each model are classified at this stage as independent results or intersected results (common to both models simultaneously). At this stage, the independent results are evaluated to determine if they are sufficient or not compared with the projected land use growth ranges recommended by the multi-objective optimization scenarios. Land allocation stage 1 consist of a new physical model (*land allocation model 1*), constructed using Model Builder and that incorporates new constraints and considerations in order to evaluate only the independent results from each model and refine those potential land use areas available for conversion.
3. Land allocation stage 2: This stage is carried out if the results from the land allocation stage 1 are not sufficient when compared with the optimization suggested ranges. In this case the intersected *potential land use* available areas are analyzed to determine if those can supply the lack of land use in the models.

new *land allocation model 2* is created using Model Builder to analyze and refine the results at this stage.

Potential Land Use

This term is associated with the potential land use characteristics according with the analyst requirements. Those potential characteristics include the physicals, such as good conditions for agricultural development (based on Agroecological Zones, *"ZAEs"* from NRCS) and, adequate slope for urban or built-up growth. Another type of potential land uses criteria responds to strategic locations like proximity to urban areas (schools, churches, and medical centers), access to basic services, and proximity to main roads in the area. Proximity to waterbodies is included as potential land uses but some constraints are established in this context due to the negative effect for the nearness to it (floodplains, risk of receiving pollutants directly).

For analysis purposes, all the criteria described above are considered into the search for potential land use expansion areas. For example, to consider the proximity to roads, a buffer (with variable width according to the analysis requirements) is created for the roads polygon with the intention to classify as optimal areas those inside the buffer. Slope is another criterion for urban or built-up and for agriculture development. Slopes between 0% and 20% are suitable for urban growth according to the observed expansion behavior in the past for urban areas. Using the agroecological zones from NRCS, depending on the crop, different slope ranges are optimal. For vegetables and plantains moderate to high slopes are allowed; coffee, farinaceous, and bananas can growth on lower to moderate slopes. Agroecological zones (ZAEs) classified as Edtl, Edtle, Edtlg Edtlo and Emh are the most appropriate for agricultural activities where slopes are not higher than 60%.

Preference conversion

Preference conversion is based on the decision maker criteria. For this purpose, the above section mentioned two different physical models from the preliminary stage were used as the starting point for land allocation analysis. Both were considerated and evaluated independently to identify the *potential land use* conversion areas in the watershed and to compare this spatial analysis with the multi-objective optimization approach results.

The first model is the Urban or built-up based on urban increment land use and it considers factors like slope, infrastructure, services, commerce, etc. Compliance with the set of factors or criteria increment the possibilities for a determined trade off in both models.

The second model is the Agricultural that considers conversion rules for the trade off between the existing land use and the possibilities to increment the agricultural economic activity. Factors like the slope, soil conditions, nearness to rivers and lakes, are considered in this model.

Both models focused to obtain the best increment in economic activities taking into account social and environmental considerations, creating a balance between the development in the watershed and environmental quality preservation. A detailed description of the construction of models is presented in the next section.

Urban or built-up model

The urban or built-up model is characterized to be a combination between vectorial data and raster data. This model begins with a selection using the *SELECT* tool of land use areas classified as Rangeland and Barrenland, considered as “wildcards” because they have the potential to be converted into urban or built-up areas. For this selection the row defined as LU_OPT_COD is used and coded with a value equal to 1 for best selection.

The next step in this model is the *INTERSECT* using the previous optimal selection and combine it with the buffer associated to the roads system. This buffer allows the selection of close areas to the road system adding value to the search of optimal land use. Once intersection is done a combination with the subbasins is considered to divide the previous optimal areas in the three main subbasins of the system and a *DISSOLVE* to homogenize areas with same attribute is carried out.

At this point, the analysis is based on vectorial data and raster files are introduced to evaluate the slope in the optimal land use. For this, a digital elevation model (DEM) is incorporated into the analysis and using the *EXTRACT BY MASK* tool the optimal areas obtained from the vectorial process are utilized as the mask that combined with the DEM produce new optimal areas with the incorporation of the elevation component. The next step calculates the *SLOPE* using the previous layer.

Using the *RECLASSIFY* tool, the slopes were classified into two classes with ranges between 0-20% and 40% and above. Slopes in the first class are defined as optimal according to the historical behavior in the urban areas of the watershed and codified with a code value equal to 1. Using the *EXTRACT BY ATTRIBUTES* tool the selection was done producing a new optimal output.

The final stage of the Urban or built-up model is to convert the last raster optimal land uses into a vector file to be combined with the results from the Agricultural model. This conversion is combined with the subbasins layer using the INTERSECT to obtain once again optimal areas by subbasin.

The final two steps consist of *DISSOLVE* the optimal zones and calculate the respective areas using the *CALCULATE AREAS* tool for numerical quantification.

Summarizing, the urban or built-up model has the main objective of identify areas with potential to be converted into this land use. Criteria like the existing land use, the distance to the roads system and the slope are take into account. Topography and specifically the slopes play an important role because the future development of urban areas depends greatly on this parameter. To consider this, the actual urban areas slopes were analyzed and used as criteria for the model builder design. Figure 6.5 depicts the Urban or built-up model created in ArcView Model Builder. Table 6.8 is a description of the inputs and outputs in this model. (See Appendix E for a detailed description of the inputs based on the Entity Relational Data base).

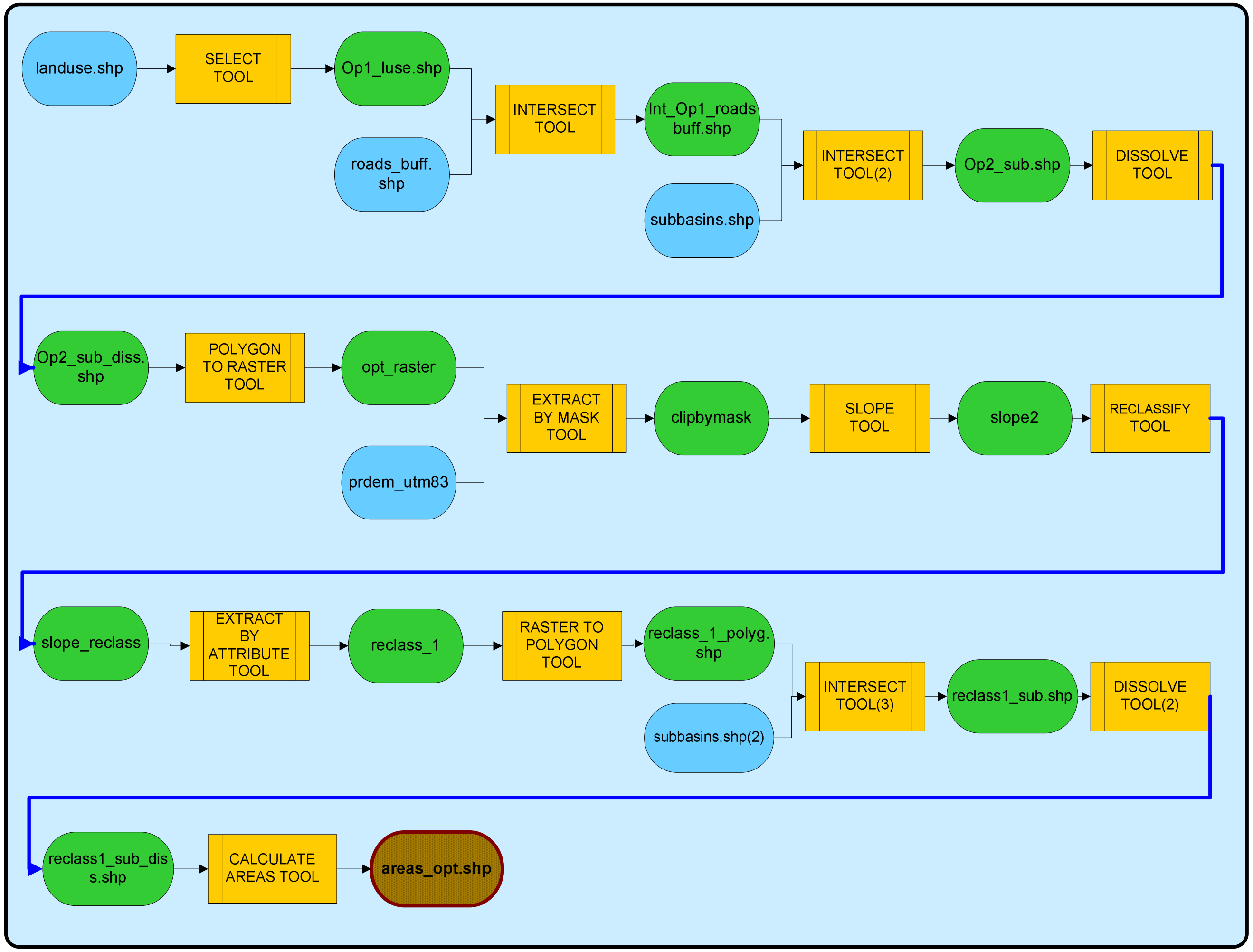
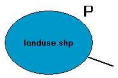


Figure 6.5 Model builder detail for Urban or built-up model

Table 6.8 Urban or built-up model description (Inputs and Outputs)

INPUTS 	**DESCRIPTION (type)**
Land Use	Land Use (shape file)
Roads_buff	Buffer associated to the roads system, (shape file)
Subbasins	Subbasins division in the RGA watershed, (shape file)
prdem_utm83	Digital Elevation Model (DEM) for Puerto Rico.
OUTPUTS 	**DESCRIPTION (type)**
Op1_luse	Optimal land use selection using as criteria the land use Rangeland and Barrenland coded as 1 in the field *LU_OPT_COD*
Int_Op1_roadsbuff	Intersect between optimal values obtained in *Op1_luse* and the roads buffer. Areas inside the buffer are defined as optimal.
Op2_sub	Intersection of previous output with the subbasins layer, producing optimal areas by subbasin.
Op2_sub_diss	Dissolve of optimal areas to unique polygons associated to each subbasin
Opt_raster	Conversion from vectorial to raster format of previous *Op2_sub_diss* layer.
clipbymask	Using the *Opt_raster* layer as mask, a extract by mask was done to the Puerto Rico DEM.
Slope2	Slope calculation from the previous layer.
Slope_reclass	Slopes less than 20% are classified with a code value equal to 1. Remaining slopes are classified with a code value equal to 0.
reclass_1	Corresponding to slope with a 20% and lower values, classified with a code value equal to 1.
reclass_1_polyg	Before layer is changed to vectorial format.
reclass_1_sub	Intersecting *reclass_1_polyg* with subbasins layer produces optimal areas by subbasin.
reclass_1_sub_diss	Dissolve of previous optimal areas with same characteristics.
areas_opt	Optimal areas calculation.

Agriculture model

This section describes the design of the Agricultural model. First of all this model is based on vectorial inputs and does not include raster files. This model considers the existing land use by subwatershed as well as the Agroecological zones (AEZ's) identification for Puerto Rico by NRCS. At this stage the soils layer obtained from the SSURGO database were preprocessed to identify the AEZ associated to each soil type. Next step is *INTERSECT* both layers and identify using the *SELECT* tool the areas containing Barrenland and Rangeland land uses and AEZ with optimal codes (Edtl, Edtle, Edtlg, Edtlo and Emh).

Following the model, the previously created optimal combination is unified using *UNION* with the buffer created for the rivers network. The idea is to create a new optimal area including the areas outside the buffer, defined as optimal. In this sense the buffer created for rivers is to consider that Agriculture areas can not growth near the water bodies to avoid contamination risks.

Next step is the *INTERSECT* with the previous optimal layer and the subbasins layer to classify by subwatershed the optimal areas. Once the identification proceeds, a *DISSOLVE* tool is utilized to agglomerate polygons with the same characteristics for data management purposes simplification.

The final step of the Agricultural model is to calculate the areas with the CALCULATE AREAS tool to numerically quantify the optimal areas.

Summarizing, the main objective of the Agricultural model is to identify the potential areas for conversion to Agricultural land use based on criteria such as slope, optimal soil type, temperature, precipitation range, soil temperature regime, soil moisture regime, life zone, hydrological conditions (enveloped in the AEZ's zones), in addition to potential land use for trade off. Also, a criteria based on the nearness to rivers or water bodies to minimize the impact to water quality is considered using a buffer (variable according the DM criteria) and finally considerations taking into account the distribution of optimal areas in the three main subwatersheds analyzed independently.

For the physical model design some additional logical constraints were considered indirectly. Constraints used were: 1) not allowing forest, urban or agricultural land use decrease and 2) avoid barrenland or rangeland growth.

Figure 6.6 represents a schematic of the agricultural model created in ArcView Model Builder. Table 6.9 presents a description of the inputs and outputs in this model. (See Appendix E for a detailed description of the inputs based on the Entity Relational Data base).

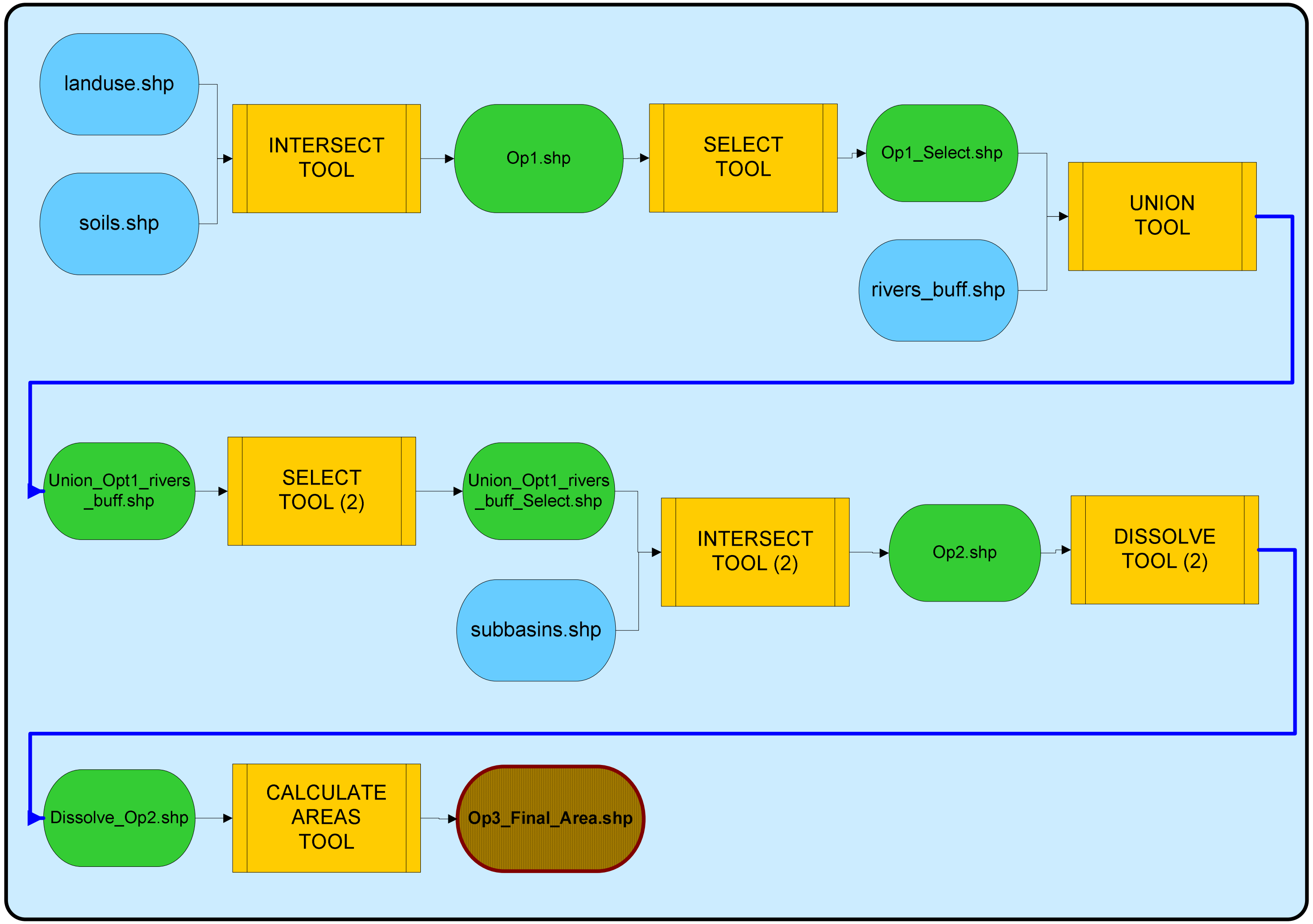
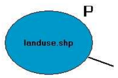


Figure 6.6 Model builder detail for Agriculture model

Table 6.9 Agriculture model description (Inputs and Outputs)

INPUTS 	**DESCRIPTION (type)**
Land Use	Land Use (shape file)
Soils	Soils (shape file)
Rivers_buff	Buffer associated to river network, (shape file)
Subbasins	Subbasins division in the RGA watershed, (shape file)
OUTPUTS 	**DESCRIPTION (type)**
Op1	Optimal combination between land use and AEZ (shape file)
Op1_Select	Optimal land use selection using as criteria the land use Rangeland and Barrenland coded as 1 in the field *LU_OPT_COD* and the optimal AEZ coded as 1 in the field *ZAE_OPT_CO*
Union_Op1_riversbuff	Union between optimal values obtained in *Op1_Select* and the rivers buffer.
Union_Op1_riversbuff_Select	Selection of areas outside the rivers buffer width, defined as optimal.
Op2	Intersect of *Union_Op1_riversbuff_Select* with the subbasins division.
Dissolve_Op2	Dissolve of optimal areas to unique polygons associated to each subbasin.
Op3_Final_Areas	Final areas computing from *Dissolve_Op2* optimal areas

Implementing the preliminary stage results

As stated at the beginning of this chapter, the final stage of the land allocation methodology is to evaluate the independent and the intersected results from both models (Agriculture and Urban or Built-up) and analyze them according to the DM priorities and multi-objective optimization requirements for land use growth.

For this purpose, new models from model builder are created to evaluate the available *potential land use* from the first stage and classify them into independent results for a specific model and common results to both models.

Using the *INTERSECT* tool as a filter, both optimal available areas (independent and common areas), are separated to produce two additional physical models. The first one called *land allocation model* uses the independent results to compare them to multi-objective optimization suggested ranges and the second one called *land allocation model 2* uses the common intersected supplementary areas obtained from the intersect, only if necessary.

Land allocation model 1

This model is used to evaluate the independent results from each model (Agricultural or Urban) and determine if they are sufficient to comply with the multi-objective optimization land use recommended ranges. If this condition is not reached, the common intersected areas are analyzed to supply the deficit, if possible.

In the land allocation model 1, a new physical model for urban and agricultural land allocation is developed with new constraints and criteria. Both models start subtracting the intersected common areas from the optimal preliminary *potential land use*. The second step is to produce using the *EXTRACT BY ATTRIBUTE* tool, a new layer from the actually land use containing only the agricultural or urban areas. This step allows generating a buffer with a defined size used as criteria to define the proximity between actual and optimal areas. The buffer is one of the most important criteria to assign land in both models because the basic idea is to expand the recommended land uses to adjacent areas with the same land use code.

In the urban assignment, slope is another important factor to assign the optimal areas identified in the previous step. The criteria for slope in the urban physical model were under 20% based on the historic records at the study area. Although 20% in the slope parameter is a general constraint value for urban development, lower values are desirable. Figure 6.7 represents the physical land allocation stage 1 model created using Model Builder application from ArcINFO and Table 6.10 describes the inputs in this model as well as the outputs in it.

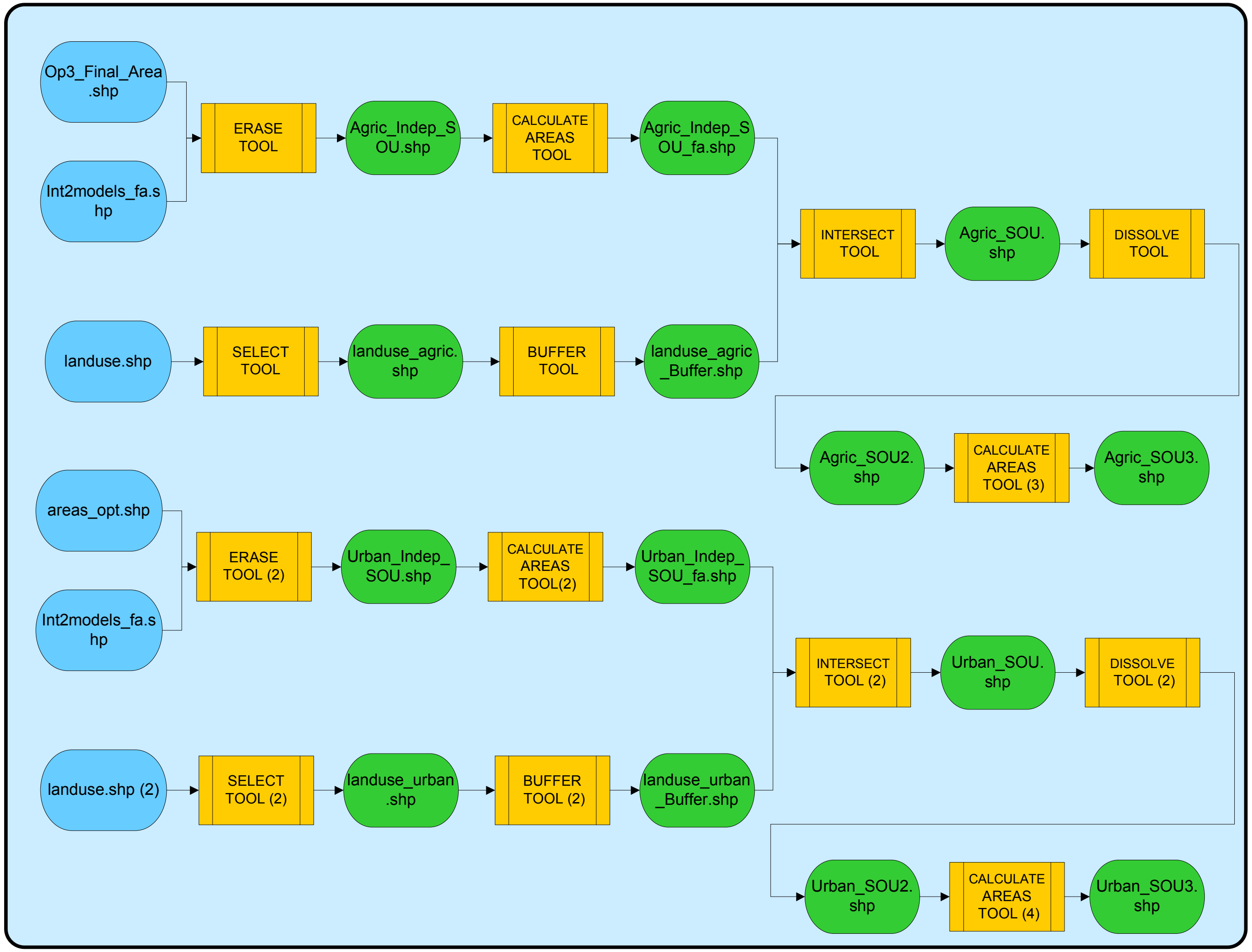
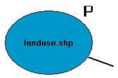


Figure 6.7 Model builder detail for land allocation stage 1

Table 6.10 Land allocation model 1 description (Inputs and Outputs)

INPUTS 	**DESCRIPTION (type)**
Op3_Final_Areas	Final Optimal Areas from the Agriculture model.
Int2models_fa	Common intersected areas for agriculture and urban models.
Land Use	Land Use (shape file).
areas_opt	Final Optimal Areas for the urban or built-up model. .
OUTPUTS 	**DESCRIPTION (type)**
Agric_Indep_SOU	Optimal Independent Areas for Agriculture model.
Agric_Indep_SOU_fa	Calculation of the Optimal Independent Areas for Agriculture model.
landuse_agric	Agriculture land use.
landuse_agric_Buffer	Buffer applied to agriculture land use.
Agric_SOU	Spatial Optimal Units for agriculture land use.
Agric_SOU2	Dissolved Spatial Optimal Units for agriculture land use.
Agric_SOU3	Calculation of the areas associated to Spatial Optimal Units for agriculture land use.
Urban_Indep_SOU	Optimal Independent Areas for Urban model.
Urban_Indep_SOU_fa	Calculation of the Optimal Independent Areas for Urban model.
landuse_urban	Urban or built-up land use.
landuse_urban_Buffer	Buffer applied to land use.
Urban_SOU	Spatial Optimal Units for urban land use.
Urban_SOU2	Dissolved Spatial Optimal Units for urban land use.
Urban_SOU3	Calculation of the areas associated to Spatial Optimal Units for urban land use.

Land allocation model 2

Additionally to the results from the land allocation model 1, the land allocation model 2 consists of the analysis for the intersected areas obtained in the preliminary stage of this methodology. This model is applied to complement the results from the previous model and give additional areas for the decision making process. Considerations of this model take into account options to the decision maker for compliance with the multi-objective optimization scenarios requirements. Therefore, common areas to both models are analyzed to define the best combination supplying the lack from independent areas in order to give flexibility in the land allocation assignment process.

The land allocation model 2 developed using model builder application has the inclusion of intersected areas to define the Spatial Optimal Units (SOU) for the urban or agricultural land use growth. The model has the advantage to search for the complementary areas of the land allocation model 1, either the areas are coded as urban or agriculture.

Figure 6.8 presents the physical land allocation model 2 with the respective description of inputs and outputs summarized in Table 6.11.

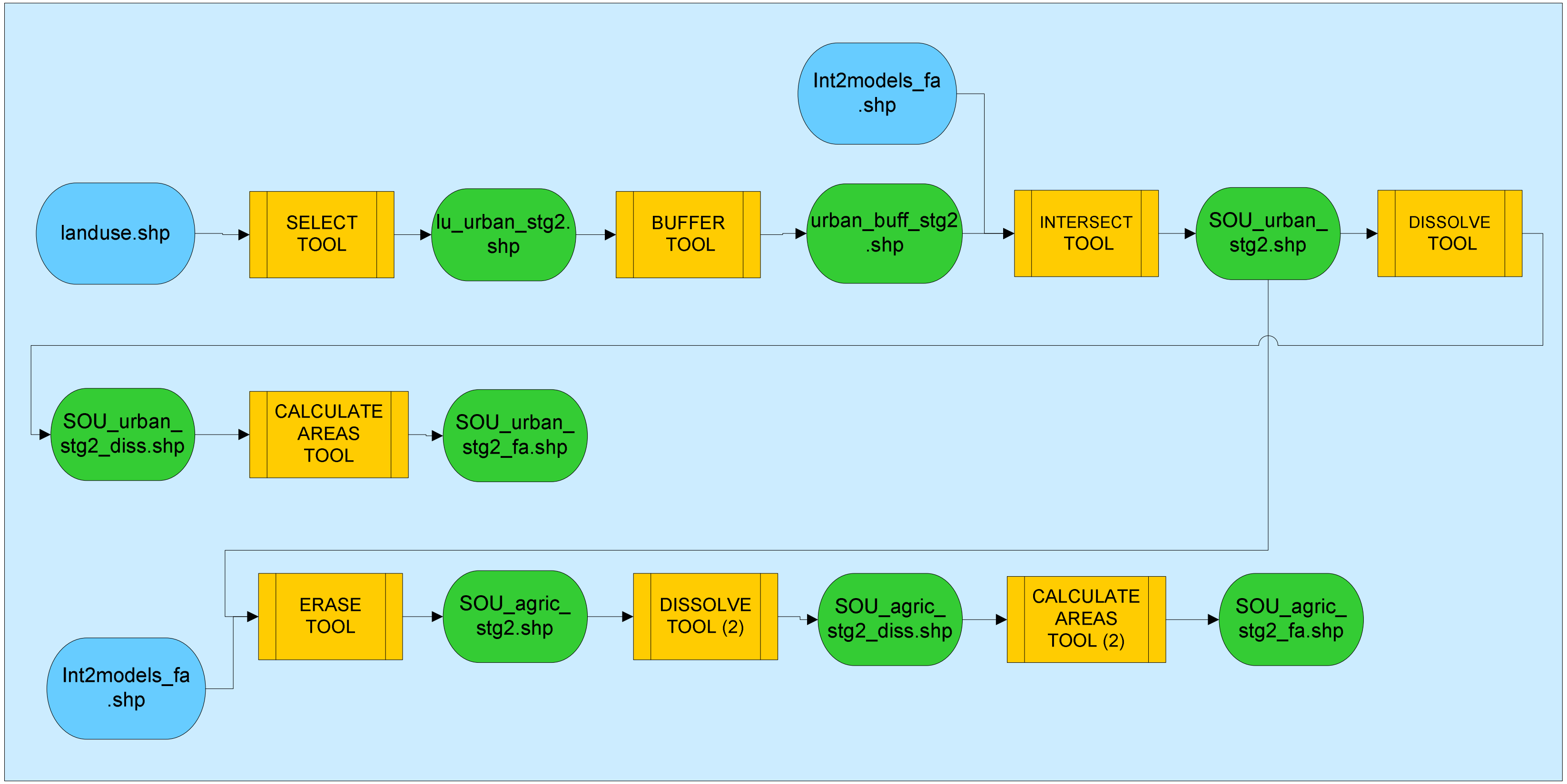
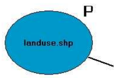


Figure 6.8 Model builder detail for land allocation stage 2

Table 6.11 Land allocation model 2 description (Inputs and Outputs)

INPUTS 	**DESCRIPTION (type)**
Int2models_fa	Common intersected areas for agriculture and urban models.
Land Use	Land Use (shape file).
OUTPUTS 	**DESCRIPTION (type)**
lu_urban_stg2	Urban or built-up land use.
urban_buff_stg2	Buffer applied to the Urban or built-up land use.
SOU_urban_stg2	Spatial Optimal Unit for urban intersected areas.
SOU_urban_stg2_diss	Dissolved Spatial Optimal Unit for urban intersected areas.
SOU_urban_stg2_fa	Calculation of the areas for Spatial Optimal Unit in urban intersected areas.
SOU_agric_stg2	Spatial Optimal Unit for agriculture intersected areas.
SOU_agric_stg2_diss	Dissolved Spatial Optimal Unit for agriculture intersected areas.
SOU_agric_stg2_fa	Calculation of the areas for Spatial Optimal Unit in agriculture intersected areas.

6.3.1.5 Land Use Allocation Results

This section presents the implementing of the results from the land allocation models, showing step by step according to the three stages methodology proposed in this chapter. The results are divided by land allocation assignment associated to the Urban or built up and the Agriculture conversion models.

Urban and Agriculture Preliminary Stage results

Using the Urban or built up and the Agricultural model detailed in the previous sections, as well as the three stages methodology guide, the first step is to obtain the preliminary results called *potential land use* where no interactions or restrictions between models are considered. In this sense, the Figure 6.9 shows the preliminary *potential land use.* Those results are reported in Table 6.12

Table 6.12 Preliminary stage results: Urban and Agricultural potential land use

Sub-watershed	Preliminary Stage: Potential land use	
	Urban Area (Km^2)	Agricultural Area (Km^2)
Río Grande de Arecibo	7.84	8.03
Caonillas	7.73	6.91
Limón	3.18	6.27

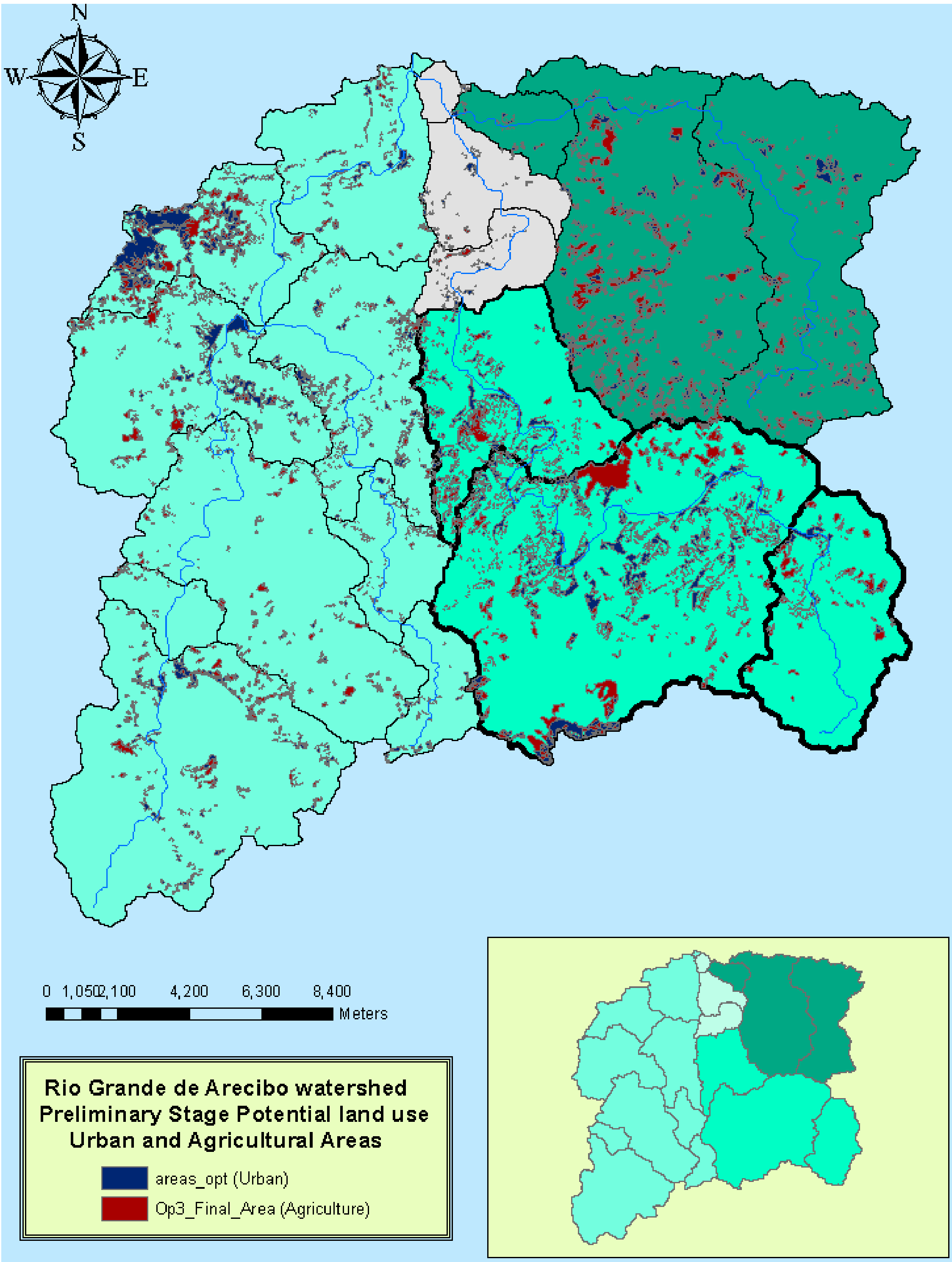


Figure 6.9 Preliminary Independent Urban and Agricultural potential land use

Land allocation Stage 1 results

Once the models are evaluated independently, the land allocation stage 1 and respective *land allocation model 1* combines both results using a *INTERSECT* to separate the shared areas from the independent areas. If necessary the common areas for both models will be analyzed in the final stage of the methodology with the land allocation model 2 tool.

Table 6.13 itemizes the results from the *INTERSECT* procedure and Figure 6.10 depicts the results. Those results show that independent areas are considerable for the three subwatersheds, with the major available percent areas at the Caonillas subwatershed.

Table 6.13 Land allocation Stage 1 results

Sub-watershed	Urban Area (Km^2)		
	Independent Area	Intersected Area	Total Preliminary Area Available
Río Grande de Arecibo	4.45	*3.39*	7.84
Caonillas	6.20	*1.53*	7.73
Limón	1.11	*2.07*	3.18
	Agricultural Area (Km^2)		
Río Grande de Arecibo	4.64	*3.39*	8.03
Caonillas	5.38	*1.53*	6.91
Limón	4.20	*2.07*	6.27

The next step is using only the column with the Independent Area results form Table 6.13, to determine according the recommended results from the MOLP scenarios, if is possible to satisfy those requirements. This analysis of results is detailed in Table 6.14.

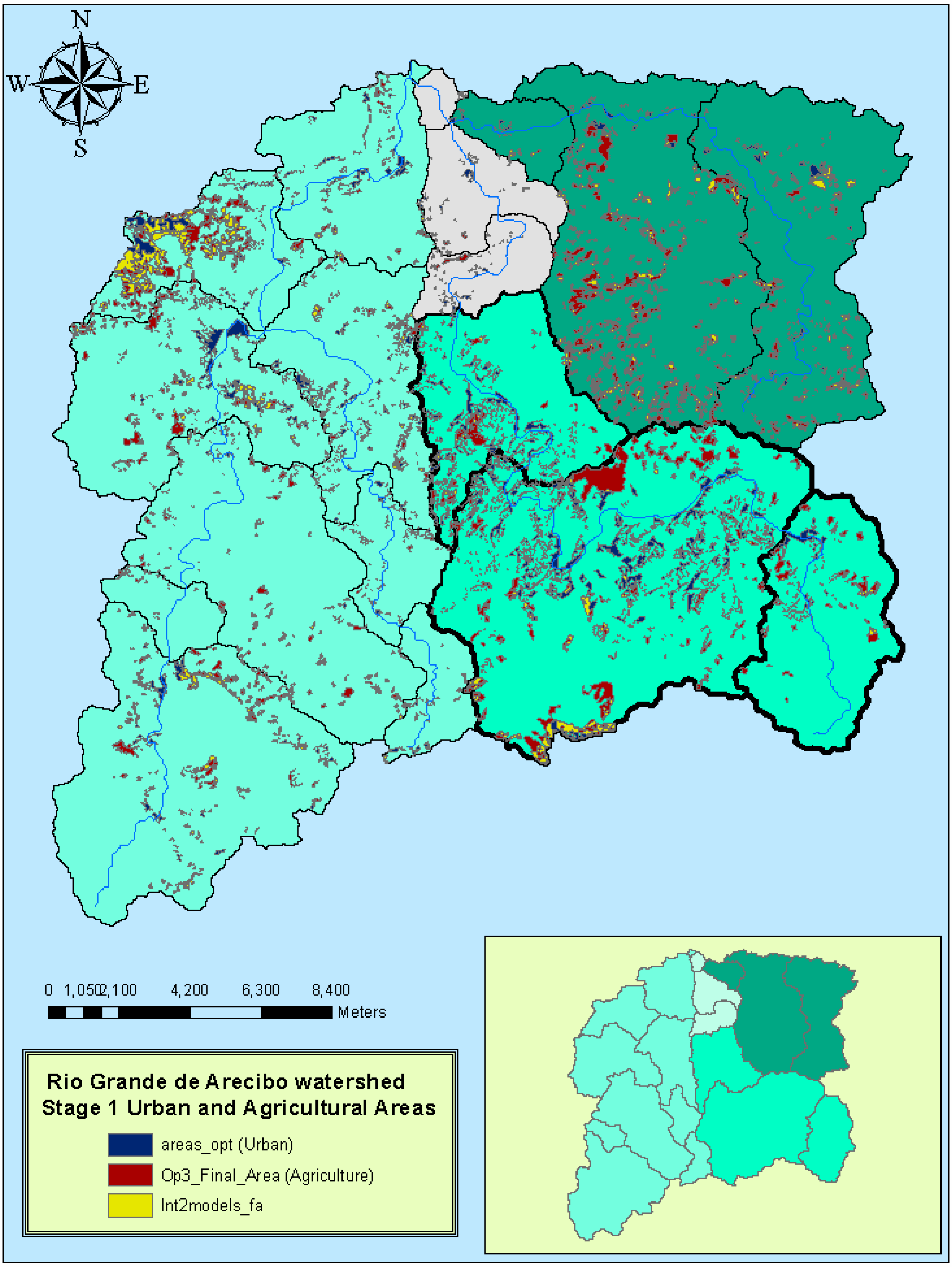


Figure 6.10 Total Preliminary Potential land use, divided by independent and intersected areas.

Table 6.14 MOLP optimal projected land use growth vs independent stage 1 available area for land conversion (SCENARIOS 1 to 3)

Subwatershed / *Land Use*	Subwatershed land conversion (Km^2)			Optimal independent land uses* (Km^2)	
	SCENARIO 1	SCENARIO 2	SCENARIO 3	Urban	Agriculture
RGA					
Forest	0.383	0.422	0.427		
Agriculture	***1.04***	0.46	***1.455***		
Urban	***0.796***	***1.515***	0.667		
Pasture	0.454	0.036	0.018	4.45	4.64
Rangeland	-2.454	-2.183	-2.316		
Barrenland	**-0.245**	**-0.25**	**-0.251**		
Water	0	0	0		
CAONILLAS					
Forest	0.041	0.042	0.043		
Agriculture	***0.789***	0.266	***1.172***		
Urban	***1.282***	***1.296***	0.246		
Pasture	0.169	0.075	0.075	6.20	5.38
Rangeland	-1.936	-1.332	-1.19		
Barrenland	**-0.341**	**-0.347**	**-0.346**		
Water	0	0	0		
LIMON					
Forest	0.525	0.617	0.516		
Agriculture	***0.509***	0.261	***0.574***		
Urban	***0.161***	***0.402***	0.11		
Pasture	0.0551	0.036	0.025	1.11	4.20
Rangeland	-1.1942	-1.26	-1.17		
Barrenland	**-0.056**	**-0.056**	**-0.055**		
Water	0	0	0		

*Optimal preliminary areas are based on tradeoff between Barreland and Rangeland

Results form Table 6.14 allows concluding that independent areas are sufficient to satisfy the MOLP requirements for Scenarios 1 to 3. Using as example the Scenario 2 (urban growth priority) and the Caonillas sub-watershed, 6.20 Km^2 are available for the urban growth and 5.38 Km^2 for the Agricultural vs a projected demand in 2025 year of 1.296 Km^2 for the Urban case and 0.341 Km^2 (0.266+0.075) Km^2 for the Agricultural.

Those results allow continuing the evaluation of the available optimal areas without the need of using intersected areas. The next step is to refine the obtained results using the land allocation model 1 tool, including new criteria and considerations in the physical model to finally determine the optimal land use conversion areas in this stage and compare those areas with the requirements of the MOLP scenarios.

Additional considerations include buffer zones around the existing urban and agricultural land use that combined with the optimal areas defines new optimal areas considering the proximity to existing land use areas. Another included criteria is the slope refining for urban growth, allowing the model builder model slopes under 20 percent (historical trend at the study area).

Figure 6.11 and the Table 6.15 shows the final optimal areas obtained using the land allocation model 1.

Table 6.15. MOLP optimal projected land use growth vs final optimal land allocation stage 1 areas (SCENARIOS 1 to 3)

Subwatershed / *Land Use*	Subwatershed land conversión (Km^2)			Optimal independent land uses* (Km^2)	
	SCENARIO 1	SCENARIO 2	SCENARIO 3	Urban	Agriculture
RGA					
Forest	0.383	0.422	0.427		
Agriculture	***1.04***	0.46	***1.455***		
Urban	***0.796***	***1.515***	0.667		
Pasture	0.454	0.036	0.018	2.40	1.54
Rangeland	-2.454	-2.183	-2.316		
Barrenland	**-0.245**	**-0.25**	**-0.251**		
Water	0	0	0		
CAONILLAS					
Forest	0.041	0.042	0.043		
Agriculture	***0.789***	0.266	***1.172***		
Urban	***1.282***	***1.296***	0.246		
Pasture	0.169	0.075	0.075	1.59	1.72
Rangeland	-1.936	-1.332	-1.19		
Barrenland	**-0.341**	**-0.347**	**-0.346**		
Water	0	0	0		
LIMON					
Forest	0.525	0.617	0.516		
Agriculture	***0.509***	0.261	***0.574***		
Urban	***0.161***	***0.402***	0.11		
Pasture	0.0551	0.036	0.025	0.77	2.69
Rangeland	-1.1942	-1.26	-1.17		
Barrenland	**-0.056**	**-0.056**	**-0.055**		
Water	0	0	0		

Once again results from Table 6.15 are sufficient to satisfy the MOLP requirements for Scenarios 1 to 3. Using as example the Scenario 2 (urban growth priority) and the Caonillas sub-watershed, 1.59 Km^2 are available for the urban growth and 1.72 Km^2 for the Agricultural vs a projected demand in year 2025 of 1.296 Km^2 for the urban case and 0.341 Km^2 (0.266+0.075) Km^2 for the Agricultural. Figure 6.11 show the final optimal areas for the land allocation stage 1 analysis.

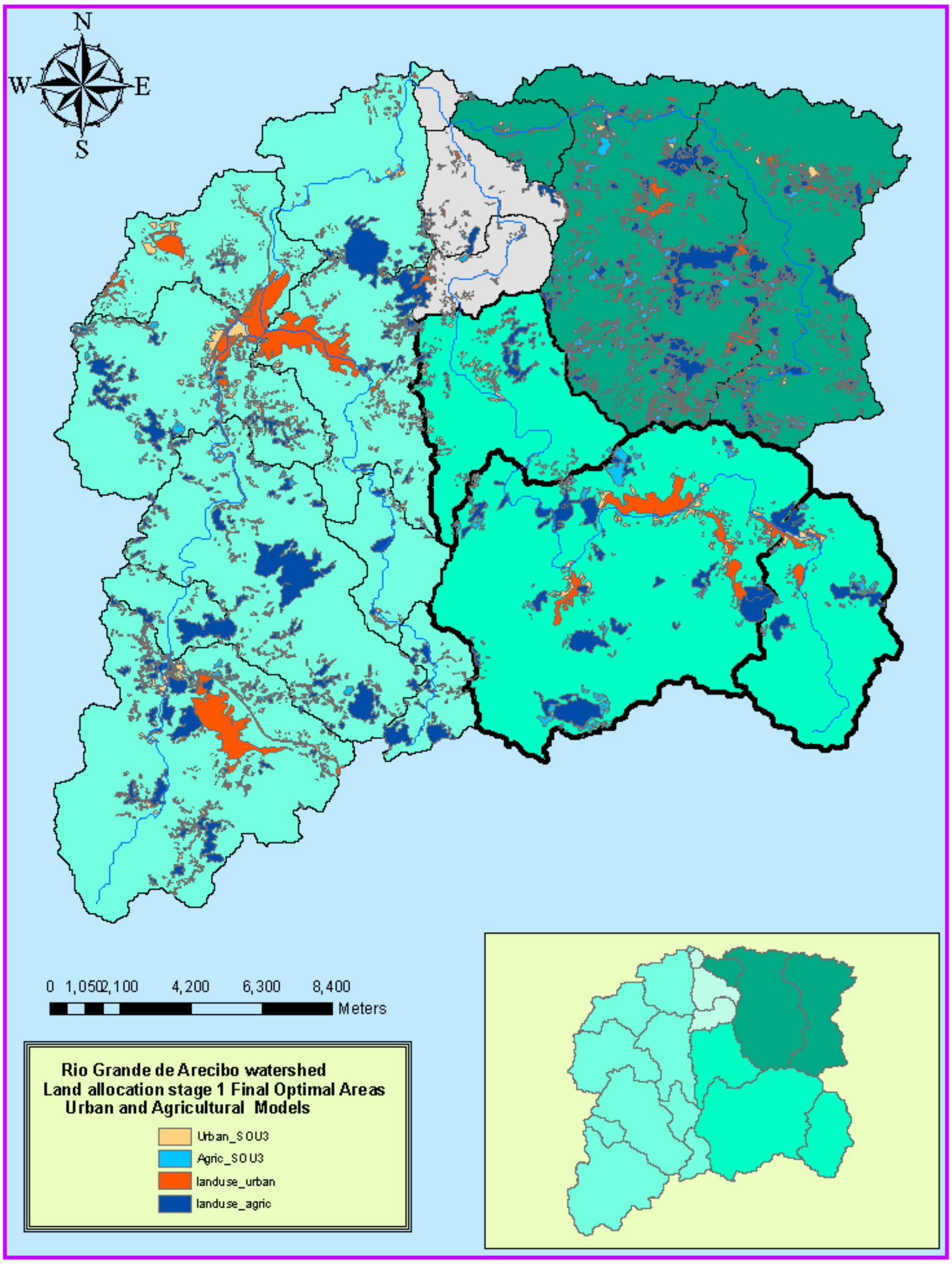


Figure 6.11. Land allocation stage 1 final optimal areas

Obtained results at this stage are enough to supply the MOLP requirements for SCENARIOS 1 to 3, meaning that the land allocation stage 2 is not necessary to supply additional areas. For a detailed visualization of the final optimal areas in Figure 6.11, a zoom to Caonillas sub-watershed is presented in Figure 6.12.

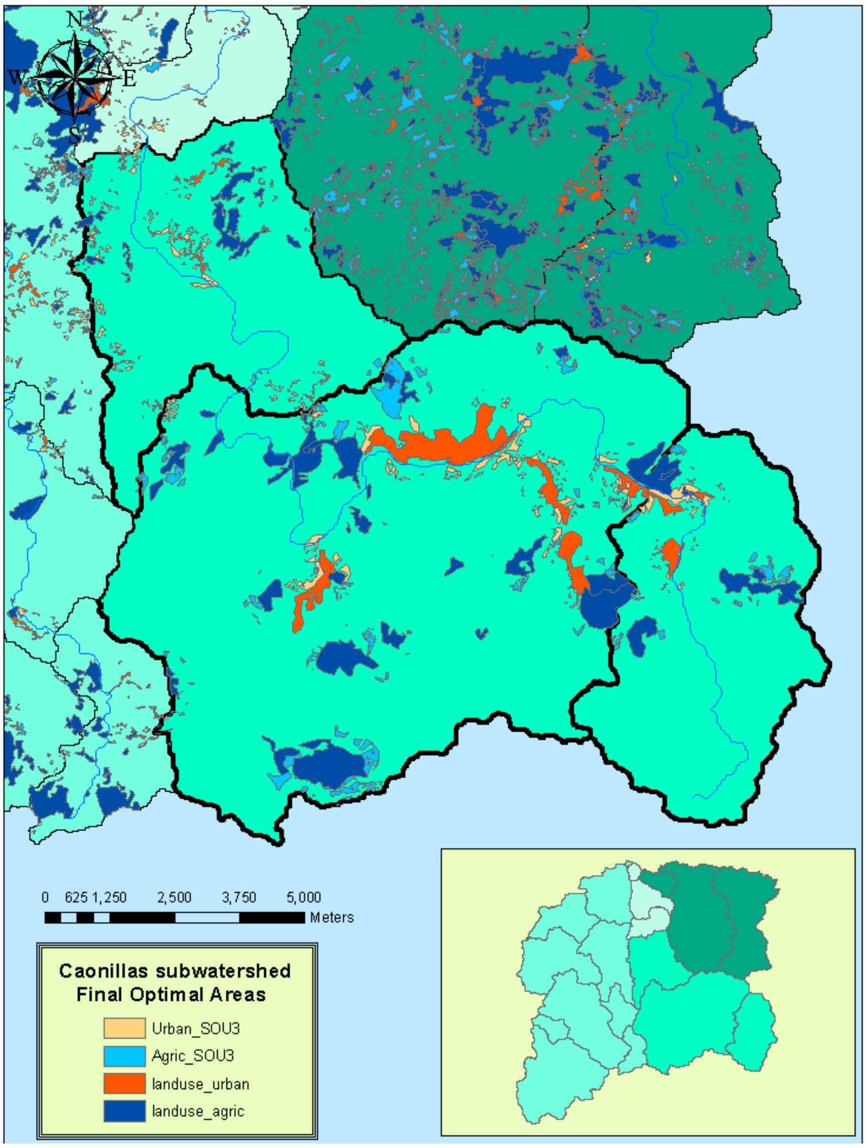


Figure 6.12. Land allocation stage 1 final optimal areas (Caonillas subwatershed)

Land allocation Stage 2 results

Intersected areas from preliminary stage are evaluated and analyzed in the land allocation stage 2 model. Those areas are used as complementary to those obtained from the land allocation stage 1 in case of insufficient areas to cover the multi-objective optimization requirements or used to complement possible additional areas for urban or built-up growth, giving additional options to the decision making process.

The basic idea in this stage is to evaluate those intersected areas giving priority to urban growth in the new model builder model. For this reason, a flexible buffer is introduced in the model near urban existing areas to get new possible areas around the existing land use. In case of need more agricultural areas than urban this buffer is set-up to zero and priority turn on around agricultural growth.

Because Scenarios 1 to 3 were satisfied with the optimal land use areas from land allocation stage 1 model, intersected areas were not evaluated.

6.4 SUMMARY AND CONCLUSIONS

The Geographical Information System (GIS) development for land use allocation is a complementary methodology based on a spatial analysis utilized together with the mathematical multi-objective optimization linear programming approach (MOLP) in order to establish the basis for an integrated land use planning system. Spatial considerations included in the GIS recommend specific land use locations based on several spatial constraints. The development of a GIS model provides a tool for decision makers in the land planning process.

Specific conclusions about the GIS methodology include:

The developed Geographical Information System (GIS) land use allocation models and their respective tools were used to localize specific area for a particular land use where growth may occur according to the physical conditions required. Also, the model takes into account the compatibility with actual land use promoting the growth of a specific land use near the actual same kind of land use.

The GIS offers flexible tools to decision makers that can be modified or adapted according to specific needs. Also, the incorporation of new routines could be included in order to complement the actual models.

The developed tool has the potential to be adapted to specific guidelines at the municipalities in the RGA watershed study area. This allows the users to consider the changing in the public policies at the local governments according to changes in their respective priorities.

The GIS also can consider the environmental and socio-economic changes at the study area, where initial consideration in the models are no more relevant. Consequently, the decision makers and land use planners can actualize the model by updating the information.

Tools were developed in ARC INFO 9.2 and the suite of ESRI products (ArcMap, ArcView) that can easily be transferred to local, state, and federal agencies for analysis in the environmental, social, and economic framework.

Additional constraints from those considered in the current GIS model were included in the MOLP methodology. It converts the entire research in an integrated methodology together with the water quality model.

CHAPTER VII

GOVERMENT ENVIROMENTAL MANAGEMENT EFFORTS

7.1 ABSTRACT

In 1987 the sustainable concept was defined by the World Commission on Environment and Development of the United Nations (UN) as: "*Meets the needs of the present generation without compromising the ability of future generations to meet their own needs*" (UN, 1987). Ever since this concept experiences an ongoing concern worldwide in response to a chaotic economic system growth with criteria like the maximum production, the consumption and unlimited resources exploitation as representative of good economic health. This movement concludes that a limited planet can not supply the resources indefinitely according to the exploitation practices.

Based on the sustainability concept, this chapter integrates and evaluates assertive indicators to define the environmental capability, one of the three pillars that conforms the sustainable development ambit. For this reason, in this chapter, the previous optimization model results are combined with results obtained from an evaluation of institutional, political, fiscal and environmental indicators for municipalities that integrate the RGA watershed. This component allows defining the environmental capability associated to each municipality to carry out the optimization results presented in this study.

Since the Municipal Reform and respective Law 81 (1991), known as the "*Ley de Municipios Autónomos de Puerto Rico*", the central government seeks to decentralize functions and powers transferring some control to local governments. This municipal autonomy status is a continuous process with several objectives and stages supervised by the PR Planning Board. Therefore, all the municipalities integrating the RGA watershed are analyzed as local governments with diverse resources and socio-economic characteristics.

Findings of this chapter include the characterization of municipalities using a list of indicators to determine the capability of each municipality to undertake measures toward protecting the environment and implement the recommendations of the optimization model. The final result of this chapter provides details of the best land use management of the RGA watershed that allows economic development, protect forest lands and expand agriculture.

This chapter represents an initial starting point for future works where the main objective is to provide tools to guide the decision making process taking into consideration the scientific knowledge, social, political and economic drivers for a watershed.

In this sense, quantifying and qualifying the environmental capabilities of each municipality within RGA watershed could be used as a predictor for the implementation of the methodology of optimal land use development at a watershed level.

7.2 INTRODUCTION

Most of the research on state and local government environmental efforts focuses on both qualitative and quantitative aspects of environmental policy (Bacot et al., 1997). The literature integrates many of the following concepts when analyzing environmental policy across governments:

a- Administrative: to categorize governments according to their ability to manage environmental programs.

b- Resource: to assess government financial capacity to carry out specific legislative requirements.

c- Political: to evaluate government political disposition toward environmental affairs.

d- Structural: to examine government ability to comply with federal regulations institutionally.

e- Organized Interests: to assess the ability of organized interests groups to influence the direction of policies.

f- Socio-economic: to explore the influences of demographic characteristics.

These factors, independently or combined in some fashion, form the nexus of elements found to enhance the understanding of states policy activities.

Conducting research to evaluate a state environmental capability or effort presents difficulties choosing an adequate framework to evaluate state policy issues. For the assessment of states efforts in environmental affairs, literature considers two main schools of thoughts. The first relies on policy development considering political and administrative factors (nonfiscal, ranking measure). The second approach relies on the state expenditures (fiscal, budgetary indicator).

In the expenditure approach, the environmental effort is defined as the total state expenditure dedicated to environmental programs (Brown and Garner, 1998). The ranking approach is defined as the legislation and programs implemented in a state (Ridley, 1987).

Often, each environmental effort indicator is criticized often. The expenditure indicator is said to be biased toward other state socioeconomic indicators and similarly, rankings is criticized as limited in function and as an artifact of state political ideological culture (Bacot et al., 1997).

Still with it weaknesses, both approaches are very useful as a comparative measure in terms of state and local government environmental efforts. State expenditures give an idea about the budget preferences of state legislators and state legislative appropriations represent the relative importance and the priorities of programmatic responsibilities in a state or local government to combat environmental degradation.

7.2.1 Environmental Effort Indicators

An indicator can be defined as a parameter or a value derived from parameters, which provides information about a phenomenon. They have a synthetic meaning and are developed for a specific purpose. This condition requires the definition of several criteria for the selection of indicators. Organization for Economic Cooperation and Development (OECD) has three basic criteria for this selection: policy relevance, analytical soundness and measurability (OECD, 1993).

There are several frameworks for the development and organization of environmental indicators. One of the most used frameworks is the Pressure-State-Response (PSR) based on a causality concept: human activities exert pressures on the environment and change its quality and the quantity of natural resources. Society responds to these changes trough environmental, general economic and sectorial policies. In a wider sense, these steps form part of an environmental policy cycle which includes problem perception, policy formulation, monitoring and policy evaluation (OECD, 1993).

Environmental indicators need to comply with some requisites to be an effective tool for the system evaluation. Among them, indicators should provide a representative picture of environmental conditions, pressures on the environment, or society response. Additionally, it needs to be simple, easy to interpret, and able to show trends over time.

For international comparisons, indicators need to be able to have a threshold or reference value against which to compare. In terms of it soundness, an indicator has to be theoretically well founded in technical and scientific terms.

Although indicators are one of the tools in the process of government environmental effort evaluations, they need to be supplemented by other qualitative and scientific information.

Environmental performance efforts are structured to further goals such as the reduction of the overall pollution burden and the manage of natural resources in a sustainable way, integrating environmental and economic or sectorial policies.

7.3 METHODOLOGY

This section details the methodology used for the evaluation of the environmental management efforts (environmental capability) in the municipalities conforming the RGA watershed.

The methodology is based on an extensive literature review about indicators and frameworks utilized to evaluate state and local government environmental efforts. Additionally, data compilation was complemented with interviews to municipal authorities, state and federal agencies as well as relevant environmental organizations for the respective data collection. Data generated by this methodology was used to conduct an evaluation of the municipal environmental capability as it regards to implement an optimization of landuse management plan.

Once the indicators are defined and used to evaluate the local government environmental efforts, the final step of this research component is the use of these findings to define the environmental capability of each municipality and combine it with the obtained results from the multi-objective optimization approach looking for the best land use management of the watershed.

This combination allows defining the environmental commitment of each municipality in order to forecast the level of success for the proposed land use management plan. Also, to integrate the complete analysis in an environmental, social, political and economic context due to the direct connection of those components in land use decision making analysis.

7.3.1 Environmental indicators set

Using the guidelines from literature as reference, Table 7.1 shows the environmental variables and respective indicators list defined as the most representative for municipal governments in order to evaluate their environmental efforts. Based on this list a detailed description of compiled data for the evaluation of indicators is presented in the next section.

Table 7.1 Environmental variables and indicators list (Utilized in this research for municipality evaluation)

VARIABLE TYPE	INDICATORS ASSESSMENT LIST
Institutional Capability	
	• Territorial Order Plan approved stage • Planning office existence • Autonomous municipality evidence
Political Capability	
	• Environmental community organization existence • Disposition towards environmental affairs • Citizen participation across organized groups.
Fiscal Capability	
	• Municipal budget analysis
Technical Capability	
	• Environmental technical affairs office existence • Environmental technical office objective
Pollution severity	
	• Water quality • National Pollutant Discharge Elimination System (NPDES) existence. • Air quality • Toxic release inventory (TRI) • Solid waste generation • Solid waste management

7.3.2 Data compilation

Using the list of variables and environmental indicators as guidance, data compilation was done by site visits and interviews to specific offices within each municipality. The municipal offices visited include finance, planning and environmental control offices. These visits included interviews with the persons in charge to request information, and to know about their position in environmental issues.

In addition to the municipal offices, interviews with federal agencies like the United States Environmental Protection Agency (USEPA) and with recognized community based organizations such as CASA PUEBLO in Adjuntas were done.

For municipal fiscal analysis, information between 2004 and 2008 was used as the basis for the analysis. The data acquisition include two sources of information one of them from the OCAM (Commissioner Municipality Affairs Office) and verified with a data base from the finance municipality offices.

Additional environmental indicators includes environmental information of Puerto Rico included in the document *"Atlas Ambiental de Puerto Rico"* from Tania del Mar López (López et al., 2006). Also, information about the municipal process in the island contained in the document *"Gobernabilidad y Municipalización en Puerto Rico"* was included and analyzed (López, 1998).

Complementing all the above data, different state laws and regulations were reviewed to provide the legal basis for the analysis. These laws include:

- Law 75, *Ley de planificación de Puerto Rico*
- Law 80, *Creación del CRIM.*
- Law 81, *Ley de municipios autónomos de Puerto Rico.*
- Law 82, *Ley de patentes municipales.*
- Law 83, *Ley de contribuciones municipales sobre la propiedad*.
- Law 550, *Ley de plan de usos de terreno, PUT.*

The first four laws define the basis for the Municipal Amendment in Puerto Rico.

7.3.3 Environmental capability indicators analysis

This section review one by one all the available data compiled and used to classify the municipalities according their environmental capability in order to evaluate the environmental efforts at each municipality conforming the RGA watershed.

Based on the five types of variables and respective indicators detailed in Table 7.1, a brief description is done to introduce the significant for each variable as well to evaluate the existence of evidence for each indicator. Results from this section will be used to weight the findings associated to the local governments and utilized as the starting point to define the capability associated to each local government.

The indicators chosen for the evaluation are classified as direct or indirect indicators according to the source of the data. Data from documents of federal agencies, municipalities and state government were classified as direct indicators. Data from interviews without official characteristics were classified as indirect indicators. In order to give veracity to the analysis almost all the indicators were classified as direct.

7.3.3.1 Institutional Capability

Institutional capability is defined as “the administrative and step capacity at the municipality or the capability to establish rules and that these be followed”. Using an environmental context, the institutional capability may be defined as the capacity to comply with existing federal or state regulations. The institutional capability variable is used for local or state government evaluation as endogenous and for this reason it evaluates the municipality performance internally.

Territorial Order Plans (Plan de Ordenamiento Territorial, POT):

The POT represents a derived product of the Municipal Amendment and the respective Law 81 "*Ley de Municipios Autónomos de Puerto Rico*".

The following list details the requested stages in order to comply with the POT requirements used to define the municipality as one autonomous:

1. Memorándum (STAGE II)
2. Plan Advance (STAGE III)
3. Final Plan (STAGE IV)
4. Approved Plan
5. Hierarchy I to V

In Puerto Rico, the municipalities of Carolina, Bayamón, Guaynabo, Caguas and Ponce are the only ones with the "Hierarchy V", the maximum category before the autonomous declaration. In Ponce, the integrated revision was done, meaning that it is the first autonomous municipality in Puerto Rico.

Above data reflects the general tendency of the island for the autonomous municipalities process starting in the earlies 90's with the Law 81 promulgation (Law 81, 1991). In 1998, the professor Héctor López Pumarejo in his book "*Gobernabilidad y Municipalización en Puerto Rico*" made comments about the slowness in this process and the difficulties due to amendments in the Law 81 limiting the municipalities capabilities in order to centralize again the power around the central government.

At this time, the status for the autonomous process in the three municipalities inside the RGA watershed with respect to the POT is as follows:

- Jayuya municipality: POT Approved
- Utuado municipality: PHASE III
- Adjuntas municipality: No POT submitted.

Using the above results is possible to get an early guess about the Institutional Capability indicators used in this study to evaluate this municipality variable. Jayuya responds to the municipality with the major compliance in this indicator giving a preliminary good Institutional Capability rating.

Planning Office

Actually, Jayuya is the only municipality with a Planning Office associated to the POT implementation. This office directs the main activities corresponding to solve the territorial order issues from a technical point of view.

Clearly, the existence of a Planning Office and especially the POT stage are sufficient evidence that Jayuya has a high Institutional Capability.

The POT may be defined as a strong indicator about the future tendency in the autonomy process and power of decentralization from the state government. This decentralization gives in some ways a powerful tool to take their own decisions in the municipality.

Comparing the compilation of evidence at these three local governments is possible to conclude that for this variable Jayuya has the advantage with respect to Utuado and over Adjuntas in terms of Institutional Capability.

7.3.3.2 Fiscal Capability

Another conventional variable for discerning local or state government environmental effort is fiscal health. Berry and Berry (1990) have shown that the relative strength of government treasuries interacts with measures of the political environment. A state current fiscal health displays its ability to fund certain programs beyond traditional budgetary items.

For the purpose of this research, a detailed evaluation of the municipal annual budgets of the last four fiscal years (2004-2008) was conducted. This analysis allows defining the fiscal health and the fiscal capability in terms of environmental management efforts. For this reason these municipal budgets were used to evaluate the percent of the total budget allocated to environmental programs in each municipality. The proportion of funds in the budget dedicated to environmental efforts defines in this research the fiscal capability for each municipality.

Table 7.2 summarizes the general budgets data compilation for the years 2004 to 2008. This table shows a similar tendency in the annual increment except for Adjuntas in the 2004-2005 and 2005-2006 periods where the budget was almost the same.

Appendix G details the complete budget for all municipalities showing the data proportionate by the Municipal Affairs Commissioner Office, OCAM. The Appendix includes the annual incomes and expenditures. Also, the data from the OCAM was verified with the data provided by the Financial Offices at the municipalities.

Table 7.2 Municipal Annual Budget (Fiscal years from 2004-2008)

Municipality	Fiscal Year			
	2004-2005	2005-2006	2006-2007	2007-2008
	Budget ($)			
Adjuntas	6,711,472	6,690,648	7,101,650	7,640,814
Jayuya	6,938,756	7,507,541	7,178,875	7,938,278
Utuado	10,192,804	11,052,194	10,764,444	11,260,926

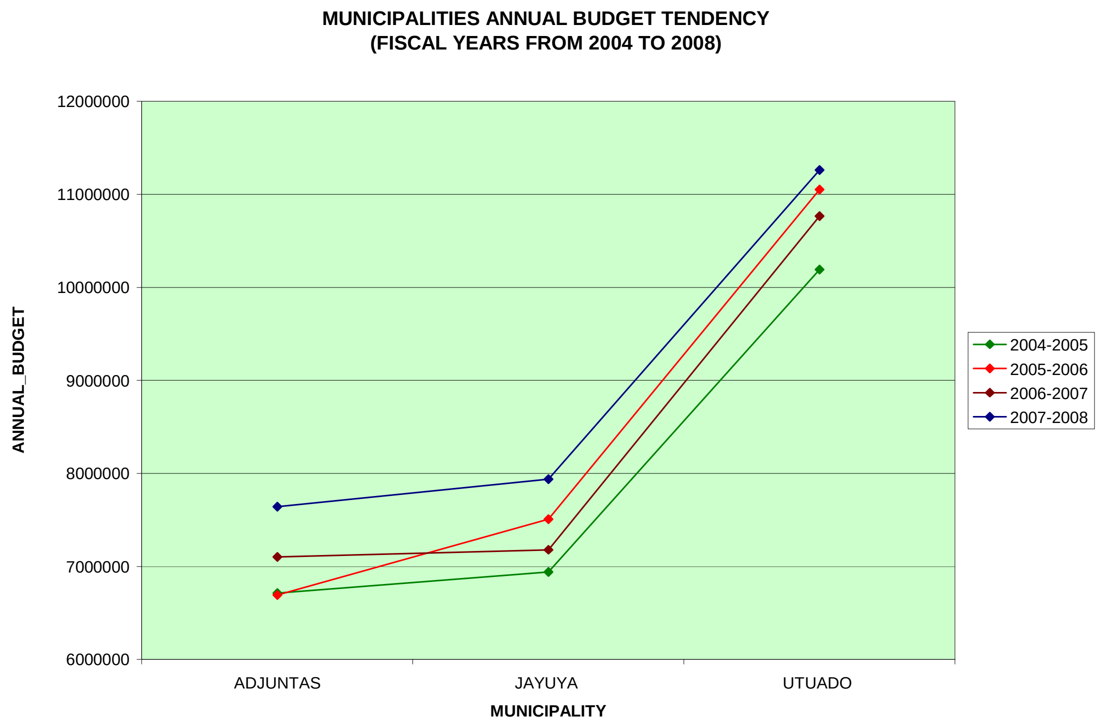


Figure 7.1 Municipal Budget Tendencies (Fiscal Years 2004 to 2008)

Budgetary data from previous table was normalized by municipal population in order to generate a comparable indicator between local analyzed governments. Table 7.3 shows the results of the normalization where the 2005 census data was used to normalize the annual budgets.

Table 7.3 Annual budget normalization

Municipality / (Population)	Fiscal Year			
	2004-2005	2005-2006	2006-2007	2007-2008
	Annual budget normalized by population ($/habitant)			
Adjuntas (19,030)	353	352	373	402
Jayuya (18,003)	385	417	399	441
Utuado (35,748)	285	309	301	315

An additional indicator of municipal fiscal capability is the normalized budget (Table 7.3). Utuado has the greatest annual budget comparing with the remaining municipalities; nevertheless, Jayuya shows the greatest budget normalized by population. Jayuya has greater fiscal capability than Adjuntas and Utuado, respectively.

Fiscal egress for environmental management

Another indicator to evaluate fiscal health corresponds to the specific budget assigned to each municipality for environmental management affairs. For Jayuya and Utuado the specific budget is assigned to the Environmental Control Office. For Adjuntas there is no evidence of such office or program.

The existence of this indicator reflects in some way the awareness at the municipalities in terms of environmental readiness and allows comparing and complementing the information about the fiscal capability between municipalities. Table 7.4 summarizes the available data to quantify this indicator.

Table 7.4 Fiscal egress for environmental management

Municipality	Annual average budget ($/year)	Annual Budget average assigned to environmental affairs ($/year)*	Environmental Percent Investment (%)
Adjuntas	7,036,146	NE	NE
Jayuya*	7,390,863	768,595	10.4
Utuado	10,817,592	647,600	6.0

*Based on the available years of data.

Results show that Jayuya with a 10% is the municipality with the greatest investment in environmental management efforts through a Environmental Control Office. This result can be translated into a major commitment in Jayuya in terms of environmental readiness with respect to Utuado and Adjuntas.

Summarizing, some indicators were used to define the fiscal capability of the three municipalities. Jayuya come out at the top of the list among the three municipalities that share the RGA watershed in terms of environmental capability.

7.3.3.3 Political Capability

Political capability is defined in this research as the existence of communication channels that promotes and encourages citizen’s participation. This participation can be through organizations with active roles in the decision making process within their respective municipalities. The political capability is an exogenous variable, which means is a variable that measures the government performance internally.

Some times the political capability is associated with the government ideology in office, either if it is liberal or conservative. Liberal governments are more proactive than conservatives and consequently they are more open in presence of communitarian groups or organizations. Consequently the government ideology could be utilized as indicator of the political opening of the municipalities.

As enacted in the Chapter XVI "*Participación Ciudadana*" of Law 81, municipalities have to promote citizen's participation (Law 81, 1991). For this research purpose, Chapter XVI stipulates that community associations can contribute to mitigate and control the environmental damage associated to the works in the municipality.

At the Central Region of Puerto Rico, many environmental groups reflect the citizen's participation and then the local governments openness. Before the 1970's, the municipal decisions were done without the public's opinion and were based on scientific and expert criteria. The environmental group participation has changed the decision making process in the governments of the area and reflects the actual political capability that participating groups have in the region. Another organization existence like the contained in the "Special communities program" complements this political capability.

Environmental Groups in the region

CASA PUEBLO in Adjuntas is one of the pillars of the region in terms of communal organizations. Casa Pueblo is defined as a communal autogestion organization that promotes volunteer participation through individual and collective initiatives. Also, promotes and develops alternatives to protect the environmental and to affirm the cultural and human values.

Actually Casa Pueblo headed by Mr. Alexis Massol, constitutes the main environmental group in the central region of Puerto Rico. In the last years organizations like “Amigos y Amigas del Ambiente de la Tierra Alta” in Jayuya directed by Mr. Jaime Rosario and “Fundación Pro-Ambiente Inc” at Utuado directed by Mr. Luis Rodríguez follow the work of Casa Pueblo.

According to the movement in the region and mainly at the municipalities that conforms the RGA watershed, it is possible to conclude that all of them have communal organizations presence in defense of the environmental and used as an indicator of the political capability and openness of the local governments to civil organizations. According to Dr. Carmen Concepción, historically the organization movement is based on local issues in Puerto Rico meaning that actual environmental organizations responds to the actual situation in the region and could be different in the past in accordance with the situation in that moment.

7.3.3.4 Pollution and environmental quality

Pollution severity is another variable to understand the variation in environmental efforts across local or state governments. Commonly, governments focus their efforts in environmental programs as a function of the pollution severity. Authors like Bacot (1997), in the analysis of two models directed to measure the environmental effort concludes that pollution severity is inversely proportional to the environmental efforts and is directly proportional to an expenditure model approach.

Three sources were considered in this study to evaluate the pollution severity. The first source is the point sources according to the National Pollutant Discharge Elimination System (NPDES) from the USEPA. The second is the toxic releases given by the Toxic Release Inventory Program (TRI), also from USEPA. Finally, the third component of the evaluation was based on the management and disposal of solid waste at the respective municipalities. Although the non point sources were not included, these can be reviewed in the Chapter IV of this research.

Point sources pollution estimation

The USEPA is the regulatory federal agency according to their water quality criteria for point sources in the waters of the nation through the NPDES program. Table 7.5 summarizes the actual discharge permits at the municipalities of Jayuya, Utuado and Adjuntas that conform the RGA watershed. From this table and for the nitrogen regulated species (total ammonia and total nitrates), Utuado has the greatest nitrogen load by point sources with 15,698 Kg/year, followed by Adjuntas with 13,898 Kg/year and Jayuya with 10,333 Kg/year.

Is important to note that Jayuya has two pharmaceutical plants operating (BAXTER and ABBOTT) representing another point source of pollution not contained in the NPDES program. In fact, the TRI shows a violation in one of their parameters for BAXTER detailed in the next section.

Table 7.5 Point sources from NPDES program in RGA municipalities.

NPDES ID	Municipality Name	Facility Name	Average Annual Loads Total Nitrates (Kg/year)	Total Ammonia (Kg/year)	Total Phosphorus (Kg/year)
PR0026531	JAYUYA	PRASA - JAYUYA WWTP (NEW)	7,322	732	732
PR0024121		PRASA JAYUYA URBANO	1,934	193	193
PR0025224		PRASA MAMEYES ARRIBA FILTER PL	---	---	---
PR0023132		SECOND UNIT MAMEYES SCHOOL	138	13.8	13.8
		TOTAL	**9,394**	**939**	**939**
PR0020214	ADJUNTAS	PRASA ADJUNTAS STP	5,429	8,144	1,628
PR0025739		PRASA - ADJUNTAS NUEVA WTP	---	35	---
PR0022691		PRASA WTP ADJUNTAS	290	---	41
		TOTAL	**5,719**	**8,179**	**1,669**
PR0026271	UTUADO	PRASA - RONCADOR WTP	663	66.3	66.3
PR0020915		PRASA - UTUADO WWTP	4,456	8,911	446
PR0026255		PRASA - SABANA GRANDE WARD WTP	---	6.3	6.3
PR0025208		PRASA MAMEYES ABAJO WTP	---	---	---
PR0024155		PRASA WTP UTUADO	1,450	145	145
		TOTAL	**6,569**	**9,128.6**	**664**

Toxic releases

Based on the three evaluated municipalities at the RGA watershed exists evidence of toxic releases for Jayuya, specifically at the BAXTER pharmaceutical reported in the TRI inventory. This violation was done in the period between 2006 and 2008 (last reported) for the chemical known as DI (2-ETHYLHEXYL) PHTHALATE (DEHP) founded in many plastics. Table 7.6 summarizes the report about this toxic compound where is possible to observe two ways of contamination, the first as an air emission with 2.3 Kg/year (5lbs/year) and the second as an off site solid waste with 780 Kg/year (1720 lbs/year) (www.epa.gov/triexplorer). Additionally, the Utuado Paper Plant (*Papelera Puertorriqueña, Inc*) was recently included by the USEPA in the Superfund site list (EPA–HQ–SFUND–2009–0064). Main contaminants in this plant include ethyl acetate, polyethylene, Isopropanol, Tri-chloroethylene and Tetra-chloroethylene.

Solid waste management

According to the Puerto Rico Solid Waste Management Authority (ADS, for its initials in spanish), only one municipal landfill is operating at the RGA watershed study area. This landfill is located in Jayuya and collects solid waste from Jayuya, Utuado and Adjuntas.

In 2006, the Major of Jayuya signed the “Operación Cumplimiento” program and received $250,000 of funding to create a sustainable structure in order to comply with the “Fulfillment Plan”. This program was established by the PREQB and the Puerto Rico

Solid Waste Management Authority (PRSWA) to maximize the environmental fulfillment in the solid waste landfills system.

Four activities in the “Jayuya Fullfillment Plan” are prioritized and described as:

1. Well monitoring installation.
2. Run-off system design.
3. Lixiviates collection development.
4. Gas monitoring system.

Since 2006 where the “*Operación Cumplimiento*” was signed, the municipality has some additional incentives like the immunity to environmental penalties until the program is done.

According to the PRSWA (2009), no evidence of compliance from Jayuya municipality in the four main activities is available for December 2008 according to the fulfillment radicated plan. Nevertheless, using as reference the regulation 6025 “*Reglamento para la reducción, reutilización y el reciclaje de los desperdicios sólidos en Puerto Rico*” records of environmental violation does not exist according with Chapter 10 (vegetatives materials disposition).

Table 7.6 Toxic releases inventory at Jayuya municipality facilities.

Facility and chemical	On site disposal to Class I*			Other On-site Disposal or Other Releases**									Total On Site Disposal	Total On and Off Site Disposal
	IA	IB	IC	1	2	3	4	5	6	7	8	9		
BAXTER HEALTHCARE CORPOF PR, 250 STATE RD 144 KM 20.6, JAYUYA	0	0	0	5	0	0	0	0	0	0	0	5	5	1725
DI(2-ETHYLHEXYL) PHTHALATE	0	0	0	5	0	0	0	0	0	0	0	5	5	1725

* IA = Underground injection Class I wells,
IB = RCRA subtitle C Landfills,
IC = Other on site landfills;
**1= Fugitive air emissions; 2= Point source air emissions; 3= Surface water discharges; 4= Underground injection class II-V wells; 5= Land treatment; 6= RCRA subtitle C surface impoundments; 7= Other surface impoundments; 8= Other land disposal;
9= Subtotal

Solid Waste Estimation

Data from the ADS allows estimating the average daily and annual solid waste loadings by municipality. The document "Dynamic Itinerary for Infrastructure Projects" reports a value of 5.56 lbs/hab*day as the percapita solid waste generation. Table 7.7 summarizes the average annual loads according with the ADS approach for each municipality inside the watershed.

Table 7.7 Average annual solid waste production at RGA municipalities

Municipality	Population*	Average daily production rate (Kg/person*day)	Average annual production rate (Tons)
Adjuntas	19,143	2.52	17,608
Jayuya	17,318	2.52	15,929
Utuado	35,336	2.52	32,502
TOTAL			**66,039**

*According to last poblational and housing census in 2000 (www.census.gov/census2000/states/pr.html).

Table 7.9 summarizes the data compilation and respective findings that define the environmental effort at each municipality.

7.4 RESULTS

Based on the environmental effort indicators listed on Table 7.1, this section quantifies the status for the three municipalities within the upper RGA watershed in order to determine the possible level of success in the eventual implementation of the integrated land use planning methodology proposed in this research.

Two types of variables were evaluated to determine the environmental capability based on the commitment and resources in each municipality. Variables such as institutional, political and technical capability fall in the qualitative variables groups. In the same manner, the fiscal capability and the pollution level falls in the quantitative variables group.

Associated to each variable, the respective indicators were used as a guide to ponder the environmental efforts. The findings obtained from an extensive recopilation of data at the municipalities are reflected in the analysis.

Table 7.8 summarizes the qualitative variables. Qualitative variables are defined as those with no natural sense of ordering, where they are measured on a nominal scale. Additionally, Table 7.9 summarizes the results for the fiscal capability and pollution severity corresponding to qualitative variables.

Table 7.8 Results for qualitative variables associated to municipalities environmental capability.

Variablesand Indicators	**Municipality**		
	Jayuya	***Utuado***	***Adjuntas***
INSTITUTIONAL CAPABILITY			
Territorial Order Plan existence	Yes	Yes	No
Planning Office existence	Yes		No
Autonomous municipality Nule= N, No radicated plan; Low= L, associated to Phase II and III; Moderate= M; associated to Phase IV and approved Complete= Hierarchy I to V	M	L	N
POLITICAL CAPABILITY			
Environmental organizations existence	Yes	Yes	Yes
Environmental affairs disposition	Yes	Yes	Yes
Citizen participation across organized groups	Yes	Yes	No
TECHNICAL CAPABILITY			
Environmental affairs technical office evidence	Yes (Environmental Control Office)	Yes (Environmental Control Office)	No
Environmental technical office objective P = Preservationist; C=Conservationist; A = Ambientalist	A	A	A

Table 7.9 Results for qualitative variables associated to municipalities environmental capability.

Variable and indicators	Municipality		
	Jayuya	***Utuado***	***Adjuntas***
FISCAL CAPABILITY			
% Municipal budget towards environmental affairs.	10.4 %	6 %	ND
POLLUTION SEVERITY			
1. Water quality (point sources)			
National Pollutant Discharge Elimination System (NPDES) existence.	9,394 Kg/yr TNitrates 939 Kg/yr TAM 939 Kg/yr TP	6,569 Kg/yr TNitrates 9,129 Kg/yr TAM 664 Kg/yr TP	5,719 Kg/yr TNitrates 8,179 Kg/yr TAM 1,669 Kg/yr TP
2. Air quality (Bad, Regular, Good) According Atlas Ambiental de Puerto Rico.	R	G	G
3.Toxic release inventory (TRI)	5 lbs (2006) 2-Ethylexyl Phatalate	ethyl acetate, polyethylene, Isopropanol, Tri and tetra-chloroethylene	No toxic release determined
4. Solid waste			
Solid waste landfill existence	Yes	No	No
Solid waste generation	15,929 Tons/yr (1,379 Kg/ha*yr)	32,502 Tons/yr (1,106 Kg/ha*yr)	17,608 Tons/yr (1,019 Kg/ha*yr)

7.4.1 Qualitative variables weighted classification

The data from Table 7.8 was weighted to be normalized and comparable among municipalities. Although the qualitative variables are commonly measured in nominal scales, it can be coded to appear numeric but their numbers are meaningless. For analysis purpose the qualitative indicators associated to each variable receive a value of 1 if existence of evidence about this indicator is available at the municipalities and 0 if not. Final weight was done adding the points and dividing them by the maximum total of possible points. Table 7.10 summarizes the results.

7.4.2 Quantitative variables weighted classification

For the quantitative variables and their respective indicators a different analysis was conducted in order to normalize the results and classify the municipalities in terms of pollution severity as well as fiscal capability. For the pollution severity the respective available loadings were normalized by area. This normalization allows obtaining an export coefficient by year and area easily comparable among municipalities. Table 7.11 summarizes the results for the indicators associated to pollution severity.

To normalize the pollution severity and taking into account the natural differences among the evaluated contaminants and the impossibility to be added, a ranking classification was used to evaluate their relative contamination level.

Table 7.10 Results for qualitative variables associated to municipalities environmental capability.

Variablesand Indicators	Municipality		
	Jayuya	*Utuado*	*Adjuntas*
INSTITUTIONAL CAPABILITY (5)			
Territorial Order Plan existence **(1)**	1/5	1/5	0/5
Planning Office existence **(1)**	1/5	1/5	0/5
Autonomous municipality **(3)** Nule = 0; Low = 1; Moderate = 2; Complete = 3	2/5	1/5	0/5
SUB-TOTAL	**4/5**	**3/5**	**0/5**
POLITICAL CAPABILITY (3)			
Environmental organizations existence **(1)**	1/3	1/3	1/3
Environmental affairs disposition **(1)**	1/3	1/3	1/3
Citizen participation across organized groups **(1)**	1/3	1/3	0/3
SUB-TOTAL	**3/3**	**3/3**	**2/3**
TECHNICAL CAPABILITY (3)			
Environmental affairs technical office evidence **(1)**	1/3	1/3	0/3
Environmental technical office objective **(2)** P = Presevationism = 1; C=Conservationism = 2	1/3	1/3	1/3
• ***SUB-TOTAL***	**2/3**	**2/3**	**2/3**
•			
• ***TOTAL***	**9/11**	**8/11**	**4/11**

Table 7.11. Pollution severity (PS) indicators analysis

	Jayuya	***Utuado***	***Adjuntas***
1.Water regulated discharges (WRD)			
$\sum TNspecies\left(\frac{Kg}{Ha*yr}\right)$	0.89	0.53	0.80
$\sum TPspecies\left(\frac{Kg}{Ha*yr}\right)$	0.08	0.02	0.10
2.Toxic Waste Generation (TWG)			
$\sum solid\ toxic\ releases\left(\frac{Kg}{Ha*yr}\right)$	0.07; for 2-Ethylexyl Phatalate	NA	0
3.Air emissions (AE)			
$\sum Air\ emissions\left(\frac{Kg}{Ha*yr}\right)$	0.0002; for 2-Ethylexyl Phatalate	NA	0
4. Solid Waste Generation (SWG)			
$\sum SWG\left(\frac{Kg}{Ha*yr}\right)$	1.38	1.11	1.02

NA= not available at **EPA–HQ–SFUND–2009–0064;** (http://www.epa.gov/superfund/sites/npl/p090409.htm)

7.4.3 Ranking Weighing for pollution severity

The pollution severity was evaluated relatively among municipalities due to the lack of information about the considered normal or extreme levels for the evaluated contaminants. For this reason each contaminant was compared according to a specific ranking with high, moderate, low and null relative levels. For each level a value ranging from 0 to -3 was assigned with the worst value assigned to -3. Table 7.12 summarizes the results. .

Table 7.12. Pollution severity (PS) indicators analysis

	Jayuya	***Utuado***	***Adjuntas***
1.Water regulated discharges (WRD) (-6)			
$\sum TNspecies\left(\frac{Kg}{Ha*yr}\right)$	(H) (-3/3)	(M) (-2/3)	(H) (-3/3)
$\sum TPspecies\left(\frac{Kg}{Ha*yr}\right)$	(H) (-3/3)	(L) (-1/3)	(H) (-3/3)
2.Toxic Waste Generation (TWG) (-3)			
$\sum solid\ toxic\ releases\left(\frac{Kg}{Ha*yr}\right)$	L (-1/3)	N (0/3)	N (0/3)
3.Air emissions (AE) (-3)			
$\sum Air\ emissions\left(\frac{Kg}{Ha*yr}\right)$	L (-1/3)	H (-3/3)	N (0/3)
4. Solid Waste Generation (SWG) (-3)			
$\sum SWG\left(\frac{Kg}{Ha*yr}\right)$	(H) (-3/3)	(M) (-2/3)	(M) (-2/3)
TOTAL	**-11/15**	**-8/15**	**-8/15**

The results from table 7.12 allow concluding that the municipality of Jayuya has the higher contamination in terms of the evaluated species. Total annual nitrogen and phosphorus loads normalized by area in Jayuya were comparable with those from Adjuntas. For the toxic waste generation, the municipality of Utuado has the higher relative contamination associated to the Puerto Rico Paper Plant. Contaminants like ethyl acetate, polyethylene, isopropanol, tri and tetra-chloroethylene included in 2009 by the USEPA Superfund list gives to this municipality the worst case compared with the records from the USEPA Toxic Releases Inventory (TRI) for Jayuya. Adjuntas do not have evidence of toxic generation in their territories.

Finally, the annual solid waste generation normalized by area is similar at the municipalities of Utuado and Adjuntas classified relatively as moderate contamination. Jayuya reports a slightly higher level than previous mention municipalities. For this reason Jayuya was classified as the higher solid waste location joined this to a past waste processing coming from Utuado and Adjuntas.

The fiscal capability was ranked as high for Jayuya with a 10.4% of the respective annual municipal budget directed to attend environmental efforts. Utuado has a moderate fiscal capability with a 6% and Adjuntas according with the data compilation does not have evidence of fiscal capability in their respective annual budget breakdown. Table 7.13 summarizes the results for fiscal capability, where the ranking values are 0 for null fiscal capability, 1, 2 and 3 for low, moderate and high fiscal capability, respectively.

Table 7.13. Fiscal capability at municipalities

	Jayuya	*Utuado*	*Adjuntas*
Fiscal capability (3)			
	H (3/3)	M (2/3)	N (0/3)
SUB TOTAL	**3/3**	**2/3**	**0/3**

7.4.4 Final Weighing variables for pollution severity

The final weighting of the five included variables and consequently the final classification of environmental capability at the municipalities used for each variable an equal weight of 20%. That means institutional, political, technical and fiscal as well as pollution severity influences the environmental efforts at the local governments in a same way. The final weighing to define the environmental capacity **(*EC*)** was calculated as follows:

Table 7.14 Final weighting of environmental variables

Variablesand Indicators	Municipality		
	Jayuya	***Utuado***	***Adjuntas***
INSTITUTIONAL CAPABILITY (20%)	16%	12%	0%
POLITICAL CAPABILITY (20%)	20%	20%	13.3%
TECHNICAL CAPABILITY (20%)	13.3%	13.3%	13.3%
FISCAL CAPABILITY (20%)	20%	13.3%	0%
TOTAL	**69.3%**	**58.6%**	**26.6%**
POLLUTION SEVERITY (-20%)	-14.7%	-10.7%	-10.7%
TOTAL	**-14.7%**	**-10.7%**	**-10.7%**

$$EC_{JAYUYA} = 69.3\% * \left(\frac{80}{100}\right) - 14.7\%. * \left(\frac{20}{100}\right) = 87\% \, commitment + resources \quad against \;\; 74\% \quad pollution severity$$

$$EC_{UTUADO} = 58.6\% * \left(\frac{80}{100}\right) - 10.7\%. * \left(\frac{20}{100}\right) = 73\% \, commitment + resources \quad against \;\; 54\% \quad pollution severity$$

$$EC_{ADJUNTAS} = 26.6\% * \left(\frac{80}{100}\right) - 10.7\%. * \left(\frac{20}{100}\right) = 33\% \, commitment + resources \quad against \;\; 54\% \quad pollution severity$$

Results from Table 7.14 are interpreted as follow:

- The environmental capacity for Jayuya, Utuado and Adjuntas is defined as 86%, 74% and 33% in terms of institutional, political, technical and fiscal capability against a 74%, 54% and 54% respectively of pollution at these municipalities.

Based on Ortiz (1999), the environmental indicators weighted results allows to classify the municipalities as progressives, fighters, delayers and regressives using as criteria their available commitment and resources. Figure 7.2 shows the four quadrants used to classify the environmental capability and consequently level of successful in the land use planning integrated methodology.

For this research Jayuya is classified according to the Ortiz's method as a progressive municipality due to high commitment reflected in their institutional, political and technical variables and high resources according to their fiscal capability. The resources at this municipality allow concluding about a good management in their pollution severity.

Utuado is classified as a fighter municipality with high commitment reflected in their institutional, political and technical variables and low resources compared with Jayuya. The pollution severity is according to their fiscal capability allowing to conclude about their management capacities.

Finally, the Adjuntas municipality has the lower commitment reflected in their institutional, political and technical low percentages. In addition, the lack of evidence in the fiscal capability variable at this municipality, classified this local government as regressive.

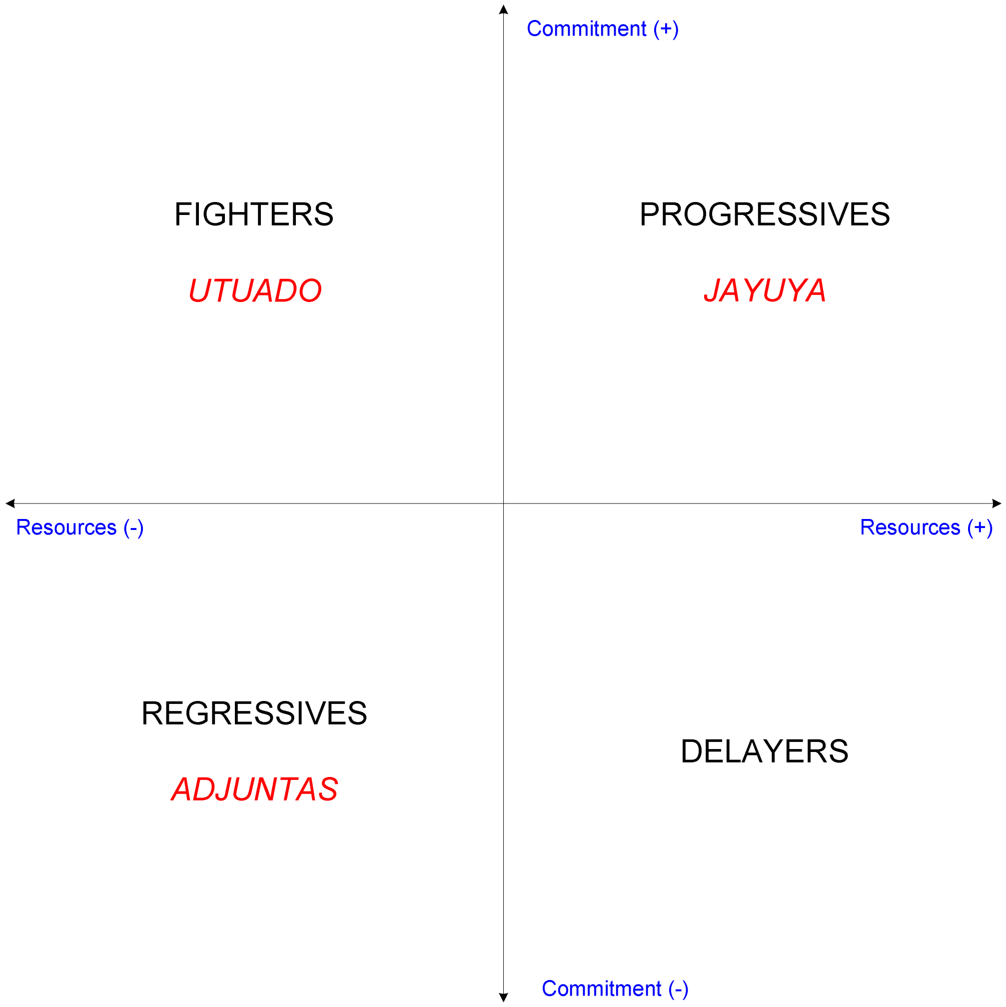


Figure 7.2 Municipality chart classification (Ortiz, 1999)

7.5 CONCLUSIONS

The analysis to determine the environmental capability is the first attempt to include the social, political, and economic component inherently associated to a land use planning approach.

The future works would be able to focus in the development of a translation from the findings of this component into a numerical coefficient that can be incorporated in the MOLP methodology.

Results obtained are relative between the included municipalities, meaning that evaluation methodology needs to be adapted for future works including other local governments.

The environmental capability associated to each municipality is a direct indicator about the level of success in the land use planning methodology implementing. Municipalities like Jayuya classified as *Progressive* reflects the commitment and resources to implement in a good manner a land use planning for the future.

For the Utuado municipality classified as *Fighter*, the available resources are not completely enough to attempt a land use planning program but their commitment compensates the lack of a robust fiscal capacity.

Instead, municipalities like Adjuntas do not have actually evidence of commitment or available resources to conduct successfully a land use planning implementing. This local government needs to reinforce their deficiencies in order to take into account an organized growth in the future with environmental target as a priority.

CHAPTER VIII

FINAL SUMMARY, CONCLUSIONS AND RECOMENDATIONS

This chapter summarizes the main findings and conclusions obtained in this research related to a land use allocation methodology based on water quality criteria in the RGA watershed. Additionally, recommendations for future works in this topic area are identified in order to maximize the resources and efforts for future studies. Land use planning represents the future of many countries around the world. Integrating this methodology with environmental goals and sectors contained in the physical area, such as social, political and economical sectors is the main challenge for decision makers in the land use implementing plans.

This research was developed on a robust scientific frame, integrated for a water quality continuous simulation model, a MOLP approach to optimize the search and implementation in a GIS platform for spatial allocation. Also, the methodology is integrated taking into account the inherent socio-economic and political conditions of the study area and can support local government authorities, to develop and implement municipal territorial order plans, and future land use growth pattern.

The complete methodology provides the base work to find possible solutions to difficult issues related to land use planning for preservation, forestry, agriculture and, urban development while maintaining the viability of environmental issues.

8.1 SUMMARY AND CONCLUSIONS

The main general conclusions associated to each component of this study are summarized as follows:

- The water quality simulation model and respective land use export coefficients intervals computed by specie gives to the integrated methodology the scientific basis to incorporate into the MOLP the uncertainty associated to temporal and spatial conditions in the study area across the coefficients of decision variables of mathematical models. These intervals were obtained from a ten years water quality simulation for TN, TP and TSS in the RGA watershed.
- Land use export coefficients intervals reflect particular conditions for RGA watershed. Nevertheless, literature reports those coefficients for other latitudes around the world including the USA and Puerto Rico for their specific conditions derived from a variety of different methodologies compared with the developed in this study. In this sense, the water quality simulation approach utilized in this research to generate the coefficients constitutes a new contribution in Puerto Rico and tropical regions around the world.
- Results from calibration and validation periods were good according with the literature suggested guidelines and statistical parameters. Hydrologic and sediment calibration results allow a solid base for nutrients simulation. Water quality model performance evaluation was in agreement with available data and

general criteria for this kind of constituents. Sometimes, scarcity of water quality data for model calibration tends to limit the results and model evaluation.

- The MOLP approach was incorporated in the integrated methodology as a mathematical tool in order to evaluate the hypothetical scenarios searching for the optimal land use growth in 2025. The developed optimization approach incorporates the inherent uncertainty associated to the watershed spatial and temporal conditions. In this sense, these conditions reflect the impossibility to know exactly the coefficients of the decision variables in the MOLP models. Instead, the land use export coefficient intervals reflect this uncertainty associated to this type of problem.
- The 1,000 random runs using as input the land use interval coefficients by specie give the fortress to the MOLP model, producing more realistic results compared with a deterministic formulation where a unique solution is available instead of multiple optimal possible combinations.
- One of the advantages of the MOLP approach is the low computational requirements given by the robust of the developed interface between the software and respective solution algorithm and the initial database input for scenarios. Additionally, the simplicity of the mathematical models subserve the computational time. This advantage allows to DM the evaluation of multiple runs by scenarios and several possible combinations in the trade-off process and environmental goals.
- GIS methodology represents a complement for the land use allocation methodology and allows to translate the numerical results and ranges given by the

MOLP approach to a spatial frame when the visualization of results is required. Also, the GIS model incorporates a series of tools associated with spatial constraints of the system for land use future development.

- The tools developed in the GIS methodology are easily modified according the land use planners needs and easily transferred and adjustable to different spatial conditions.
- The integrated methodology has the advantage of be easily modified according to changes in variables like environmental goals, socio-economic conditions in the future and government policies and priorities for land use development. This advantage gives the required flexibility for DM in a system characterized for be dynamic in time.
- Even when the integrated methodology was applied to RGA watershed and their local conditions, one of the main contributions of the research turns around the applicability of the methodology to other areas in Puerto Rico and the world for land use planning process.
- The environmental capacity evaluated in the final stage of this research allows forecasting the successful level of implementation according to political, fiscal, technical, and institutional conditions for each municipality inside the watershed.
- The social, economical, political and pollution indicators measure the actual conditions for each local government, their weakness and fortress and allows to classify them based on the commitment and resources.

- The socio-economic component represents an initial starting point for future works in order to integrate the science knowledge with the local conditions of a region giving a real context in the land use planning approach.

8.2 RECOMMENDATIONS

- In addition to the utilized PQUAL and IQUAL for water quality simulation, the Agricultural-Chemical module (AGCHEM) could be incorporated to the model in the future for a more detailed agricultural land use simulation. The incorporation will depend on the modeling purpose and the availability of extensive data required for this module.
- The scarcity of water quality data could be filled by a continuous and periodic water quality monitoring and sampling program in order to help the calibration of this HSPF component and respective simulation performance.
- The analysis to determine the environmental capability represents a first attempt to incorporate the socio-economic and political context. Future works would be able to focus in the development of a numerical coefficient that can be incorporated into the MOLP approach across a new objective function.
- The optimal land use export coefficients intervals (Appendix D), could be used in future works to assign numerically maximum allowable exportation from stakeholders in the watershed for analyzed species and respective land use.

- The environmental capability analysis could be extended to others municipalities in Puerto Rico in order to define in a global framework the relative commitment and resources associated to each of them, based on the different variables and indicators utilized to evaluate this capability.
- Incorporation of municipal territorial order plans together with the developed GIS tools for land use allocation will complement the actual results. This integration would strengthen with the addition of new tools or modifying the here proposed.

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APPENDICES

APPENDIX A
HSPF UCI File

APPENDIX A. HSPF UCI FILE

```
RUN

GLOBAL
  UCI Created by WinHSPF for dbrga
  START       1995/02/09 00:00  END    2005/12/31 00:00
  RUN INTERP OUTPT LEVELS    1    0
  RESUME     0 RUN     1                         UNITS    1
END GLOBAL

FILES
<FILE>  <UN#>***<----FILE NAME------------------------------------------
------->
MESSU      24   dbrga.ech
           91   dbrga.out
WDM1       25   RGA_OUT.wdm
WDM2       26   RGA_IN.wdm
BINO       92   dbrga.hbn
END FILES

OPN SEQUENCE
    INGRP              INDELT 01:00
      PERLND      11
      PERLND      17
      PERLND      12
      PERLND      13
      PERLND      14
      PERLND      15
      PERLND      16
      IMPLND      11
      PERLND      41
      PERLND      47
      PERLND      42
      PERLND      43
      PERLND      44
      PERLND      45
      IMPLND      41
      PERLND      51
      PERLND      52
      PERLND      53
      PERLND      54
      PERLND      55
      PERLND      56
      IMPLND      51
      PERLND      21
      PERLND      22
      PERLND      23
      PERLND      24
      PERLND      25
      PERLND      26
      IMPLND      21
      PERLND      31
      PERLND      32
      PERLND      33
      PERLND      34
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PERLND      35
PERLND      36
IMPLND      31
PERLND      91
PERLND      92
PERLND      93
PERLND      94
PERLND      95
IMPLND      91
PERLND      61
PERLND      62
PERLND      63
PERLND      64
PERLND      65
PERLND      66
IMPLND      61
PERLND      71
PERLND      72
PERLND      73
PERLND      74
IMPLND      71
PERLND     121
PERLND     122
PERLND     123
PERLND     124
PERLND     125
PERLND     126
IMPLND     121
PERLND     131
PERLND     132
PERLND     133
PERLND     134
PERLND     135
PERLND     136
IMPLND     131
PERLND     141
PERLND     142
PERLND     143
PERLND     144
PERLND     145
PERLND     146
IMPLND     141
PERLND     181
PERLND     182
PERLND     183
PERLND     184
PERLND     186
IMPLND     181
PERLND     171
PERLND     177
PERLND     172
PERLND     173
PERLND     174
PERLND     175
IMPLND     171
PERLND     161
PERLND     167
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      PERLND     162
      PERLND     163
      PERLND     164

      PERLND     165
      IMPLND     161
      PERLND     101
      PERLND     107
      PERLND     102
      PERLND     103
      PERLND     104
      PERLND     105
      IMPLND     101
      PERLND     111
      PERLND     117
      PERLND     112
      PERLND     113
      PERLND     114
      PERLND     115
      IMPLND     111
      PERLND      81
      PERLND      82
      PERLND      83
      PERLND      84
      PERLND      86
      IMPLND      81
      PERLND     153
      PERLND     154
      PERLND     156
      RCHRES       1
      RCHRES       2
      RCHRES       7
      RCHRES       3
      RCHRES       4
      RCHRES       8
      RCHRES      10
      RCHRES       9
      RCHRES      11
      RCHRES      12
      RCHRES      16
      RCHRES      17
      RCHRES      18
      RCHRES      13
      RCHRES      14
      RCHRES      15
      RCHRES       5
      RCHRES       6
    END INGRP
END OPN SEQUENCE

PERLND
  ACTIVITY
*** <PLS >               Active Sections
***
*** x -  x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC
***
   11  186    1    0    1    1    1    1    1    0    0    0    0    0
```

```
  END ACTIVITY

  PRINT-INFO
*** < PLS>                       Print-flags
PIVL  PYR
*** x  - x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC
   11  186    4    4    4    4    4    4    4    4    4    4    4    4
1    9
  END PRINT-INFO

  BINARY-INFO
*** < PLS>               Binary Output Flags
PIVL  PYR
*** x  - x ATMP SNOW PWAT  SED  PST  PWG PQAL MSTL PEST NITR PHOS TRAC
   11  186    4    4    4    4    4    4    4    4    4    4    4    4
1    9
  END BINARY-INFO

  GEN-INFO
***             Name                  Unit-systems   Printer BinaryOut
*** <PLS >                                t-series Engl Metr Engl Metr
*** x -  x                                 in  out
   11     Urban or Built-up La              1    1    0    0   92    0
   12     Agricultural Land                 1    1    0    0   92    0
   13     Forest Land                       1    1    0    0   92    0
   14     Rangeland                         1    1    0    0   92    0
   15     Barren Land                       1    1    0    0   92    0
   16     Water                             1    1    0    0   92    0
   17     Pasture                           1    1    0    0   92    0
   21     Urban or Built-up La              1    1    0    0   92    0
   22     Agricultural Land                 1    1    0    0   92    0
   23     Forest Land                       1    1    0    0   92    0
   24     Rangeland                         1    1    0    0   92    0
   25     Barren Land                       1    1    0    0   92    0
   26     Water                             1    1    0    0   92    0
   31     Urban or Built-up La              1    1    0    0   92    0
   32     Agricultural Land                 1    1    0    0   92    0
   33     Forest Land                       1    1    0    0   92    0
   34     Rangeland                         1    1    0    0   92    0
   35     Barren Land                       1    1    0    0   92    0
   36     Water                             1    1    0    0   92    0
   41     Urban or Built-up La              1    1    0    0   92    0
   42     Agricultural Land                 1    1    0    0   92    0
   43     Forest Land                       1    1    0    0   92    0
   44     Rangeland                         1    1    0    0   92    0
   45     Barren Land                       1    1    0    0   92    0
   47     Pasture                           1    1    0    0   92    0
   51     Urban or Built-up La              1    1    0    0   92    0
   52     Agricultural Land                 1    1    0    0   92    0
   53     Forest Land                       1    1    0    0   92    0
   54     Rangeland                         1    1    0    0   92    0
   55     Barren Land                       1    1    0    0   92    0
   56     Water                             1    1    0    0   92    0
   61     Urban or Built-up La              1    1    0    0   92    0
   62     Agricultural Land                 1    1    0    0   92    0
   63     Forest Land                       1    1    0    0   92    0
   64     Rangeland                         1    1    0    0   92    0
```

65	Barren Land	1	1	0	0	92	0
66	Water	1	1	0	0	92	0
71	Urban or Built-up La	1	1	0	0	92	0
72	Agricultural Land	1	1	0	0	92	0
73	Forest Land	1	1	0	0	92	0
74	Rangeland	1	1	0	0	92	0
81	Urban or Built-up La	1	1	0	0	92	0
82	Agricultural Land	1	1	0	0	92	0
83	Forest Land	1	1	0	0	92	0
84	Rangeland	1	1	0	0	92	0
86	Water	1	1	0	0	92	0
91	Urban or Built-up La	1	1	0	0	92	0
92	Agricultural Land	1	1	0	0	92	0
93	Forest Land	1	1	0	0	92	0
94	Rangeland	1	1	0	0	92	0
95	Barren Land	1	1	0	0	92	0
101	Urban or Built-up La	1	1	0	0	92	0
102	Agricultural Land	1	1	0	0	92	0
103	Forest Land	1	1	0	0	92	0
104	Rangeland	1	1	0	0	92	0
105	Barren Land	1	1	0	0	92	0
107	Pasture	1	1	0	0	92	0
111	Urban or Built-up La	1	1	0	0	92	0
112	Agricultural Land	1	1	0	0	92	0
113	Forest Land	1	1	0	0	92	0
114	Rangeland	1	1	0	0	92	0
115	Barren Land	1	1	0	0	92	0
117	Pasture	1	1	0	0	92	0
121	Urban or Built-up La	1	1	0	0	92	0
122	Agricultural Land	1	1	0	0	92	0
123	Forest Land	1	1	0	0	92	0
124	Rangeland	1	1	0	0	92	0
125	Barren Land	1	1	0	0	92	0
126	Water	1	1	0	0	92	0
131	Urban or Built-up La	1	1	0	0	92	0
132	Agricultural Land	1	1	0	0	92	0
133	Forest Land	1	1	0	0	92	0
134	Rangeland	1	1	0	0	92	0
135	Barren Land	1	1	0	0	92	0
136	Water	1	1	0	0	92	0
141	Urban or Built-up La	1	1	0	0	92	0
142	Agricultural Land	1	1	0	0	92	0
143	Forest Land	1	1	0	0	92	0
144	Rangeland	1	1	0	0	92	0
145	Barren Land	1	1	0	0	92	0
146	Water	1	1	0	0	92	0
153	Forest Land	1	1	0	0	92	0
154	Rangeland	1	1	0	0	92	0
156	Water	1	1	0	0	92	0
161	Urban or Built-up La	1	1	0	0	92	0
162	Agricultural Land	1	1	0	0	92	0
163	Forest Land	1	1	0	0	92	0
164	Rangeland	1	1	0	0	92	0
165	Barren Land	1	1	0	0	92	0
167	Pasture	1	1	0	0	92	0
171	Urban or Built-up La	1	1	0	0	92	0
172	Agricultural Land	1	1	0	0	92	0

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  173     Forest Land                          1    1    0    0   92    0
  174     Rangeland                            1    1    0    0   92    0
  175     Barren Land                          1    1    0    0   92    0
  177     Pasture                              1    1    0    0   92    0
  181     Urban or Built-up La                 1    1    0    0   92    0
  182     Agricultural Land                    1    1    0    0   92    0
  183     Forest Land                          1    1    0    0   92    0
  184     Rangeland                            1    1    0    0   92    0
  186     Water                                1    1    0    0   92    0
  END GEN-INFO

  ATEMP-DAT
*** <PLS >     ELDAT    AIRTEMP
*** x -  x      (ft)    (deg F)
   11  186        0.       33.
  END ATEMP-DAT

  PWAT-PARM1
*** <PLS >                   Flags
*** x -  x CSNO RTOP UZFG  VCS  VUZ  VNN VIFW VIRC  VLE IFFC  HWT IRRG
IFRD
   11  186    0    1    1    0    0    0    0    0    0    1    0    0
0
  END PWAT-PARM1

  PWAT-PARM2
*** < PLS>    FOREST      LZSN    INFILT      LSUR     SLSUR     KVARY
AGWRC
*** x  - x                (in)   (in/hr)      (ft)              (1/in)
(1/day)
   11             0.        2.     0.001      150.    0.3323        0.
0.98
   12             0.        2.      0.08      150.    0.3323        0.
0.98
   13   14        1.        3.       0.1      150.    0.3323        0.
0.98
   15             0.        2.      0.08      150.    0.3323        0.
0.98
   16             0.        1.     0.001      150.    0.3323        0.
0.98
   17             0.        2.       0.1      150.    0.3323        0.
0.98
   21             0.        2.     0.001      150.    0.3556        0.
0.98
   22             0.        3.       0.8      150.    0.3556        0.
0.98
   23   24        1.        5.       0.1      150.    0.3556        0.
0.98
   25             0.        2.       0.1      150.    0.3556        0.
0.98
   26             0.        1.     0.001      150.    0.3556        0.
0.98
   31             0.        2.     0.001      150.     0.389        0.
0.98
   32             0.        3.       0.1      150.     0.389        0.
0.98
```

33	34	1.	5.	0.1	150.	0.389	0.	0.98
35		0.	2.	0.08	150.	0.389	0.	0.98
36		0.	1.	0.001	150.	0.389	0.	0.98
41		0.	5.	0.01	150.	0.3755	0.	0.98
42		0.	5.	0.15	150.	0.3755	0.	0.98
43	44	1.	6.5	0.2	150.	0.3755	0.	0.98
45		0.	5.	0.1	150.	0.3755	0.	0.98
47		0.	5.	0.15	150.	0.3755	0.	0.98
51		0.	5.	0.01	150.	0.2831	0.	0.98
52		0.	5.	0.15	150.	0.2831	0.	0.98
53	54	1.	6.5	0.2	150.	0.2831	0.	0.98
55		0.	5.	0.01	150.	0.2831	0.	0.98
56		0.	1.	0.1	150.	0.2831	0.	0.98
61		0.	5.	0.01	150.	0.3713	0.	0.98
62		0.	5.	0.25	150.	0.3713	0.	0.98
63	64	1.	6.5	0.35	150.	0.3713	0.	0.98
65		0.	5.	0.16	150.	0.3713	0.	0.98
66		0.	1.	0.1	150.	0.3713	0.	0.98
71		0.	2.	0.001	150.	0.3207	0.	0.98
72		0.	2.	0.1	150.	0.3207	0.	0.98
73	74	1.	2.5	0.1	150.	0.3207	0.	0.98
81		0.	2.	0.001	150.	0.4541	0.	0.98
82		0.	2.	0.25	150.	0.4541	0.	0.98
83	84	1.	2.5	0.35	150.	0.4541	0.	0.98
86		0.	2.	0.01	150.	0.4541	0.	0.98
91		0.	2.	0.01	150.	0.3177	0.	0.98
92		0.	2.	0.25	150.	0.3177	0.	0.98
93	94	1.	2.5	0.35	150.	0.3177	0.	0.98

95		0.	2.	0.2	150.	0.3177	0.	0.98
101		0.	2.	0.001	150.	0.4465	0.	0.98
102		0.	2.	0.15	150.	0.4465	0.	0.98
103	104	1.	3.5	0.2	150.	0.4465	0.	0.98
105		0.	2.	0.1	150.	0.4465	0.	0.98
107		0.	2.	0.15	150.	0.4465	0.	0.98
111		0.	2.	0.001	150.	0.3519	0.	0.98
112		0.	2.	0.15	150.	0.3519	0.	0.98
113	114	1.	3.5	0.2	150.	0.3519	0.	0.98
115		0.	2.	0.1	150.	0.3519	0.	0.98
117		0.	2.	0.15	150.	0.3519	0.	0.98
121		0.	2.	0.001	150.	0.3594	0.	0.98
122		0.	2.	0.15	150.	0.3594	0.	0.98
123		1.	3.5	0.15	150.	0.3594	0.	0.98
124		1.	3.5	0.2	150.	0.3594	0.	0.98
125		0.	2.	0.1	150.	0.3594	0.	0.98
126		0.	2.	0.001	150.	0.3594	0.	0.98
131		0.	2.	0.001	150.	0.4943	0.	0.98
132		0.	2.	0.08	150.	0.4943	0.	0.98
133	134	1.	3.5	0.12	150.	0.4943	0.	0.98
135		0.	2.	0.08	150.	0.4943	0.	0.98
136		0.	2.	0.001	150.	0.4943	0.	0.98
141		0.	2.	0.001	150.	0.3806	0.	0.98
142		0.	2.	0.15	150.	0.3806	0.	0.98
143	144	1.	3.5	0.2	150.	0.3806	0.	0.98
145		0.	2.	0.1	150.	0.3806	0.	0.98
146		0.	2.	0.001	150.	0.3806	0.	0.98
153		1.	8.5	0.3	150.	0.3557	0.	0.98

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  154               1.        8.5       0.25       150.     0.3557         0.
0.98
  156               0.         4.       0.01       150.     0.3557         0.
0.98
  161               0.         3.        0.1       150.     0.3544         0.
0.98
  162               0.         7.       0.15       150.     0.3544         0.
0.98
  163               1.        8.5        0.3       150.     0.3544         0.
0.98
  164               1.        8.5       0.25       150.     0.3544         0.
0.98
  165               0.         3.        0.1       150.     0.3544         0.
0.98
  167               0.         7.        0.2       150.     0.3544         0.
0.98
  171               0.         3.        0.1       150.     0.3426         0.
0.98
  172               0.         7.       0.15       150.     0.3426         0.
0.98
  173               1.        8.5        0.3       150.     0.3426         0.
0.98
  174               1.        8.5       0.25       150.     0.3426         0.
0.98
  175               0.         3.        0.1       150.     0.3426         0.
0.98
  177               0.         7.        0.2       150.     0.3426         0.
0.98
  181               0.         3.        0.1       150.     0.3906         0.
0.98
  182               0.         7.       0.15       150.     0.3906         0.
0.98
  183               1.        8.5        0.3       150.     0.3906         0.
0.98
  184               1.        8.5       0.25       150.     0.3906         0.
0.98
  186               0.         4.       0.01       150.     0.3906         0.
0.98
  END PWAT-PARM2

  PWAT-PARM3
*** < PLS>    PETMAX    PETMIN    INFEXP    INFILD    DEEPFR    BASETP
AGWETP
*** x  - x   (deg F)   (deg F)
   11   17       40.       35.        1.        1.       0.3     0.005
0.
   21   36       40.       35.        2.        2.       0.9       0.9
0.
   41   66       40.       35.        2.        2.       0.1     0.005
0.
   71   95       40.       35.        2.        2.     0.001     0.005
0.
  101  126       40.       35.        2.        2.     0.002     0.002
0.
  131  136       40.       35.        1.        1.     0.001     0.001
0.
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  141  146        40.        35.         2.         2.      0.002      0.002
0.
  153  156        40.        35.         2.         2.       0.25        0.2
0.
  161  167        40.        35.         2.         2.        0.2       0.08
0.
  171  186        40.        35.         2.         2.       0.25        0.2
0.
  END PWAT-PARM3

  PWAT-PARM4
*** <PLS >     CEPSC       UZSN       NSUR      INTFW        IRC      LZETP
*** x -  x      (in)       (in)                           (1/day)
   11             0.       0.05        0.2         1.        0.3         0.
   12           0.15        0.1        0.2         1.        0.3        0.1
   13           0.15        0.3        0.2         1.        0.3        0.3
   14            0.1        0.2        0.2         1.        0.3        0.3
   15             0.       0.05        0.2         1.        0.3        0.1
   16             0.       0.05        0.2         1.        0.3         0.
   17            0.1        0.1        0.2         1.        0.3        0.1
   21             0.       0.05        0.2         1.        0.3        0.1
   22            0.1        0.1        0.2         1.        0.3        0.1
   23           0.15        0.3        0.2         1.        0.3        0.1
   24           0.15        0.2        0.2         1.        0.3        0.1
   25   31        0.       0.05        0.2         1.        0.3        0.1
   32           0.12        0.1        0.2         1.        0.3        0.1
   33           0.15        0.3        0.2         1.        0.3        0.1
   34           0.15        0.2        0.2         1.        0.3        0.1
   35   36        0.       0.05        0.2         1.        0.3        0.1
   41             0.       0.05        0.2        10.        0.5        0.1
   42            0.1        0.8        0.2        10.        0.5        0.1
   43            0.2         3.        0.2        10.        0.5        0.1
   44           0.15        2.5        0.2        10.        0.5        0.1
   45             0.        0.7        0.2        10.        0.5        0.1
   47            0.1        0.8        0.2        10.        0.5        0.1
   51             0.       0.05        0.2        10.        0.5        0.1
   52            0.1        0.8        0.2        10.        0.5        0.1
   53            0.2         3.        0.2        10.        0.5        0.1

   54           0.15        2.5        0.2        10.        0.5        0.1
   55            0.1       0.05        0.2        10.        0.5        0.1
   56             0.        0.7        0.2        10.        0.5        0.1
   61             0.       0.05        0.2        10.        0.5        0.1
   62            0.1        0.8        0.2        10.        0.5        0.1
   63            0.2         3.        0.2        10.        0.5        0.1
   64           0.15        2.5        0.2        10.        0.5        0.1
   65             0.        0.1        0.2        10.        0.5        0.1
   66             0.       0.05        0.2        10.        0.5        0.1
   71             0.        0.1        0.2       0.75        0.3         0.
   72            0.1        0.1        0.2       0.75        0.3        0.1
   73   74       0.1         1.        0.2       0.75        0.3        0.1
   81             0.        0.1        0.2       0.75        0.5        0.1
   82            0.1        0.5        0.2       0.75        0.5        0.1
   83            0.2        0.8        0.2       0.75        0.5        0.1
   84           0.15        0.8        0.2       0.75        0.5        0.1
   86             0.       0.05        0.2       0.75        0.5        0.1
   91             0.        0.1        0.2       0.75        0.5        0.1
```

92		0.1	0.5	0.2	0.75	0.5	0.1
93		0.2	0.8	0.2	0.75	0.5	0.1
94		0.15	0.8	0.2	0.75	0.5	0.1
95		0.	0.2	0.2	0.75	0.5	0.1
101		0.	0.01	0.2	1.2	0.5	0.
102		0.04	0.2	0.2	1.2	0.5	0.1
103		0.06	0.3	0.2	1.2	0.5	0.1
104		0.05	0.3	0.2	1.2	0.5	0.1
105		0.	0.2	0.2	1.2	0.5	0.
107		0.04	0.2	0.2	1.2	0.5	0.1
111		0.	0.01	0.2	1.2	0.5	0.
112		0.04	0.2	0.2	1.2	0.5	0.1
113		0.06	0.3	0.2	1.2	0.5	0.1
114		0.05	0.3	0.2	1.2	0.5	0.1
115		0.	0.2	0.2	1.2	0.5	0.
117		0.04	0.2	0.2	1.2	0.5	0.1
121		0.	0.01	0.2	1.2	0.5	0.
122		0.04	0.2	0.2	1.2	0.5	0.1
123		0.06	0.3	0.2	1.2	0.5	0.1
124		0.05	0.3	0.2	1.2	0.5	0.1
125	126	0.	0.2	0.2	1.2	0.5	0.
131		0.	0.01	0.2	1.	0.5	0.
132		0.04	0.2	0.2	1.	0.5	0.1
133		0.06	0.3	0.2	1.	0.5	0.1
134		0.05	0.3	0.2	1.	0.5	0.1
135		0.	0.2	0.2	1.	0.5	0.1
136		0.	0.2	0.2	1.	0.5	0.
141		0.	0.01	0.2	1.	0.5	0.
142		0.04	0.2	0.2	1.	0.5	0.1
143		0.06	0.3	0.2	1.	0.5	0.1
144		0.05	0.3	0.2	1.	0.5	0.1
145		0.	0.2	0.2	1.	0.5	0.1
146		0.	0.01	0.2	1.	0.5	0.
153		0.2	1.5	0.2	1.	0.5	0.3
154		0.2	1.2	0.2	1.	0.5	0.3
156		0.	0.01	0.2	1.	0.5	0.2
161		0.	0.01	0.2	1.	0.5	0.
162		0.1	0.8	0.2	1.	0.5	0.2
163		0.2	1.5	0.2	1.	0.5	0.3
164		0.2	1.2	0.2	1.	0.5	0.3
165		0.	0.2	0.2	1.	0.5	0.
167		0.1	0.8	0.2	1.	0.5	0.2
171		0.	0.01	0.2	2.	0.5	0.
172		0.1	0.8	0.2	2.	0.5	0.2
173		0.2	1.5	0.2	2.	0.5	0.3
174		0.2	1.2	0.2	2.	0.5	0.3
175		0.	0.2	0.2	2.	0.5	0.
177		0.1	0.8	0.2	2.	0.5	0.2
181		0.	0.01	0.2	2.	0.5	0.
182		0.1	0.8	0.2	2.	0.5	0.2
183		0.2	1.5	0.2	2.	0.5	0.3
184		0.2	1.2	0.2	2.	0.5	0.3
186		0.	0.01	0.2	2.	0.5	0.2

END PWAT-PARM4

```
  PWAT-STATE1
*** < PLS>  PWATER state variables (in)
*** x  - x       CEPS      SURS       UZS      IFWS       LZS      AGWS
GWVS
   11  186       0.01      0.01       0.3      0.01       1.5      0.01
0.01
  END PWAT-STATE1

  MON-INTERCEP
*** <PLS >  Interception storage capacity at start of each month (in)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11  186  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
  END MON-INTERCEP

  MON-LZETPARM
*** <PLS >  Lower zone evapotransp   parm at start of each month
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11  186  0.2  0.2  0.3  0.3  0.4  0.4  0.4  0.4  0.4  0.3  0.2  0.2
  END MON-LZETPARM

  SED-PARM1
*** <PLS >  Sediment parameters 1
*** x -  x  CRV VSIV SDOP
   11  186    0    0    1
  END SED-PARM1

  SED-PARM2
*** <PLS >       SMPF      KRER      JRER     AFFIX     COVER      NVSI
*** x -  x                                  (/day)           lb/ac-day
   11              1.        0.        3.      0.03        0.        0.
   12              1.       0.3        1.      0.03       0.4        0.
   13              1.       0.1        1.      0.03       0.9        0.
   14              1.       0.1        1.      0.03       0.8        0.
   15              1.       0.6        1.      0.03        0.        0.
   16              1.        0.        1.      0.03        0.        0.
   17              1.       0.1        1.      0.03       0.7        0.

   21              1.        0.        2.      0.03        0.        0.
   22              1.       0.5        2.      0.03       0.5        0.
   23              1.      0.15        2.      0.03      0.95        0.
   24              1.      0.15        2.      0.03      0.85        0.
   25              1.      0.75        2.      0.03        0.        0.
   26   31         1.        0.        2.      0.03        0.        0.
   32              1.       0.5        2.      0.03       0.5        0.
   33              1.      0.15        2.      0.03       0.9        0.
   34              1.      0.15        2.      0.03      0.85        0.
   35              1.      0.75        2.      0.03        0.        0.
   36              1.        0.        2.      0.03        0.        0.
   41              1.        0.        1.      0.03        0.        0.
   42              1.       0.5        1.      0.03       0.4        0.
   43              1.      0.14        1.      0.03       0.9        0.
   44              1.      0.14        1.      0.03      0.85        0.
   45              1.      0.75        1.      0.03        0.        0.
   47              1.       0.2        1.      0.03       0.7        0.
   51              1.        0.        1.      0.03        0.        0.
   52              1.       0.7        1.      0.03       0.4        0.
   53              1.       0.2        1.      0.03       0.9        0.
```

54		1.	0.2	1.	0.03	0.8	0.
55		1.	0.75	1.	0.03	0.	0.
56	61	1.	0.	1.	0.03	0.	0.
62		1.	0.5	1.	0.03	0.5	0.
63		1.	0.15	1.	0.03	0.9	0.
64		1.	0.15	1.	0.03	0.85	0.
65		1.	0.75	1.	0.03	0.	0.
66		1.	0.	2.	0.03	0.	0.
71		1.	0.	1.	0.03	0.	0.
72		1.	0.2	3.	0.03	0.5	0.
73		1.	0.15	3.	0.03	0.9	0.
74		1.	0.15	3.	0.03	0.85	0.
81		1.	0.	1.	0.03	0.88	0.
82		1.	0.5	1.	0.03	0.5	0.
83		1.	0.15	1.	0.03	0.9	0.
84		1.	0.15	1.	0.03	0.85	0.
86	91	1.	0.	1.	0.03	0.	0.
92		1.	0.5	1.	0.03	0.5	0.
93		1.	0.15	1.	0.03	0.9	0.
94		1.	0.15	1.	0.03	0.85	0.
95		1.	0.75	1.	0.03	0.	0.
101		1.	0.	2.	0.	0.	0.
102		0.7	0.3	2.	0.03	0.5	0.
103		0.4	0.01	2.	0.03	0.98	0.
104		0.4	0.01	2.	0.03	0.95	0.
105		1.	0.5	2.	0.01	0.	0.
107		0.5	0.15	2.	0.03	0.8	0.
111		1.	0.	2.	0.	0.	0.
112		0.8	0.3	2.	0.03	0.5	0.
113		0.4	0.1	2.	0.03	0.98	0.
114		0.4	0.1	2.	0.03	0.95	0.
115		1.	0.5	2.	0.01	0.	0.
117		0.5	0.15	2.	0.03	0.8	0.
121		1.	0.	2.	0.	0.	0.
122		0.7	0.3	2.	0.03	0.5	0.
123		0.4	0.05	2.	0.03	0.98	0.
124		0.4	0.05	2.	0.03	0.95	0.
125		1.	0.5	2.	0.01	0.	0.
126		1.	0.	2.	0.03	0.	0.
131		1.	0.	1.	0.03	0.	0.
132		1.	0.5	1.	0.03	0.5	0.
133		1.	0.15	1.	0.03	0.9	0.
134		1.	0.15	1.	0.03	0.85	0.
135		1.	0.75	1.	0.03	0.	0.
136	141	1.	0.	1.	0.03	0.	0.
142		1.	0.5	1.	0.03	0.5	0.
143		1.	0.15	1.	0.03	0.9	0.
144		1.	0.15	1.	0.03	0.85	0.
145		1.	0.14	1.	0.03	0.	0.
146		1.	0.	1.	0.03	0.	0.
153		1.	0.15	1.	0.03	0.9	0.
154		1.	0.15	1.	0.03	0.85	0.
156		1.	0.	1.	0.03	0.	0.
161		1.	0.	2.	0.03	0.	0.
162		0.7	0.1	3.	0.09	0.5	0.

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  163            0.4      0.05        3.      0.03      0.98        0.
  164            0.4      0.05        3.      0.03       0.9        0.
  165             1.       0.2        3.      0.09        0.        0.
  167             1.       0.1        3.      0.06       0.7        0.
  171             1.        0.        1.      0.03        0.        0.
  172             1.       0.2        1.      0.03       0.4        0.
  173             1.       0.1        1.      0.03       0.9        0.
  174             1.       0.1        1.      0.03       0.8        0.
  175             1.       0.3        1.      0.03        0.        0.
  177             1.       0.1        1.      0.03       0.7        0.
  181             1.        0.        1.      0.03        0.        0.
  182             1.       0.5        1.      0.03       0.5        0.
  183             1.      0.15        1.      0.03       0.9        0.
  184             1.      0.15        1.      0.03      0.85        0.
  186             1.        0.        1.      0.03        0.        0.
  END SED-PARM2

  SED-PARM3
*** <PLS >  Sediment parameter 3
*** x -  x      KSER      JSER      KGER      JGER
   11             0.        2.        0.        2.
   12             2.       1.5        2.        2.
   13   14       0.5        2.       0.1        2.
   15             5.       1.5        5.        2.
   16             0.        2.        0.        2.
   17            0.4        2.       0.5        2.
   21             0.        1.        0.       1.2
   22             2.        1.        2.       1.2
   23   24       0.5        1.       0.1       1.2
   25             5.        1.        5.       1.2
   26   31        0.        1.        0.       1.2
   32             2.        1.        2.       1.2
   33   34       0.5        1.       0.1       1.2
   35             5.        1.        5.       1.2
   36             0.        1.        0.        2.
   41             0.        1.        0.        1.
   42            30.        1.       30.        1.
   43   44        1.        1.       0.3        1.
   45            50.        1.       50.        1.
   47             1.        1.        1.        1.
   51             0.        2.        0.        1.
   52            30.        1.       30.        1.
   53   54        1.        1.       0.3        1.
   55            50.        1.       50.        1.
   56   61        0.        1.        0.        1.
   62            10.        1.       10.        1.
   63   64       0.5        1.       0.1        1.
   65            40.        1.       40.        1.
   66             0.        1.      0.01        1.
   71             0.        2.        0.        2.
   72            2.3       1.2       2.3       1.2
   73   74       0.1        2.      0.01        2.
   81             0.        1.        0.        1.
   82            10.        1.       10.        1.
   83   84        1.        1.       0.3        1.
   86   91        0.        1.        0.        1.
   92            30.        1.       30.        1.
```

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   93   94         1.         1.        0.3         1.
   95             50.         1.        50.         1.
  101              0.         1.         0.         1.
  102             0.8         1.        0.6         1.
  103             0.1         1.       0.01         1.
  104             0.2         1.       0.02         1.
  105              4.         3.         4.         3.
  107             0.4         1.       0.02         1.
  111              0.         1.         0.         1.
  112             0.8         1.        0.6         1.
  113             0.1         1.       0.01         1.
  114             0.2         1.       0.02         1.
  115              8.         1.         8.         1.
  117             0.4         1.       0.02         1.
  121              0.         1.         0.         1.
  122             0.8         1.        0.6         1.
  123             0.1         1.       0.01         1.
  124             0.2         1.       0.02         1.
  125              8.         1.         8.         1.
  126  131         0.         1.         0.         1.
  132              2.         1.         2.         1.
  133  134        0.1         1.        0.1         1.
  135             10.         1.        10.         1.
  136  141         0.         1.         0.         1.
  142              2.         1.         2.         1.
  143  144        0.1         1.        0.1         1.
  145             10.         1.        10.         1.
  146              0.         1.         0.         1.
  153  154        0.1         1.        0.1         1.
  156              0.         1.         0.         1.
  161              0.         2.         0.         1.
  162             0.8         3.        0.5         5.
  163  164        0.2         3.        0.1         3.
  165              3.         3.         3.         3.
  167             0.4         3.        0.1         5.
  171              0.         2.         0.         5.
  172             0.3         2.        0.2         5.
  173  174        0.1         2.       0.01         5.
  175             0.5         2.        0.5         5.
  177             0.2         2.        0.1         5.
  181              0.         2.         0.         1.
  182              2.         1.         2.         1.
  183  184        0.1         1.        0.1         1.
  186              0.         1.         0.         1.
  END SED-PARM3

  PSTEMP-PARM1
*** <PLS >  Flags for section PSTEMP
*** x -  x SLTV ULTV LGTV TSOP
   11  186    1    1    1    1
  END PSTEMP-PARM1

  PSTEMP-PARM2
*** <PLS >      ASLT       BSLT      ULTP1      ULTP2      LGTP1      LGTP2
*** x -  x   (deg F)   (deg F)              (deg F)              (deg F)
   11  186       55.       0.15        60.       0.15        50.         0.
  END PSTEMP-PARM2
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  MON-ASLT
*** <PLS >  Value of ASLT at start of each month (deg F)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11  186  45.  45.  45.  48.  55.  65.  70.  77.  73.  68.  60.  50.
  END MON-ASLT

  MON-BSLT
*** <PLS >  Value of BSLT at start of each month (deg F/F)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11  186 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
  END MON-BSLT

  MON-ULTP1
*** <PLS >  Value of ULTP1 at start of each month in deg F (TSOPFG=1)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11  186  52.  52.  52.  56.  62.  70.  77.  77.  73.  68.  60.  54.
  END MON-ULTP1

  MON-ULTP2
*** <PLS >  Value of ULTP2 at start of each month in Deg F/F (TSOPFG=1)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11  186 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
  END MON-ULTP2

  MON-LGTP1
*** <PLS >  Value of LGTP1 at start of each month in Deg F (TSOPFG=1)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11  186  48.  48.  52.  58.  60.  63.  63.  64.  60.  55.  52.  48.
  END MON-LGTP1

  PSTEMP-TEMPS
*** <PLS >  Initial temperatures (deg F)
*** x -  x     AIRTC     SLTMP     ULTMP     LGTMP
   11  186       30.       30.       40.       40.
  END PSTEMP-TEMPS

  PWT-PARM1
*** <PLS >  Flags for section PWTGAS
*** x -  x  IDV  ICV  GDV  GVC
   11  186    1    0    1    0
  END PWT-PARM1

  PWT-PARM2
***         Second group of PWTGAS parms
*** <PLS >      ELEV     IDOXP     ICO2P     ADOXP     ACO2P
*** x -  x      (ft)    (mg/l)  (mg C/l)    (mg/l)  (mg C/l)
   11  186      120.       8.8        0.       8.8        0.
  END PWT-PARM2

  MON-IFWDOX
*** <PLS > Value at start of each month for interflow DO concentration
(mg/l)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11  186  11.  10.   8.   7.   6.   5.   5.   5.   7.   8.   9.  10.
  END MON-IFWDOX
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  MON-GRNDDOX
*** <PLS >Value at start of each month for groundwater DO concentration
(mg/l)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11  186   9.   8.   6.   5.   5.   4.   4.   4.   5.   6.   7.   8.
  END MON-GRNDDOX

  PWT-GASES
***                    Initial DO and CO2 concentrations
*** <PLS >     SODOX     SOCO2     IODOX     IOCO2     AODOX     AOCO2
*** x -  x    (mg/l)  (mg C/l)    (mg/l)   (mg C/l)   (mg/l)  (mg C/l)
   11  186       8.8        0.       8.8        0.       8.8        0.
  END PWT-GASES

  NQUALS
*** <PLS >
*** x -  xNQUAL
   11  186    3
  END NQUALS

  QUAL-PROPS
*** <PLS >  Identifiers and Flags
*** x -  x    QUALID      QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW
VAQC
   11  186NH3+NH4         LBS     0    0    0    1    1    1    3    1
3
  END QUAL-PROPS

  QUAL-INPUT
***         Storage on surface and nonseasonal parameters
***            SQO   POTFW   POTFS   ACQOP  SQOLIM   WSQOP    IOQC
AOQC
*** <PLS >  qty/ac qty/ton qty/ton    qty/  qty/ac   in/hr qty/ft3
qty/ft3
*** x -  x                           ac.day
   11        0.365      0.      0.   0.005    0.05
1.64.0000025.0000025
   12         0.03      0.      0.   0.005    0.05
1.64.0000025.0000025
   13   14   0.033      0.      0.   0.005    0.05
1.64.0000025.0000025
   15         0.03      0.      0.   0.005    0.05
1.64.0000025.0000025
   16        0.065      0.      0.   0.005    0.05
1.64.0000025.0000025
   17         0.03      0.      0.   0.005    0.05
1.64.0000025.0000025
   21        0.365      0.      0.   0.002   0.005
1.64.0000025.0000025
   22         0.03      0.      0.   0.002   0.005
1.64.0000025.0000025
   23   24   0.033      0.      0.   0.002   0.005
1.64.0000025.0000025
   25         0.03      0.      0.   0.002   0.005
1.64.0000025.0000025
   26        0.065      0.      0.   0.002   0.005
1.64.0000025.0000025
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   31         0.365      0.       0.   0.002   0.005
1.64.0000025.0000025
   32          0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
   33   34    0.033      0.       0.   0.002   0.005
1.64.0000025.0000025
   35          0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
   36         0.065      0.       0.   0.002   0.005
1.64.0000025.0000025
   41         0.365      0.       0.      2.     15.
1.64.0000025.0000025
   42          0.03      0.       0.      2.     15.
1.64.0000025.0000025
   43   44    0.033      0.       0.      2.     15.
1.64.0000025.0000025
   45   47     0.03      0.       0.      2.     15.
1.64.0000025.0000025
   51         0.365      0.       0.      2.     15.
1.64.0000025.0000025
   52          0.03      0.       0.      2.     15.
1.64.0000025.0000025
   53   54    0.033      0.       0.      2.     15.
1.64.0000025.0000025
   55          0.03      0.       0.      2.     15.
1.64.0000025.0000025
   56         0.065      0.       0.      2.     15.
1.64.0000025.0000025
   61         0.365      0.       0.   0.002   0.005
1.64.0000025.0000025
   62          0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
   63   64    0.033      0.       0.   0.002   0.005
1.64.0000025.0000025
   65          0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
   66         0.065      0.       0.   0.002   0.005
1.64.0000025.0000025
   71         0.365      0.       0.   0.002   0.005
1.64.0000025.0000025
   72          0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
   73   74    0.033      0.       0.   0.002   0.005
1.64.0000025.0000025
   81         0.365      0.       0.   0.002   0.005
1.64.0000025.0000025
   82          0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
   83   84    0.033      0.       0.   0.002   0.005
1.64.0000025.0000025
   86         0.065      0.       0.   0.002   0.005
1.64.0000025.0000025
   91         0.365      0.       0.   0.002   0.005
1.64.0000025.0000025
   92          0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
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   93   94   0.033      0.       0.   0.002   0.005
1.64.0000025.0000025
   95         0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
  101        0.365      0.       0.   0.002   0.005
1.64.0000025.0000025
  102         0.03      0.       0.   0.002   0.005
1.64.0000025.0000025

  103  104   0.033      0.       0.   0.002   0.005
1.64.0000025.0000025
  105  107    0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
  111        0.365      0.       0.   0.002   0.005
1.64.0000025.0000025
  112         0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
  113  114   0.033      0.       0.   0.002   0.005
1.64.0000025.0000025
  115  117    0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
  121        0.365      0.       0.   0.002   0.005
1.64.0000025.0000025
  122         0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
  123  124   0.033      0.       0.   0.002   0.005
1.64.0000025.0000025
  125         0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
  126        0.065      0.       0.   0.002   0.005
1.64.0000025.0000025
  131        0.365      0.       0.   0.002   0.005
1.64.0000025.0000025
  132         0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
  133  134   0.033      0.       0.   0.002   0.005
1.64.0000025.0000025
  135         0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
  136        0.065      0.       0.   0.002   0.005
1.64.0000025.0000025
  141        0.365      0.       0.   0.002   0.005
1.64.0000025.0000025
  142         0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
  143  144   0.033      0.       0.   0.002   0.005
1.64.0000025.0000025
  145         0.03      0.       0.   0.002   0.005
1.64.0000025.0000025
  146        0.065      0.       0.   0.002   0.005
1.64.0000025.0000025
  153  154   0.033      0.       0.   0.002   0.005
1.64.0000025.0000025
  156        0.065      0.       0.   0.002   0.005
1.64.0000025.0000025
  161        0.365      0.       0.   0.002   0.005
1.64.0000025.0000025
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  162         0.03      0.      0.   0.002   0.005
1.64.0000025.0000025
  163  164   0.033      0.      0.   0.002   0.005
1.64.0000025.0000025
  165  167    0.03      0.      0.   0.002   0.005
1.64.0000025.0000025
  171        0.365      0.      0.   0.002   0.005
1.64.0000025.0000025
  172         0.03      0.      0.   0.002   0.005
1.64.0000025.0000025
  173  174   0.033      0.      0.   0.002   0.005
1.64.0000025.0000025
  175  177    0.03      0.      0.   0.002   0.005
1.64.0000025.0000025
  181        0.365      0.      0.   0.002   0.005
1.64.0000025.0000025
  182         0.03      0.      0.   0.002   0.005
1.64.0000025.0000025
  183  184   0.033      0.      0.   0.002   0.005
1.64.0000025.0000025
  186        0.065      0.      0.   0.002   0.005
1.64.0000025.0000025
  END QUAL-INPUT


  MON-ACCUM
*** <PLS >  Value at start of each month for accum rate of QUALOF
(lb/ac.day)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
   12     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
   13     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
   14     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
   15     0.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.001
   16     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
   17     0.0040.0040.0040.0040.0040.0040.0040.0040.0040.0040.0040.004
   21     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
   22     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
   23     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
   24     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
   25     0.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.001
   26     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
   31     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
   32     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
   33     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
   34     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
   35     0.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.001
   36     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
   41     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
   42     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
   43     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
   44     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
   45     0.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.001
   47     0.0040.0040.0040.0040.0040.0040.0040.0040.0040.0040.0040.004
   51     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
   52     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
   53     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
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 54     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
 55     0.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.001
 56     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
 61     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
 62     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
 63     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
 64     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
 65     0.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.001
 66     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
 71     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
 72     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
 73     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
 74     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
 81     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
 82     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
 83     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
 84     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
 86     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
 91     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
 92     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
 93     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
 94     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
 95  1010.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.001
102     0.0030.0030.0030.0030.0030.0030.0030.0030.0030.0030.0030.003
103     .0003.0003.0003.0003.0003.0003.0003.0003.0003.0003.0003.0003
104     .0009.0009.0009.0009.0009.0009.0009.0009.0009.0009.0009.0009
105     .0007.0007.0007.0007.0007.0007.0007.0007.0007.0007.0007.0007
107     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
111     0.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.001
112     0.0030.0030.0030.0030.0030.0030.0030.0030.0030.0030.0030.003
113     .0007.0007.0007.0007.0007.0007.0007.0007.0007.0007.0007.0007
114     .0009.0009.0009.0009.0009.0009.0009.0009.0009.0009.0009.0009
115     .0007.0007.0007.0007.0007.0007.0007.0007.0007.0007.0007.0007
117     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
121     0.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.001
122     0.0030.0030.0030.0030.0030.0030.0030.0030.0030.0030.0030.003
123     .0003.0003.0003.0003.0003.0003.0003.0003.0003.0003.0003.0003
124     .0009.0009.0009.0009.0009.0009.0009.0009.0009.0009.0009.0009
125     .0007.0007.0007.0007.0007.0007.0007.0007.0007.0007.0007.0007
126     .0003.0003.0003.0003.0003.0003.0003.0003.0003.0003.0003.0003
131     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
132     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
133     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
134     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
135     0.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.001
136     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
141     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
142     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
143     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
144     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
145     0.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.001
146  153.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
154     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
156     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
161     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
162     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
163     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
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  164     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
  165     0.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.001
  167     0.0040.0040.0040.0040.0040.0040.0040.0040.0040.0040.0040.004
  171     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
  172     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
  173     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
  174     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
  175     0.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.0010.001
  177     0.0040.0040.0040.0040.0040.0040.0040.0040.0040.0040.0040.004
  181     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
  182     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
  183     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
  184     .0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015.0015
  186     .0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005.0005
  END MON-ACCUM

  MON-SQOLIM
*** <PLS >  Value at start of month for limiting storage of QUALOF
(lb/ac)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11   17 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
   21  107  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5
  111  117 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
  121  186  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5
  END MON-SQOLIM

  MON-IFLW-CONC
*** <PLS >  Conc of QUAL in interflow outflow for each month (qty/ft3)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11  186 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01 0.01
  END MON-IFLW-CONC

  MON-GRND-CONC
*** <PLS >  Value at start of month for conc of QUAL in groundwater
(qty/ft3)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
   12      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
   13   14 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
   15      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
   16      0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
   17      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
   21       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
   22      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
   23   24 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
   25      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
   26      0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
   31       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
   32      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
   33   34 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
   35      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
   36      0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
   41       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
   42      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
   43   44 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
   45   47 0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
   51       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
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 52      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
 53   54 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04

 55      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
 56      0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
 61       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
 62      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
 63   64 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
 65      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
 66      0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
 71       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
 72      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
 73   74 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
 81       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
 82      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
 83   86 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
 91       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
 92      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
 93   94 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
 95      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
101       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
102      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
103  104 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
105  107 0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
111       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
112      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
113  114 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
115  117 0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
121       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
122      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
123  124 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
125      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
126      0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
131       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
132      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15

133  134 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
135      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
136      0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
141       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
142      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
143  144 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
145      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
146  156 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
161       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
162      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
163  164 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
165  167 0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
171       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
172      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
173  174 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
175  177 0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
181       0.1  0.1  0.1 0.08 0.08 0.08 0.08 0.08 0.08  0.1  0.1  0.1
182      0.15 0.15 0.15 0.08 0.08 0.08 0.08 0.08 0.08 0.15 0.15 0.15
183  186 0.04 0.04 0.040.0250.0250.0250.0250.0250.025 0.04 0.04 0.04
END MON-GRND-CONC
```

```
  QUAL-PROPS
*** <PLS >  Identifiers and Flags
*** x -  x    QUALID      QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW
VAQC
   11  186NO3             LBS     0    0    0    1    1    1    3    1
3
  END QUAL-PROPS

  QUAL-INPUT
***         Storage on surface and nonseasonal parameters
***            SQO   POTFW   POTFS   ACQOP  SQOLIM   WSQOP    IOQC
AOQC
*** <PLS >  qty/ac qty/ton qty/ton    qty/  qty/ac   in/hr qty/ft3
qty/ft3
*** x -  x                          ac.day
   11         0.45      0.      0.      0.      0.     0.5      0.
0.
   12          1.4      0.      0.      0.      0.     0.5      0.
0.
   13   14    0.25      0.      0.      0.      0.     0.7      0.
0.
   15          1.4      0.      0.      0.      0.     0.5      0.
0.
   16          0.5      0.      0.      0.      0.     0.2      0.
0.
   17          1.4      0.      0.      0.      0.     0.5      0.
0.
   21         0.45      0.      0.      0.      0.     0.5      0.
0.
   22          1.4      0.      0.      0.      0.     0.5      0.
0.
   23   24    0.25      0.      0.      0.      0.     0.7      0.
0.
   25          1.4      0.      0.      0.      0.     0.5      0.
0.
   26          0.5      0.      0.      0.      0.     0.2      0.
0.
   31         0.45      0.      0.      0.      0.     0.5      0.
0.
   32          1.4      0.      0.      0.      0.     0.5      0.
0.
   33   34    0.25      0.      0.      0.      0.     0.7      0.
0.
   35          1.4      0.      0.      0.      0.     0.5      0.
0.
   36          0.5      0.      0.      0.      0.     0.2      0.
0.
   41         0.45      0.      0.      0.      0.     0.5      0.
0.
   42          1.4      0.      0.      0.      0.     0.5      0.
0.
   43   44    0.25      0.      0.      0.      0.     0.7      0.
0.
   45   47     1.4      0.      0.      0.      0.     0.5      0.
0.
   51         0.45      0.      0.      0.      0.     0.5      0.
0.
```

52		1.4	0.	0.	0.	0.	0.5	0.	0.
53	54	0.25	0.	0.	0.	0.	0.7	0.	0.
55		1.4	0.	0.	0.	0.	0.5	0.	0.
56		0.5	0.	0.	0.	0.	0.2	0.	0.
61		0.45	0.	0.	0.	0.	0.5	0.	0.
62		1.4	0.	0.	0.	0.	0.5	0.	0.
63	64	0.25	0.	0.	0.	0.	0.7	0.	0.
65		1.4	0.	0.	0.	0.	0.5	0.	0.
66		0.5	0.	0.	0.	0.	0.2	0.	0.
71		0.45	0.	0.	0.	0.	0.5	0.	0.
72		1.4	0.	0.	0.	0.	0.5	0.	0.
73	74	0.25	0.	0.	0.	0.	0.7	0.	0.
81		0.45	0.	0.	0.	0.	0.5	0.	0.
82		1.4	0.	0.	0.	0.	0.5	0.	0.
83	84	0.25	0.	0.	0.	0.	0.7	0.	0.
86		0.5	0.	0.	0.	0.	0.2	0.	0.
91		0.45	0.	0.	0.	0.	0.5	0.	0.
92		1.4	0.	0.	0.	0.	0.5	0.	0.
93	94	0.25	0.	0.	0.	0.	0.7	0.	0.
95		1.4	0.	0.	0.	0.	0.5	0.	0.
101		0.45	0.	0.	0.	0.	0.5	0.	0.
102		1.4	0.	0.	0.	0.	0.5	0.	0.
103	104	0.25	0.	0.	0.	0.	0.7	0.	0.
105	107	1.4	0.	0.	0.	0.	0.5	0.	0.
111		0.45	0.	0.	0.	0.	0.5	0.	0.
112		1.4	0.	0.	0.	0.	0.5	0.	0.
113	114	0.25	0.	0.	0.	0.	0.7	0.	0.
115	117	1.4	0.	0.	0.	0.	0.5	0.	0.

121		0.45	0.	0.	0.	0.	0.5	0.	0.
122		1.4	0.	0.	0.	0.	0.5	0.	0.
123	124	0.25	0.	0.	0.	0.	0.7	0.	0.
125		1.4	0.	0.	0.	0.	0.5	0.	0.
126		0.5	0.	0.	0.	0.	0.2	0.	0.
131		0.45	0.	0.	0.	0.	0.5	0.	0.
132		1.4	0.	0.	0.	0.	0.5	0.	0.
133	134	0.25	0.	0.	0.	0.	0.7	0.	0.
135		1.4	0.	0.	0.	0.	0.5	0.	0.
136		0.5	0.	0.	0.	0.	0.2	0.	0.
141		0.45	0.	0.	0.	0.	0.5	0.	0.
142		1.4	0.	0.	0.	0.	0.5	0.	0.
143	144	0.25	0.	0.	0.	0.	0.7	0.	0.
145		1.4	0.	0.	0.	0.	0.5	0.	0.
146		0.5	0.	0.	0.	0.	0.2	0.	0.
153	154	0.25	0.	0.	0.	0.	0.7	0.	0.
156		0.5	0.	0.	0.	0.	0.2	0.	0.
161		0.45	0.	0.	0.	0.	0.5	0.	0.
162		1.4	0.	0.	0.	0.	0.5	0.	0.
163	164	0.25	0.	0.	0.	0.	0.7	0.	0.
165	167	1.4	0.	0.	0.	0.	0.5	0.	0.
171		0.45	0.	0.	0.	0.	0.5	0.	0.
172		1.4	0.	0.	0.	0.	0.5	0.	0.
173	174	0.25	0.	0.	0.	0.	0.7	0.	0.
175	177	1.4	0.	0.	0.	0.	0.5	0.	0.
181		0.45	0.	0.	0.	0.	0.5	0.	0.
182		1.4	0.	0.	0.	0.	0.5	0.	0.
183	184	0.25	0.	0.	0.	0.	0.7	0.	0.

```
  186          0.5      0.      0.      0.      0.     0.2      0.
0.
  END QUAL-INPUT


  MON-ACCUM
*** <PLS >  Value at start of each month for accum rate of QUALOF
(lb/ac.day)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11      0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   12       0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
   13     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
   14      0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
   15      0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
   16     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
   17      0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09
   21      0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   22       0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
   23     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
   24      0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
   25      0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
   26     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
   31      0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   32       0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
   33     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
   34      0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
   35      0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
   36     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
   41      0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   42       0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
   43     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
   44      0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
   45      0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
   47      0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09
   51      0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   52       0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
   53     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
   54      0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
   55      0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
   56     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
   61      0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   62       0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
   63     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
   64      0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
   65      0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
   66     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
   71      0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   72       0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
   73     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
   74      0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
   81      0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   82       0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
   83     0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
   84      0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
   86     0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
   91      0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   92       0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
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 93      0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
 94       0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
 95       0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
101       0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.030.015
102        0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
103      0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
104       0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
105       0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
107       0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09
111       0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.030.015
112        0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
113      0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
114       0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
115       0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
117       0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09
121       0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.030.015
122        0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
123      0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
124       0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
125       0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
126      0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
131       0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
132        0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
133      0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
134       0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
135       0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
136      0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
141       0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
142        0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
143      0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
144       0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
145       0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
146      0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
153      0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
154       0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
156      0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
161       0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
162        0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
163      0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
164       0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
165       0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
167       0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09
171       0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
172        0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
173      0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
174       0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
175       0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04 0.04
177       0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09
181       0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
182        0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
183      0.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.0050.005
184       0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
186      0.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.0020.002
END MON-ACCUM

MON-SQOLIM
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```
*** <PLS >  Value at start of month for limiting storage of QUALOF
(lb/ac)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11   17  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
   21   26  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5
   31   36  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
   41  107  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5
  111  117  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1  0.1
  121  186  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5  0.5
  END MON-SQOLIM

  MON-IFLW-CONC
*** <PLS >  Conc of QUAL in interflow outflow for each month (qty/ft3)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11      1.05 1.05 1.05 1.75 1.75 1.75 1.75 1.75 1.75 1.05 1.05 1.05
   12       0.7  0.7  2.1 12.6 13.3 10.5 10.5  8.4  8.4  8.4  3.5  1.4
   13   14 0.42 0.42 0.42 0.28 0.28 0.28 0.28 0.28 0.28 0.56 0.56 0.56
   15       0.7  0.7  2.1 12.6 13.3 10.5 10.5  8.4  8.4  8.4  3.5  1.4
   16      0.35 0.35 0.35 0.21 0.21 0.21 0.21 0.21 0.21 0.49 0.49 0.49
   17       0.7  0.7  2.1 12.6 13.3 10.5 10.5  8.4  8.4  8.4  3.5  1.4
   21      1.05 1.05 1.05 1.75 1.75 1.75 1.75 1.75 1.75 1.05 1.05 1.05
   22       0.7  0.7  2.1 12.6 13.3 10.5 10.5  8.4  8.4  8.4  3.5  1.4

   23   24 0.42 0.42 0.42 0.28 0.28 0.28 0.28 0.28 0.28 0.56 0.56 0.56
   25       0.7  0.7  2.1 12.6 13.3 10.5 10.5  8.4  8.4  8.4  3.5  1.4
   26      0.35 0.35 0.35 0.21 0.21 0.21 0.21 0.21 0.21 0.49 0.49 0.49
   31      1.05 1.05 1.05 1.75 1.75 1.75 1.75 1.75 1.75 1.05 1.05 1.05
   32       0.7  0.7  2.1 12.6 13.3 10.5 10.5  8.4  8.4  8.4  3.5  1.4
   33   34 0.42 0.42 0.42 0.28 0.28 0.28 0.28 0.28 0.28 0.56 0.56 0.56
   35       0.7  0.7  2.1 12.6 13.3 10.5 10.5  8.4  8.4  8.4  3.5  1.4
   36      0.35 0.35 0.35 0.21 0.21 0.21 0.21 0.21 0.21 0.49 0.49 0.49
   41       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
   42        1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
   43   44  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8
   45   47   1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
   51       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
   52        1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
   53   54  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8
   55        1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
   56       0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
   61       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
   62        1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
   63   64  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8
   65        1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
   66       0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
   71       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
   72        1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
   73   74  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8
   81       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
   82        1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
   83   84  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8
   86       0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
   91       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
   92        1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
   93   94  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8

   95        1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
```

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  101        1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  102         1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
  103   104  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8
  105   107   1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
  111        1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  112         1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
  113   114  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8
  115   117   1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
  121        1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  122         1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
  123   124  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8
  125         1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
  126        0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  131        1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  132         1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
  133   134  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8
  135         1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
  136        0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  141        1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  142         1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
  143   144  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8
  145         1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
  146        0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  153   154  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8
  156        0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  161        1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  162         1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
  163   164  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8
  165   167   1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
  171        1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  172         1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.

  173   174  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8
  175   177   1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
  181        1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  182         1.   1.   3.  18.  19.  15.  15.  12.  12.  12.   5.   2.
  183   184  0.6  0.6  0.6  0.4  0.4  0.4  0.4  0.4  0.4  0.8  0.8  0.8
  186        0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  END MON-IFLW-CONC

  MON-GRND-CONC
*** <PLS >  Value at start of month for conc of QUAL in groundwater
(qty/ft3)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11       2.25 2.25 2.25 3.75 3.75 3.75 3.75 3.75 3.75 2.25 2.25 2.25
   12       0.75 0.75  1.5   9.   9.  7.5  7.5 5.25 5.25 5.25   3.1.125
   13    14 0.75 0.75 0.75 0.45 0.45 0.45 0.45 0.45 0.45 1.05 1.05 1.05
   15      0.0380.0380.075 0.45 0.450.3750.3750.2630.2630.263 0.150.057
   16       0.75 0.75 0.75 0.45 0.45 0.45 0.45 0.45 0.45 1.05 1.05 1.05
   17      0.0630.0940.1881.1251.1250.9380.9380.6560.6560.6560.3750.143
   21         3.   3.   3.   5.   5.   5.   5.   5.   5.   3.   3.   3.
   22         1.   1.   2.  12.  12.  10.  10.   7.   7.   7.   4.  1.5
   23    24   1.   1.   1.  0.6  0.6  0.6  0.6  0.6  0.6  1.4  1.4  1.4
   25       0.05 0.05  0.1  0.6  0.6  0.5  0.5 0.35 0.35 0.35  0.20.076
   26         1.   1.   1.  0.6  0.6  0.6  0.6  0.6  0.6  1.4  1.4  1.4
   31         3.   3.   3.   5.   5.   5.   5.   5.   5.   3.   3.   3.
   32         1.   1.   2.  12.  12.  10.  10.   7.   7.   7.   4.  1.5
```

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   33   34   1.   1.   1.  0.6  0.6  0.6  0.6  0.6  0.6  1.4  1.4  1.4
   35      0.05 0.05  0.1  0.6  0.6  0.5  0.5 0.35 0.35 0.35  0.20.076
   36        1.   1.   1.  0.6  0.6  0.6  0.6  0.6  0.6  1.4  1.4  1.4
   41       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
   42       0.5  0.5   1.   6.   6.   5.   5.  3.5  3.5  3.5   2. 0.75
   43   44  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
   45     0.0250.025 0.05  0.3  0.3 0.25 0.250.1750.1750.175  0.10.038
   47     .0417.0417.0833  0.5  0.5.4167.4167.2917.2917.2917.1667.0633
   51       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
   52       0.5  0.5   1.   6.   6.   5.   5.  3.5  3.5  3.5   2. 0.75
   53   54  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
   55     0.0250.025 0.05  0.3  0.3 0.25 0.250.1750.1750.175  0.10.038
   56       0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
   61       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
   62       0.5  0.5   1.   6.   6.   5.   5.  3.5  3.5  3.5   2. 0.75
   63   64  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
   65     0.0250.025 0.05  0.3  0.3 0.25 0.250.1750.1750.175  0.10.038
   66       0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
   71       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
   72       0.5  0.5   1.   6.   6.   5.   5.  3.5  3.5  3.5   2. 0.75
   73   74  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
   81       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
   82       0.5  0.5   1.   6.   6.   5.   5.  3.5  3.5  3.5   2. 0.75
   83   86  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
   91       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
   92       0.5  0.5   1.   6.   6.   5.   5.  3.5  3.5  3.5   2. 0.75
   93   94  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
   95     0.0250.025 0.05  0.3  0.3 0.25 0.250.1750.1750.175  0.10.038
  101       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  102       0.5  0.5   1.   6.   6.   5.   5.  3.5  3.5  3.5   2. 0.75
  103  104  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  105     0.0250.025 0.05  0.3  0.3 0.25 0.250.1750.1750.175  0.10.038
  107     .0417.0417.0833  0.5  0.5.4167.4167.2917.2917.2917.1667.0633
  111       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  112       0.5  0.5   1.   6.   6.   5.   5.  3.5  3.5  3.5   2. 0.75
  113  114  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  115     0.0250.025 0.05  0.3  0.3 0.25 0.250.1750.1750.175  0.10.038
  117     .0417.0417.0833  0.5  0.5.4167.4167.2917.2917.2917.1667.0633
  121       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  122       0.5  0.5   1.   6.   6.   5.   5.  3.5  3.5  3.5   2. 0.75
  123  124  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  125     0.0250.025 0.05  0.3  0.3 0.25 0.250.1750.1750.175  0.10.038
  126       0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  131       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  132       0.5  0.5   1.   6.   6.   5.   5.  3.5  3.5  3.5   2. 0.75
  133  134  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  135     0.0250.025 0.05  0.3  0.3 0.25 0.250.1750.1750.175  0.10.038
  136       0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  141       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  142       0.5  0.5   1.   6.   6.   5.   5.  3.5  3.5  3.5   2. 0.75
  143  144  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  145     0.0250.025 0.05  0.3  0.3 0.25 0.250.1750.1750.175  0.10.038
  146  156  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  161       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  162       0.5  0.5   1.   6.   6.   5.   5.  3.5  3.5  3.5   2. 0.75
  163  164  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  165     0.0250.025 0.05  0.3  0.3 0.25 0.250.1750.1750.175  0.10.038
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  167     .0417.0417.0833  0.5  0.5.4167.4167.2917.2917.2917.1667.0633
  171       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  172       0.5  0.5   1.   6.   6.   5.   5.  3.5  3.5  3.5   2. 0.75
  173  174  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  175     0.0250.025 0.05  0.3  0.3 0.25 0.250.1750.1750.175  0.10.038
  177     .0417.0417.0833  0.5  0.5.4167.4167.2917.2917.2917.1667.0633
  181       1.5  1.5  1.5  2.5  2.5  2.5  2.5  2.5  2.5  1.5  1.5  1.5
  182       0.5  0.5   1.   6.   6.   5.   5.  3.5  3.5  3.5   2. 0.75
  183  186  0.5  0.5  0.5  0.3  0.3  0.3  0.3  0.3  0.3  0.7  0.7  0.7
  END MON-GRND-CONC

  QUAL-PROPS
*** <PLS >  Identifiers and Flags
*** x -  x    QUALID      QTID  QSD VPFW VPFS  QSO  VQO QIFW VIQC QAGW
VAQC
   11  186ORTHO P         LBS     1    2    0    0    0    1    3    1
3
  END QUAL-PROPS

  QUAL-INPUT
***         Storage on surface and nonseasonal parameters
***            SQO   POTFW   POTFS   ACQOP  SQOLIM   WSQOP    IOQC
AOQC
*** <PLS >  qty/ac qty/ton qty/ton    qty/  qty/ac   in/hr qty/ft3
qty/ft3
*** x -  x                          ac.day
   11          0.04      0.       0.      0.      0.     0.6      0.
0.
   12          0.38      0.       0.      0.      0.     0.5      0.
0.
   13   14   0.017      0.       0.      0.      0.     0.7      0.
0.
   15          0.38      0.       0.      0.      0.     0.5      0.
0.
   16          0.04      0.       0.      0.      0.     0.2      0.
0.
   17          0.38      0.       0.      0.      0.     0.5      0.
0.
   21          0.04      0.       0.      0.      0.     0.6      0.
0.
   22          0.38      0.       0.      0.      0.     0.5      0.
0.
   23   24   0.017      0.       0.      0.      0.     0.7      0.
0.
   25          0.38      0.       0.      0.      0.     0.5      0.
0.
   26          0.04      0.       0.      0.      0.     0.2      0.
0.
   31          0.04      0.       0.      0.      0.     0.6      0.
0.
   32          0.38      0.       0.      0.      0.     0.5      0.
0.
   33   34   0.017      0.       0.      0.      0.     0.7      0.
0.
   35          0.38      0.       0.      0.      0.     0.5      0.
0.
```

36		0.04	0.	0.	0.	0.	0.2	0.	0.
41		0.04	0.	0.	0.	0.	0.6	0.	0.
42		0.38	0.	0.	0.	0.	0.5	0.	0.
43	44	0.017	0.	0.	0.	0.	0.7	0.	0.
45	47	0.38	0.	0.	0.	0.	0.5	0.	0.
51		0.04	0.	0.	0.	0.	0.6	0.	0.
52		0.38	0.	0.	0.	0.	0.5	0.	0.
53	54	0.017	0.	0.	0.	0.	0.7	0.	0.
55		0.38	0.	0.	0.	0.	0.5	0.	0.
56		0.04	0.	0.	0.	0.	0.2	0.	0.
61		0.04	0.	0.	0.	0.	0.6	0.	0.
62		0.38	0.	0.	0.	0.	0.5	0.	0.
63	64	0.017	0.	0.	0.	0.	0.7	0.	0.
65		0.38	0.	0.	0.	0.	0.5	0.	0.
66		0.04	0.	0.	0.	0.	0.2	0.	0.
71		0.04	0.	0.	0.	0.	0.6	0.	0.
72		0.38	0.	0.	0.	0.	0.5	0.	0.
73	74	0.017	0.	0.	0.	0.	0.7	0.	0.
81		0.04	0.	0.	0.	0.	0.6	0.	0.
82		0.38	0.	0.	0.	0.	0.5	0.	0.
83	84	0.017	0.	0.	0.	0.	0.7	0.	0.
86		0.04	0.	0.	0.	0.	0.2	0.	0.
91		0.04	0.	0.	0.	0.	0.6	0.	0.
92		0.38	0.	0.	0.	0.	0.5	0.	0.
93	94	0.017	0.	0.	0.	0.	0.7	0.	0.
95		0.38	0.	0.	0.	0.	0.5	0.	0.
101		0.04	0.	0.	0.	0.	0.6	0.	0.
102		0.38	0.	0.	0.	0.	0.5	0.	0.

103	104	0.017	0.	0.	0.	0.	0.7	0.	0.
105	107	0.38	0.	0.	0.	0.	0.5	0.	0.
111		0.04	0.	0.	0.	0.	0.6	0.	0.
112		0.38	0.	0.	0.	0.	0.5	0.	0.
113	114	0.017	0.	0.	0.	0.	0.7	0.	0.
115	117	0.38	0.	0.	0.	0.	0.5	0.	0.
121		0.04	0.	0.	0.	0.	0.6	0.	0.
122		0.38	0.	0.	0.	0.	0.5	0.	0.
123	124	0.017	0.	0.	0.	0.	0.7	0.	0.
125		0.38	0.	0.	0.	0.	0.5	0.	0.
126		0.04	0.	0.	0.	0.	0.2	0.	0.
131		0.04	0.	0.	0.	0.	0.6	0.	0.
132		0.38	0.	0.	0.	0.	0.5	0.	0.
133	134	0.017	0.	0.	0.	0.	0.7	0.	0.
135		0.38	0.	0.	0.	0.	0.5	0.	0.
136		0.04	0.	0.	0.	0.	0.2	0.	0.
141		0.04	0.	0.	0.	0.	0.6	0.	0.
142		0.38	0.	0.	0.	0.	0.5	0.	0.
143	144	0.017	0.	0.	0.	0.	0.7	0.	0.
145		0.38	0.	0.	0.	0.	0.5	0.	0.
146		0.04	0.	0.	0.	0.	0.2	0.	0.
153	154	0.017	0.	0.	0.	0.	0.7	0.	0.
156		0.04	0.	0.	0.	0.	0.2	0.	0.
161		0.04	0.	0.	0.	0.	0.6	0.	0.
162		0.38	0.	0.	0.	0.	0.5	0.	0.
163	164	0.017	0.	0.	0.	0.	0.7	0.	0.
165	167	0.38	0.	0.	0.	0.	0.5	0.	0.
171		0.04	0.	0.	0.	0.	0.6	0.	0.

```
  172          0.38      0.       0.       0.       0.      0.5       0.
0.
  173  174   0.017      0.       0.       0.       0.      0.7       0.
0.
  175  177    0.38      0.       0.       0.       0.      0.5       0.
0.
  181          0.04      0.       0.       0.       0.      0.6       0.
0.
  182          0.38      0.       0.       0.       0.      0.5       0.
0.
  183  184   0.017      0.       0.       0.       0.      0.7       0.
0.
  186          0.04      0.       0.       0.       0.      0.2       0.
0.
  END QUAL-INPUT

  MON-POTFW
*** <PLS >  Value at start of each month for washoff potency factor
(lb/ton)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11     0.4950.4950.4950.4950.4950.4950.4950.4950.4950.4950.4950.495
   12     0.2460.2460.2460.2460.2460.2460.2460.2460.2460.2460.2460.246
   13     0.0180.0180.0180.0180.0180.0180.0180.0180.0180.0180.0180.018
   14     0.0450.0450.0450.0450.0450.0450.0450.0450.0450.0450.0450.045
   15      0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
   16     0.0450.0450.0450.0450.0450.0450.0450.0450.0450.0450.0450.045
   17      0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18
   21      0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33 0.33
   22     0.1640.1640.1640.1640.1640.1640.1640.1640.1640.1640.1640.164
   23     0.0120.0120.0120.0120.0120.0120.0120.0120.0120.0120.0120.012
   24      0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   25      0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
   26      0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   31      0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99 0.99
   32     0.4920.4920.4920.4920.4920.4920.4920.4920.4920.4920.4920.492
   33     0.0360.0360.0360.0360.0360.0360.0360.0360.0360.0360.0360.036
   34      0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09
   35      0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
   36      0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09 0.09
   41      1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65
   42      0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82
   43      0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06
   44      0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
   45      0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
   47       0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
   51      1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65
   52      0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82
   53      0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06
   54      0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
   55      0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
   56      0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
   61      1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65
   62      0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82
   63      0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06
   64      0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
   65      0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05 0.05
   66      0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
```

71		1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
72		0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
73		0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
74		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
81		1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
82		0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
83		0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
84	86	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
91		1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
92		0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
93		0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
94		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
95		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
101		1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
102		0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
103		0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
104		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
105		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
107		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
111		1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
112		0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
113		0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
114		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
115		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
117		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
121		1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
122		0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
123		0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
124		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
125		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
126		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
131		1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
132		0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246
133		0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
134		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
135		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
136		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
141		1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
142		0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246	0.246
143		0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
144		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
145		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
146		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
153		0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
154	156	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
161		1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
162		0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
163		0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
164		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
165		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
167		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
171		1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65	1.65
172		0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82	0.82
173		0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06
174		0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
175		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
177		0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6

```
  181       1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65 1.65
  182       0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82 0.82
  183       0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06 0.06
  184  186 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
  END MON-POTFW


  MON-IFLW-CONC
*** <PLS >  Conc of QUAL in interflow outflow for each month (qty/ft3)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
    11      0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
    12       0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
    13   140.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
    15       0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
    16     0.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
    17       0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
    21     0.7810.7810.7811.8811.8811.8811.8811.8810.7810.7810.781
    22     1.5731.5731.8813.7623.7623.1353.135  2.2  2.2  2.21.2540.473
    23   240.3190.3190.3190.1870.1870.1870.1870.1870.187 0.44 0.44 0.44
    25     0.1540.1540.3191.8811.8811.5731.573  1.1  1.1  1.10.6270.242
    26     0.3190.3190.3190.1870.1870.1870.1870.1870.187 0.44 0.44 0.44
    31     0.7810.7810.7811.8811.8811.8811.8811.8810.7810.7810.781
    32     0.3190.3190.6273.7623.7623.1353.135  2.2  2.2  2.21.2540.473
    33   340.3190.3190.3190.1870.1870.1870.1870.1870.187 0.44 0.44 0.44
    35     0.1540.1540.3191.8811.8811.5731.573  1.1  1.1  1.10.6270.242
    36     0.3190.3190.3190.1870.1870.1870.1870.1870.187 0.44 0.44 0.44
    41      0.75 0.75 0.75  1.8  1.8  1.8  1.8  1.8  1.8 0.75 0.75 0.75
    42       1.5  1.5  1.8  3.6  3.6   3.   3.  2.1  2.1  2.1  1.2 0.45
    43   44  0.3  0.3  0.3 0.18 0.18 0.18 0.18 0.18 0.18 0.42 0.42 0.42
    45      0.15 0.15  0.3  1.8  1.8  1.5  1.5 1.05 1.05 1.05  0.6 0.23
    47      0.22 0.22 0.22 0.22 0.22 0.22 0.22 0.22 0.22 0.22 0.22 0.22
    51      0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15

    52       0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
    53   540.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
    55       0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
    56     0.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
    61      0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
    62       0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
    63   640.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
    65       0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
    66     0.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
    71      0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
    72       0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
    73   740.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
    81      0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
    82       0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
    83   860.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
    91      0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
    92       0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
    93   940.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
    95       0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
  101         6.   6.   6.   6.   6.   6.   6.   6.   6.   6.   6.   6.
  102        0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
  103  1040.0540.0540.0540.0540.0540.0540.0540.0540.0540.0540.0540.054
  105  107  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6  0.6
  111       0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
```

```
  112        0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
  113   1140.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
  115   117  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
  121       0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
  122        0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
  123   1240.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
  125        0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
  126      0.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027

  131       0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
  132        0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
  133   1340.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
  135        0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
  136      0.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
  141       0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
  142        0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
  143   1440.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
  145        0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
  146   1560.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
  161      0.0540.0540.0090.0540.0540.0540.0540.0540.0090.1080.0540.009
  162      0.1070.1070.0180.1070.1070.1070.1070.1070.0180.2140.1070.018
  163   164 0.01 0.010.002 0.01 0.01 0.01 0.01 0.010.002 0.02 0.010.002
  165   1670.1070.1070.0180.1070.1070.1070.1070.1070.0180.2140.1070.018
  171      0.0540.0540.0090.0540.0540.0540.0540.0540.0090.1080.0540.009
  172      0.1070.1070.0180.1070.1070.1070.1070.1070.0180.2140.1070.018
  173   174 0.01 0.010.002 0.01 0.01 0.01 0.01 0.010.002 0.02 0.010.002
  175   1770.1070.1070.0180.1070.1070.1070.1070.1070.0180.2140.1070.018
  181       0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15 0.15
  182        0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
  183   1860.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.0270.027
  END MON-IFLW-CONC

  MON-GRND-CONC
*** <PLS >  Value at start of month for conc of QUAL in groundwater
(qty/ft3)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11       0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18 0.18
   12        0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
   13    14 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   15        0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
   16       0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   17        0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3  0.3
   21        0.2  0.2  0.2  0.3  0.3  0.3  0.3  0.3  0.3  0.2  0.2  0.2
   22        0.3  0.3  0.6  3.6  3.6   3.   3.  2.1  2.1  2.1  1.2 0.45
   23       0.03 0.03 0.030.0180.0180.0180.0180.0180.0180.0420.0420.042
   24        0.3  0.3  0.3 0.18 0.18 0.18 0.18 0.18 0.18 0.42 0.42 0.42
   25       0.15 0.15  0.3  1.8  1.8  1.5  1.5 1.05 1.05 1.05  0.60.228
   26       0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   31        0.2  0.2  0.2  0.3  0.3  0.3  0.3  0.3  0.3  0.2  0.2  0.2
   32        0.3  0.3  0.6  3.6  3.6   3.   3.  2.1  2.1  2.1  1.2 0.45
   33       0.03 0.03 0.030.0180.0180.0180.0180.0180.0180.0420.0420.042
   34        0.3  0.3  0.3 0.18 0.18 0.18 0.18 0.18 0.18 0.42 0.42 0.42
   35       0.15 0.15  0.3  1.8  1.8  1.5  1.5 1.05 1.05 1.05  0.60.228
   36       0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03 0.03
   41        0.2  0.2  0.2  0.3  0.3  0.3  0.3  0.3  0.3  0.2  0.2  0.2
   42        0.3  0.3  0.6  3.6  3.6   3.   3.  2.1  2.1  2.1  1.2 0.45
   43       0.03 0.03 0.030.0180.0180.0180.0180.0180.0180.0420.0420.042
```

44		0.3	0.3	0.3	0.18	0.18	0.18	0.18	0.18	0.18	0.42	0.42	0.42
45		0.15	0.15	0.3	1.8	1.8	1.5	1.5	1.05	1.05	1.05	0.6	0.228
47		0.25	0.25	0.5	3.	3.	2.5	2.5	1.75	1.75	1.75	1.	0.38
51		0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
52		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
53	54	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
55		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
56		0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
61		0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
62		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
63	64	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
65		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
66		0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
71		0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
72		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
73	74	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
81		0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
82		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
83	86	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
91		0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
92		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
93	94	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
95		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
101		0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
102		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
103	104	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
105	107	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
111		0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072	0.072
112		0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
113	114	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012	0.012
115	117	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12	0.12
121		0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
122		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
123	124	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
125		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
126		0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
131		0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
132		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
133	134	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
135		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
136		0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
141		0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
142		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
143	144	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
145		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
146	156	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03
161		0.15	0.15	0.06	0.15	0.15	0.15	0.15	0.15	0.06	0.2	0.15	0.06
162		0.26	0.26	0.104	0.26	0.26	0.26	0.26	0.26	0.104	0.34	0.26	0.104
163	164	0.03	0.03	0.012	0.03	0.03	0.03	0.03	0.03	0.012	0.04	0.03	0.012
165	167	0.26	0.26	0.104	0.26	0.26	0.26	0.26	0.26	0.104	0.34	0.26	0.104
171		0.15	0.15	0.06	0.15	0.15	0.15	0.15	0.15	0.06	0.2	0.15	0.06
172		0.26	0.26	0.104	0.26	0.26	0.26	0.26	0.26	0.104	0.34	0.26	0.104
173	174	0.03	0.03	0.012	0.03	0.03	0.03	0.03	0.03	0.012	0.04	0.03	0.012
175	177	0.26	0.26	0.104	0.26	0.26	0.26	0.26	0.26	0.104	0.34	0.26	0.104
181		0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18	0.18
182		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
183	186	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03

```
  END MON-GRND-CONC

END PERLND

IMPLND
  ACTIVITY
*** <ILS >               Active Sections
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL
   11  181    1    0    1    1    1    1
  END ACTIVITY

  PRINT-INFO
*** <ILS > ******** Print-flags ******** PIVL  PYR
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL *********
   11  181    4    4    4    4    4    4    1    9
  END PRINT-INFO

  BINARY-INFO
*** <ILS > **** Binary-Output-flags **** PIVL  PYR
*** x -  x ATMP SNOW IWAT  SLD  IWG IQAL *********
   11  181    4    4    4    4    4    4    1    9
  END BINARY-INFO

  GEN-INFO
***             Name             Unit-systems   Printer BinaryOut
*** <ILS >                           t-series Engl Metr Engl Metr
*** x -  x                            in  out
   11  181Urban or Built-up La         1    1    0    0   92    0
  END GEN-INFO

  ATEMP-DAT
*** <ILS >     ELDAT    AIRTEMP
*** x -  x      (ft)    (deg F)
   11  181        0.       33.
  END ATEMP-DAT

  IWAT-PARM1
*** <ILS >        Flags
*** x -  x CSNO RTOP  VRS  VNN RTLI
   11  181    0    0    0    0    0
  END IWAT-PARM1

  IWAT-PARM2
*** <ILS >      LSUR     SLSUR      NSUR     RETSC
*** x -  x      (ft)                          (in)
   11           150.    0.3323      0.05       0.1
   21           150.    0.3556      0.05       0.1
   31           150.     0.389      0.05       0.1
   41           150.    0.3755      0.05       0.1
   51           150.    0.2831      0.05       0.1
   61           150.    0.3713      0.05       0.1
   71           150.    0.3207      0.05       0.1
   81           150.    0.4541      0.05       0.1
   91           150.    0.3177      0.05       0.1
  101           150.    0.4465      0.05       0.1
  111           150.    0.3519      0.05       0.1
  121           150.    0.3594      0.05       0.1
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  131           150.    0.4943      0.05       0.1
  141           150.    0.3806      0.05       0.1
  161           150.    0.3544      0.05       0.1
  171           150.    0.3426      0.05       0.1
  181           150.    0.3906      0.05       0.1
  END IWAT-PARM2

  IWAT-PARM3
*** <ILS >    PETMAX    PETMIN
*** x -  x   (deg F)   (deg F)
   11  181       40.       35.
  END IWAT-PARM3

  IWAT-STATE1
*** <ILS >  IWATER state variables (inches)
*** x -  x      RETS      SURS
   11  181      0.01      0.01
  END IWAT-STATE1

  SLD-PARM1
*** <ILS >     Flags
*** x -  x VASD VRSD SDOP
   11  181    0    0    1
  END SLD-PARM1

  SLD-PARM2
***             KEIM      JEIM    ACCSDP    REMSDP
*** <ILS >                         tons/      /day
*** x -  x                        ac.day
   11             2.        2.    0.0044      0.03
   21   31       0.1        2.    0.0044      0.03
   41   51      0.15        1.        2.       0.4
   61            0.1        1.    0.0044      0.03
   71           0.15        1.    0.0044      0.03
   81            0.1        1.        1.       0.4
   91            0.5        1.        2.       0.4
  101           0.01        1.        2.      0.03
  111           0.01        1.        1.      0.03
  121           0.01        1.        1.       0.4
  131  141       0.1        2.    0.0044      0.03
  161             1.        1.      0.01       0.4
  171  181       0.1        2.    0.0044      0.03
  END SLD-PARM2

  SLD-STOR
*** <ILS >  Solids storage (tons/acre)
*** x -  x
   11  181      0.01
  END SLD-STOR

  IWT-PARM1
*** <ILS >  Flags for section IWTGAS
*** x -  x WTFV CSNO
   11  181    0    0
  END IWT-PARM1

  IWT-PARM2
```

```
***         Second group of IWTGAS parms
*** <ILS >       ELEV      AWTF      BWTF
*** x -  x       (ft)   (deg F) (deg F/F)
   11  181      120.       34.       0.3
  END IWT-PARM2

  MON-AWTF
*** <ILS >  Value of AWTF at start of each month (deg F)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11  181  29.  29.  30.  34.  54.  63.  65.  64.  60.  48.  35.  30.
  END MON-AWTF

  MON-BWTF
*** <ILS >  Value of BWTF at start of each month (deg F/F)
*** x -  x  JAN  FEB  MAR  APR  MAY  JUN  JUL  AUG  SEP  OCT  NOV  DEC
   11  181 0.55 0.55 0.65 0.75  0.9  1.1  1.2  1.1   1. 0.65 0.65  0.6
  END MON-BWTF

  NQUALS
*** <ILS >
*** x -  xNQUAL
   11  181    3
  END NQUALS

  QUAL-PROPS
*** <ILS >    Identifiers and Flags
*** x -  x      QUALID    QTID  QSD VPFW  QSO  VQO
   11  181NH3+NH4         LBS     0    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
***         Storage on surface and nonseasonal parameters
***            SQO   POTFW   ACQOP  SQOLIM   WSQOP
*** <ILS >  qty/ac qty/ton    qty/  qty/ac   in/hr
*** x -  x                  ac.day
   11  181  0.0297      0.  0.0038  0.0756     0.5
  END QUAL-INPUT

  QUAL-PROPS
*** <ILS >    Identifiers and Flags
*** x -  x      QUALID    QTID  QSD VPFW  QSO  VQO
   11  181NO3             LBS     0    0    1    0
  END QUAL-PROPS

  QUAL-INPUT
***         Storage on surface and nonseasonal parameters
***            SQO   POTFW   ACQOP  SQOLIM   WSQOP
*** <ILS >  qty/ac qty/ton    qty/  qty/ac   in/hr
*** x -  x                  ac.day
   11  181     0.4      0.  0.0415  0.2668     0.5
  END QUAL-INPUT

  QUAL-PROPS
*** <ILS >    Identifiers and Flags
*** x -  x      QUALID    QTID  QSD VPFW  QSO  VQO
   11  181ORTHO P         LBS     0    0    1    0
  END QUAL-PROPS
```

```
  QUAL-INPUT
***         Storage on surface and nonseasonal parameters
***            SQO   POTFW   ACQOP  SQOLIM   WSQOP
*** <ILS >  qty/ac qty/ton    qty/  qty/ac   in/hr
*** x -  x                  ac.day
   11  181    0.05      0.  0.0034  0.0163     0.5
  END QUAL-INPUT

END IMPLND

RCHRES
  ACTIVITY
*** RCHRES  Active sections
*** x -  x HYFG ADFG CNFG HTFG SDFG GQFG OXFG NUFG PKFG PHFG
    1   18    1    1    0    1    1    0    1    1    0    0
  END ACTIVITY

  PRINT-INFO
*** RCHRES  Printout level flags
*** x -  x HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB PIVL  PYR
    1   18    4    4    4    4    4    4    4    4    4    4    1    9
  END PRINT-INFO

  BINARY-INFO
*** RCHRES  Binary Output level flags
*** x -  x HYDR ADCA CONS HEAT  SED  GQL OXRX NUTR PLNK PHCB PIVL  PYR
    1   18    4    4    4    4    4    4    4    4    4    4    1    9
  END BINARY-INFO

  GEN-INFO
***              Name        Nexits   Unit Systems   Printer
*** RCHRES                               t-series  Engl Metr LKFG
*** x -  x                                 in  out
    1     ARECIBO                 1         1    1   91    0    0   92
0
    2     ARECIBO                 1         1    1   91    0    1   92
0
    3    5ARECIBO                 1         1    1   91    0    0   92
0
    6     ARECIBO                 1         1    1   91    0    1   92
0
    7     VIVI HP                 1         1    1   91    0    0   92
0
    8     VIVI                    1         1    1   91    0    1   92
0
    9     VIVI                    1         1    1   91    0    0   92
0
   10     SALIENTE                1         1    1   91    0    0   92
0
   11     CAONILLAS               1         1    1   91    0    0   92
0
   12     CAONILLAS LAGO          1         1    1   91    0    1   92
0
   13     CAONILLAS TUNNEL        1         1    1   91    0    0   92
0
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   14     CAONILLAS              1         1    1   91    0    0   92
0
   15     LAGO                   1         1    1   91    0    0   92
0
   16     YUNES                  1         1    1   91    0    0   92
0
   17   18LIMON                  1         1    1   91    0    0   92
0
  END GEN-INFO

  HYDR-PARM1
***         Flags for HYDR section
***RC HRES  VC A1 A2 A3  ODFVFG for each *** ODGTFG for each     FUNCT
for each
*** x  - x  FG FG FG FG  possible   exit *** possible   exit
possible   exit
    1   18   0  1  1  1    4  0  0  0  0       0  0  0  0  0       1  1
1  1  1
  END HYDR-PARM1

  HYDR-PARM2
*** RCHRES FTBW FTBU       LEN     DELTH     STCOR        KS       DB50
*** x -  x             (miles)      (ft)      (ft)                 (in)
    1        0.   1.       6.2     1397.       3.2       0.5       0.01
    2        0.   2.      1.49      208.       3.2       0.5       0.01
    3        0.   3.      5.47      720.       3.2       0.5       0.01
    4        0.   4.       3.1       88.       3.2       0.5       0.01
    5        0.   5.      2.84      122.       3.2       0.5       0.01
    6        0.   6.      5.18       14.       3.2       0.5       0.01
    7        0.   7.      3.18      839.       3.2       0.5       0.01
    8        0.   8.       4.1      667.       3.2       0.5       0.01
    9        0.   9.      5.45      620.       3.2       0.5       0.01
   10        0.  10.      5.59     1926.       3.2       0.5       0.01
   11        0.  11.      9.78      718.       3.2       0.5       0.01
   12        0.  12.      5.08      142.       3.2       0.5       0.01
   13        0.  13.      3.37      548.       3.2       0.5       0.01
   14        0.  14.       2.2        0.       3.2       0.5       0.01
   15        0.  15.      1.32        0.       3.2       0.5       0.01
   16        0.  16.      9.35     1875.       3.2       0.5       0.01
   17        0.  17.        3.      148.       3.2       0.5       0.01
   18        0.  18.      2.57       22.       3.2       0.5       0.01
  END HYDR-PARM2

  HYDR-INIT
***         Initial conditions for HYDR section
***RC HRES       VOL  CAT Initial value  of COLIND     initial  value
of OUTDGT
*** x  - x     ac-ft      for each possible   exit  for each possible
exit,ft3
    1   18      0.01       4.2  4.5  4.5  4.5  4.2       2.1  1.2  0.5
1.2  1.8
  END HYDR-INIT

  HT-BED-FLAGS
*** RCHRES Bed Heat Conductance Flags
*** x -  x BDFG TGFG TSTP
    1   18    1    3   55
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  END HT-BED-FLAGS

  HEAT-PARM
*** RCHRES      ELEV     ELDAT    CFSAEX    KATRAD     KCOND     KEVAP
*** x -  x      (ft)      (ft)
    1           123.        2.       0.7       14.      6.12        1.
    2          1449.    1419.5       0.7       14.      6.12        1.
    3    5      123.        2.       0.7       14.      6.12        1.
    6          295.3     265.8       0.7       14.      6.12        1.
    7   10      123.        2.       0.7       14.      6.12        1.
   11          964.6     935.1       0.7       14.      6.12        1.
   12   16      123.        2.       0.7       14.      6.12        1.
   17          328.1     298.6       0.7       14.      6.12        1.
   18           123.        2.       0.7       14.      6.12        1.
  END HEAT-PARM

  HT-BED-PARM
***         Bed Heat Conduction Parameters for Single and Two-layer
Methods
*** RCHRES    MUDDEP     TGRND      KMUD     KGRND
*** x -  x      (ft)   (deg F)      (kcal/m2/C/hr)
    1   18      0.33       59.       30.       1.4
  END HT-BED-PARM

  MON-HT-TGRND
*** RCHRES  Monthly values of ground temperatures (deg F)
*** x -  x  TG1  TG2  TG3  TG4  TG5  TG6  TG7  TG8  TG9 TG10 TG11 TG12
    1   18  65.  68.  72.  75.  78.  80.  85.  88.  80.  78.  75.  72.
  END MON-HT-TGRND

  HEAT-INIT
*** RCHRES        TW    AIRTMP
*** x -  x   (deg F)   (deg F)
    1   18       85.       85.
  END HEAT-INIT

  SANDFG
*** RCHRES
*** x -  x SNDFG
    1   18    3
  END SANDFG

  SED-GENPARM
*** RCHRES    BEDWID    BEDWRN       POR
*** x -  x      (ft)      (ft)
    1    3       33.      250.       0.5
    4           300.      250.       0.5
    5           500.      250.       0.5
    6           120.     1000.       0.5
    7            16.      100.       0.5
    8    9       16.      250.       0.5
   10   11       33.      300.       0.4
   12           592.      200.       0.3
   13   18       16.      100.       0.5
  END SED-GENPARM

  SAND-PM
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```
*** RCHRES          D          W        RHO      KSAND     EXPSND
*** x -  x       (in)  (in/sec)  (gm/cm3)
    1           0.014       1.42         4.         5.         2.
    2           0.014       1.42       2.65      0.002         1.
    3           0.014       1.42       2.65        0.1       3.92
    4    5      0.014       1.42       2.65         6.         8.
    6           0.014       1.42       2.65      0.001         1.
    7           0.014       1.42       2.65        0.1       3.92
    8           0.014       1.42       2.65      0.001         1.
    9           0.014       1.42       2.65         2.         2.
   10   11      0.014        1.4        2.6         5.       11.7
   12           0.014         2.        2.6         0.         0.
   13           0.014       1.42       2.65         1.         2.
   14           0.014       1.42       2.65         2.         4.
   15           0.014       1.42       2.65         5.         8.
   16   17      0.014       1.42       2.65         5.         3.
   18           0.014       1.42       2.65         2.         2.
  END SAND-PM

  SILT-CLAY-PM
*** RCHRES          D          W        RHO      TAUCD      TAUCS          M
*** x -  x       (in)  (in/sec)     gm/cm3     lb/ft2     lb/ft2   lb/ft2.d
    1          0.0005      0.006        2.2         1.        4.5        0.1
    2          0.0006      0.007        2.5        0.1       0.16      0.001
    3          0.0006      0.007        2.5        0.1         4.         1.
    4          0.0006      0.007        2.5       0.05        1.5        0.1
    5          0.0006      0.007        2.5       0.05        1.5         1.
    6          0.0006      0.007        2.5     0.0001     0.0002     0.0001
    7          0.0006      0.007        2.5         1.        1.5      0.001
    8          0.0006      0.007        2.5     0.0001     0.0002      0.001
    9          0.0006      0.007        2.5       0.05        1.5        0.1
   10          0.0006      0.006        2.2         1.        1.5     0.0001
   11          0.0006      0.006        2.2         1.        1.5      0.001
   12          0.0006      0.007        2.2     0.0002      0.003      0.001
   13          0.0006      0.007        2.5         4.         6.       0.01
   14   15     0.0006      0.007        2.5        0.1        0.3        0.9
   16          0.0006      0.008        2.7        0.8        1.2      0.001
   17          0.0006      0.007        2.5        0.2        0.8       0.01
   18          0.0006      0.007        2.5        0.4        0.8      0.001
  END SILT-CLAY-PM

  SILT-CLAY-PM
*** RCHRES          D          W        RHO      TAUCD      TAUCS          M
*** x -  x       (in)  (in/sec)     gm/cm3     lb/ft2     lb/ft2   lb/ft2.d
    1         0.00005     0.0004        2.5         1.        4.5        0.1
    2        0.000055     0.0004        2.7        0.1       0.16     0.0001
    3        0.000055     0.0004        2.7        0.1         4.         1.
    4        0.000055     0.0004        2.7       0.05        1.5        0.1
    5        0.000055     0.0004        2.7       0.05        1.5         1.
    6        0.000055     0.0004        2.7     0.0001     0.0002    0.00001
    7        0.000055     0.0004        2.7         1.        1.5      0.001
    8        0.000055     0.0004        2.7     0.0001     0.0002      0.001
    9        0.000055     0.0004        2.7       0.05        1.5        0.1
   10        0.000055     0.0003        2.2         1.        1.5     0.0001
   11        0.000055     0.0003        2.2         1.        1.5      0.001
   12        0.000055     0.0004        2.2     0.0001     0.0002    0.00001
   13   15   0.000055     0.0004        2.7        0.1        0.3        0.9
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  16       0.000055    0.0005        2.7       0.8       1.1     0.001
  17       0.000055    0.0004        2.5       0.2       0.8      0.01
  18       0.000055    0.0004        2.5       0.4       0.8      0.01
  END SILT-CLAY-PM

  SSED-INIT
*** RCHRES     Suspended sed concs (mg/l)
*** x -  x       Sand      Silt      Clay
    1    9       100.       50.       20.
   10   11        20.       10.       10.
   12             10.       10.       10.

   13   18       100.       50.       20.
  END SSED-INIT

  BED-INIT
*** RCHRES    BEDDEP  Initial bed composition
*** x -  x      (ft)      Sand      Silt      Clay
    1             8.       0.9      0.05      0.05
    2            50.       0.8       0.1       0.1
    3            50.       0.6       0.2       0.2
    4    5       50.       0.9      0.05      0.05
    6           120.       0.6       0.2       0.2
    7            1.5       0.6       0.2       0.2
    8             8.       0.6       0.2       0.2
    9           150.       0.6       0.2       0.2
   10   11      200.       0.8       0.1       0.1
   12           7.83       0.8       0.1       0.1
   13            50.       0.6       0.2       0.2
   14   15       10.       0.6       0.2       0.2
   16            50.       0.6       0.2       0.2
   17             5.       0.6       0.2       0.2
   18            20.       0.6       0.2       0.2
  END BED-INIT

  BENTH-FLAG
*** RCHRES  Benthic release flag
*** x -  x BENF
    1   18    1
  END BENTH-FLAG

  OX-FLAGS
*** RCHRES Oxygen flags
*** x -  x REAM
    1   18    3
  END OX-FLAGS

  OX-GENPARM
*** RCHRES    KBOD20     TCBOD    KODSET    SUPSAT
*** x -  x       /hr               ft/hr
    1   18       0.1      1.06        8.       1.2
  END OX-GENPARM

  OX-BENPARM
*** RCHRES     BENOD     TCBEN     EXPOD  BRBOD(1)  BRBOD(2)   EXPREL
*** x -  x  mg/m2.hr                    mg/m2.hr  mg/m2.hr
    1   18       50.     1.074      1.22     0.001     0.001      2.82
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  END OX-BENPARM

  OX-REAPARM
*** RCHRES    TCGINV      REAK    EXPRED    EXPREV
*** x -  x                 /hr
    1   18     1.024       0.2    -1.673     0.969
  END OX-REAPARM

  OX-INIT
*** RCHRES       DOX       BOD     SATDO
*** x -  x      mg/l      mg/l      mg/l
    1   18      12.8       3.5      13.5
  END OX-INIT

  NUT-FLAGS
*** RCHRES  Nutrient flags
*** x -  x  NH3  NO2  PO4  AMV  DEN ADNH ADPO PHFL
    1   18    1    0    1    0    1    0    0    2
  END NUT-FLAGS

  CONV-VAL1
*** RCHRES      CVBO     CVBPC     CVBPN    BPCNTC
*** x -  x     mg/mg  mols/mol  mols/mol
    1   18      1.63      106.       10.       49.
  END CONV-VAL1

  NUT-BENPARM
*** RCHRES  BRNIT(1)  BRNIT(2)  BRPO4(1)  BRPO4(2)     ANAER
*** x -  x  mg/m2.hr  mg/m2.hr  mg/m2.hr  mg/m2.hr      mg/l
    1   18        0.        0.        0.        0.     0.001
  END NUT-BENPARM

  NUT-NITDENIT
*** RCHRES    KTAM20    KNO220     TCNIT    KNO320     TCDEN    DENOXT
*** x -  x       /hr       /hr                 /hr                mg/l
    1    9     0.015     0.002      1.07     0.002      1.04        5.
   10   12     0.019     0.002      1.07     0.002      1.04        5.
   13   18     0.015     0.002      1.07     0.002      1.04        5.
  END NUT-NITDENIT

  NUT-DINIT
*** RCHRES       NO3       TAM       NO2       PO4
*** x -  x      mg/l      mg/l      mg/l      mg/l
    1   18        4.       0.1        0.      0.05        7.
  END NUT-DINIT

END RCHRES

FTABLES

  FTABLE      1
 rows cols                             ***
    8    4
     depth      area    volume  outflow1 ***
        0.     34.12        0.        0.
       0.4     35.81     13.85      2.64
      3.96     51.01    168.57      129.
```

```
      5.04     55.62    226.15    197.16
      8.67    126.05    648.46    675.25
      12.3    145.47   1141.27   1567.67
    211.15   1462.53  161016.8  1289586.
      410.   2779.59  582789.4  7172163.
  END FTABLE  1

  FTABLE      2
 rows cols                                        ***
   24    5
     depth      area    volume  outflow1  outflow2 ***
        0.        0.        0.        0.        0.
      3.48      0.78      0.87      34.4     17.67
      6.96       1.5      3.34      34.4     17.67
     10.43       2.2      7.33      34.4     17.67
     13.91      2.88     12.82      34.4     17.67
     17.39      3.56     19.78      34.4     17.67
     20.87      4.22      28.2      34.4     17.67
     24.35      4.88     38.04      34.4     17.67
     27.83      5.54     49.31      34.4     17.67
      31.3      6.19     61.99      34.4     17.67
     34.78      6.83     76.07      34.4     17.67
     38.26      7.48     91.54      34.4     17.67
     41.74      8.12     108.4      34.4     17.67
     45.22      8.75    126.64      34.4     17.67
      48.7      9.39    146.26      34.4     17.67
     52.17     10.02    167.24      34.4     17.67
     55.65     10.65    189.58      34.4     17.67
     59.13     11.27    213.28      34.4     17.67
     62.61      11.9    238.33      34.4     17.67
     66.09     12.52    264.72      34.4     17.67
     69.57     13.14    292.47      34.4     17.67
       80.       15.      384.     2000.     17.67
       81.      15.5      385.     4000.     17.67
       82.       16.      386.    12000.     17.67
  END FTABLE  2

  FTABLE      7
 rows cols                              ***
    8    4
     depth      area    volume  outflow1 ***
        0.      0.68        0.        0.
      0.38      1.49      0.41      0.19
       3.8      8.73     17.88     30.96
      5.03     11.34     30.23     62.33
      8.67     14.42     77.06     243.8
      12.3     17.51    135.09    534.28
    211.15    391.54  40804.54  967327.3
      410.    765.58  155851.1  5781091.
  END FTABLE  7

  FTABLE      3
 rows cols                              ***
    8    4
     depth      area    volume  outflow1 ***
        0.      1.13        0.        0.
      0.66      1.58      0.89      0.49
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      6.56       5.64      22.21      39.62
       8.2       6.77       32.4      65.35
     10.25      20.88      72.31     132.27
      12.3       23.7     118.02     275.17
    211.15     297.44   32047.69  583069.75
      410.     571.17  118409.31   3333306.
  END FTABLE  3

  FTABLE      4
 rows cols                                   ***
    8    4
     depth       area     volume   outflow1 ***
        0.       9.98         0.         0.
      0.38      11.29       4.08       1.79
      3.84      23.13      63.56     106.67
      4.87      26.66       89.2     170.54
      6.21      45.05      147.2     276.59
      7.54      48.24     209.47     473.57
     53.77     111.66    3905.64   33063.47
      100.     175.08   10533.68   125708.9
  END FTABLE  4

  FTABLE      8
 rows cols                                              ***
   25    5
     depth       area     volume   outflow1   outflow2 ***
        0.         0.         0.         0.         0.
       3.7       0.42       0.52       6.33       2.14
      7.39        0.8       2.02       6.33       2.14
     11.09       1.17       4.44       6.33       2.14
     14.78       1.54       7.76       6.33       2.14
     18.48        1.9      11.97       6.33       2.14
     22.17       2.25      17.05       6.33       2.14
     25.87       2.61      23.01       6.33       2.14
     29.57       2.96      29.83       6.33       2.14
     33.26        3.3      37.49       6.33       2.14
     36.96       3.65      46.01       6.33       2.14
     40.65       3.99      55.37       6.33       2.14
     44.35       4.33      65.57       6.33       2.14
     48.04       4.67       76.6       6.33       2.14
     51.74       5.01      88.47       6.33       2.14
     55.43       5.35     101.16        10.       2.14
     59.13       5.68     114.67        50.       2.14
     62.83       6.02     129.01       100.       2.14
     66.52       6.35     144.16       200.       2.14
      81.3       7.67     212.89       600.       2.14
       85.         8.       232.       800.       2.14
       86.       8.05       233.      1000.       2.14
       87.        8.1       234.      1150.       2.14
      100.        10.       500.      1300.       2.14
      120.        20.      1000.      1400.       2.14
  END FTABLE  8

  FTABLE     10
 rows cols                                   ***
    8    4
     depth       area     volume   outflow1 ***
```

```
       0.     29.07         0.         0.
     0.16     30.11      4.65       0.33
     1.57     39.43     53.77      16.08
     3.03     49.06    118.37      50.88
     4.34     70.25    205.51     101.32
     5.64     77.22    301.73     180.09
    27.82    297.87   4461.44    6644.88
      50.    518.52  13515.17   29205.48
  END FTABLE 10

  FTABLE      9
 rows cols                               ***
    8    4
    depth      area    volume  outflow1 ***
       0.      9.98        0.        0.
     0.38     11.29      4.08      1.79
     3.84     23.13     63.56    106.67
     4.87     26.66      89.2    170.54
     6.21     45.05     147.2    276.59
     7.54     48.24    209.47    473.57
    53.77    111.66   3905.64  33063.47
     100.    175.08  10533.68  125708.9
  END FTABLE  9

  FTABLE     11
 rows cols                               ***
    8    4
    depth      area    volume  outflow1 ***
       0.     29.07        0.        0.
     0.16     30.11      4.65      0.33
     1.57     39.43     53.77     16.08
     3.03     49.06    118.37     50.88
     4.34     70.25    205.51    101.32
     5.64     77.22    301.73    180.09
    27.82    297.87   4461.44   6644.88
      50.    518.52  13515.17  29205.48
  END FTABLE 11

  FTABLE     12
 rows cols                                         ***
   25    5
    depth      area    volume  outflow1  outflow2 ***
       0.        0.        0.        0.        0.
      10.     54.97      218.      100.       67.
      13.     79.92      412.      100.       67.
      19.    120.24      906.      100.       67.
      23.    133.98     1222.      100.       67.
      29.    172.43     1983.      100.       67.
      33.    184.69     2417.      100.       67.
      42.    232.05     3865.      100.       67.
      49.    253.61     4928.      100.       67.
      52.    266.52     5496.      100.       67.
      59.    287.68     6731.      100.       67.
      62.    300.81     7396.      100.       67.
      72.    337.03     9623.      370.       67.
      75.    351.69    10460.      370.       67.
      82.    376.34    12238.      400.       67.
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      85.    391.45    13195.       370.        67.
      92.    419.61    15309.       440.        67.
      95.    437.31    16475.       430.        67.
      98.     455.6    17706.       480.        67.
     108.     511.1    21890.       640.        67.
     111.     531.7    23405.       750.        67.
     118.    569.38    26644.       890.        67.
     128.    633.66    32165.      2030.        67.
     131.      700.    36365.      3030.        67.
     132.    711.89    37265.      3500.        67.
  END FTABLE 12

  FTABLE     16
 rows cols                               ***
    8    4
     depth      area    volume  outflow1 ***
        0.     34.12        0.        0.
       0.4     35.81     13.85      2.64
      3.96     51.01    168.57      129.

      5.04     55.62    226.15    197.16
      8.67    126.05    648.46    675.25
      12.3    145.47   1141.27   1567.67
    211.15   1462.53  161016.8  1289586.
      410.   2779.59  582789.4  7172163.
  END FTABLE 16

  FTABLE     17
 rows cols                               ***
    8    4
     depth      area    volume  outflow1 ***
        0.     34.12        0.        0.
       0.4     35.81     13.85      2.64
      3.96     51.01    168.57      129.
      5.04     55.62    226.15    197.16
      8.67    126.05    648.46    675.25
      12.3    145.47   1141.27   1567.67
    211.15   1462.53  161016.8  1289586.
      410.   2779.59  582789.4  7172163.
  END FTABLE 17

  FTABLE     18
 rows cols                               ***
    8    4
     depth      area    volume  outflow1 ***
        0.      0.53        0.        0.
      0.66      0.74      0.41      0.49
      6.56      2.63     10.34     39.62
       8.2      3.15     15.09     65.35
     10.25      9.72     33.67    132.27
      12.3     11.04     54.96    275.17
    211.15    138.51  14923.95 583069.75
      410.    265.98  55140.78  3333306.
  END FTABLE 18

  FTABLE     13
 rows cols                               ***
```

```
   8    4
     depth       area     volume  outflow1 ***
        0.      29.07         0.        0.
      0.16      30.11       4.65      0.33
      1.57      39.43      53.77     16.08
      3.03      49.06     118.37     50.88
      4.34      70.25     205.51    101.32
      5.64      77.22     301.73    180.09
     27.82     297.87    4461.44   6644.88
       50.     518.52   13515.17  29205.48
  END FTABLE 13

  FTABLE     14
 rows cols                                ***
   8    4
     depth       area     volume  outflow1 ***
        0.       3.72         0.        0.
      0.66        5.2       2.93      0.55
      6.56      18.59      73.16     45.18
       8.2       22.3     106.69     74.52
     10.25      68.77     238.15    150.81
      12.3      78.07     388.66    313.75
    211.15     979.54   105540.8 664801.81
      410.    1881.01  389950.59 3800553.5
  END FTABLE 14

  FTABLE     15
 rows cols                                ***
   8    4
     depth       area     volume  outflow1 ***
        0.       2.22         0.        0.
      0.66       3.11       1.75      0.49
      6.56      11.12      43.76     39.62
       8.2      13.34      63.81     65.35
     10.25      41.13     142.44    132.27
      12.3      46.69     232.46    275.17
    211.15     585.87   63124.81 583069.75
      410.    1125.05  233232.63  3333306.
  END FTABLE 15

  FTABLE      5
 rows cols                                ***
   8    4
     depth       area     volume  outflow1 ***
        0.       9.98         0.        0.
      0.38      11.29       4.08      1.79
      3.84      23.13      63.56    106.67
      4.87      26.66       89.2    170.54
      6.21      45.05      147.2    276.59
      7.54      48.24     209.47    473.57
     53.77     111.66    3905.64  33063.47
      100.     175.08   10533.68  125708.9

  END FTABLE  5

  FTABLE      6
 rows cols                                ***
```

```
   25    4
     depth       area    volume  outflow1 ***
        0.         0.        0.        0.
        3.      17.56      16.2     26.73
        6.      92.12      170.     26.73
        9.     128.97      357.     26.73
       13.     156.06      624.     26.73
       16.     186.14      916.     26.73
       19.     217.84     1273.     26.73
       23.     232.68     1646.     26.73
       26.     257.48     2059.     26.73
       29.     280.84     2505.     26.73
       32.     309.68     3048.     26.73
       36.     328.02     3632.     26.73
       39.     354.14     4248.     26.73
       42.     379.08     4897.     26.73
       45.     404.17     5594.     26.73
       49.     419.61     6324.     26.73
       52.     444.55     7110.     26.73
       55.     468.24     7921.     26.73
       59.     486.09     8821.     26.73
       62.     513.55     9793.     26.73
       65.     542.56    10847.     73.03
       75.       634.    14625.    1532.7
       76.     661.02  15452.23    2031.5
       81.     700.47   17451.6   7877.98
      300.      2800.   100000.     9000.
  END FTABLE  6
END FTABLES

EXT SOURCES
<-Volume-> <Member> SsysSgap<--Mult-->Tran <-Target vols> <-Grp> <-
Member-> ***
<Name>   x <Name> x tem strg<-factor->strg <Name>   x   x        <Name>
x x ***
*** Met Seg RGAAADJ
WDM2   203 PREC     ENGL              SAME PERLND  11  95 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME PERLND  11  95 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME PERLND  11  95 EXTNL  DTMPG
WDM2    14 WIND     ENGL              SAME PERLND  11  95 EXTNL  WINMOV
WDM2    55 SOLR     ENGL              SAME PERLND  11  95 EXTNL  SOLRAD
WDM2     7 EVAP     ENGL              SAME PERLND  11  95 EXTNL  PETINP
*** Met Seg CAOPAL
WDM2   129 PREC     ENGL              SAME PERLND 111 136 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME PERLND 111 136 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME PERLND 111 136 EXTNL  DTMPG
WDM2    14 WIND     ENGL              SAME PERLND 111 136 EXTNL  WINMOV
WDM2    55 SOLR     ENGL              SAME PERLND 111 136 EXTNL  SOLRAD
WDM2     5 EVAP     ENGL              SAME PERLND 111 136 EXTNL  PETINP
*** Met Seg CAOMAM
WDM2   202 PREC     ENGL              SAME PERLND 141 186 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME PERLND 141 186 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME PERLND 141 186 EXTNL  DTMPG
WDM2    14 WIND     ENGL              SAME PERLND 141 186 EXTNL  WINMOV
WDM2    55 SOLR     ENGL              SAME PERLND 141 186 EXTNL  SOLRAD
WDM2    10 EVAP     ENGL              SAME PERLND 141 186 EXTNL  PETINP
*** Met Seg SALIENTE
```

```
WDM2   104 PREC     ENGL              SAME PERLND 101 107 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME PERLND 101 107 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME PERLND 101 107 EXTNL  DTMPG
WDM2    14 WIND     ENGL              SAME PERLND 101 107 EXTNL  WINMOV
WDM2    55 SOLR     ENGL              SAME PERLND 101 107 EXTNL  SOLRAD
WDM2     4 EVAP     ENGL              SAME PERLND 101 107 EXTNL  PETINP
*** Met Seg RGAAADJ
WDM2   203 PREC     ENGL              SAME IMPLND  11  91 EXTNL  PREC

WDM2    13 ATEM     ENGL              SAME IMPLND  11  91 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME IMPLND  11  91 EXTNL  DTMPG
WDM2    14 WIND     ENGL              SAME IMPLND  11  91 EXTNL  WINMOV
WDM2    55 SOLR     ENGL              SAME IMPLND  11  91 EXTNL  SOLRAD
WDM2     7 EVAP     ENGL              SAME IMPLND  11  91 EXTNL  PETINP
*** Met Seg CAOPAL
WDM2   129 PREC     ENGL              SAME IMPLND 111 131 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME IMPLND 111 131 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME IMPLND 111 131 EXTNL  DTMPG
WDM2    14 WIND     ENGL              SAME IMPLND 111 131 EXTNL  WINMOV
WDM2    55 SOLR     ENGL              SAME IMPLND 111 131 EXTNL  SOLRAD
WDM2     5 EVAP     ENGL              SAME IMPLND 111 131 EXTNL  PETINP
*** Met Seg CAOMAM
WDM2   202 PREC     ENGL              SAME IMPLND 141 181 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME IMPLND 141 181 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME IMPLND 141 181 EXTNL  DTMPG
WDM2    14 WIND     ENGL              SAME IMPLND 141 181 EXTNL  WINMOV
WDM2    55 SOLR     ENGL              SAME IMPLND 141 181 EXTNL  SOLRAD
WDM2    10 EVAP     ENGL              SAME IMPLND 141 181 EXTNL  PETINP
*** Met Seg SALIENTE
WDM2   104 PREC     ENGL              SAME IMPLND 101     EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME IMPLND 101     EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME IMPLND 101     EXTNL  DTMPG
WDM2    14 WIND     ENGL              SAME IMPLND 101     EXTNL  WINMOV
WDM2    55 SOLR     ENGL              SAME IMPLND 101     EXTNL  SOLRAD
WDM2     4 EVAP     ENGL              SAME IMPLND 101     EXTNL  PETINP
*** Met Seg RGAAADJ
WDM2   203 PREC     ENGL              SAME RCHRES   1   9 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME RCHRES   1   9 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME RCHRES   1   9 EXTNL  DEWTMP
WDM2    14 WIND     ENGL              SAME RCHRES   1   9 EXTNL  WIND
WDM2    55 SOLR     ENGL              SAME RCHRES   1   9 EXTNL  SOLRAD
WDM2    18 CLOU     ENGL              SAME RCHRES   1   9 EXTNL  CLOUD
*** Met Seg CAOPAL
WDM2   129 PREC     ENGL              SAME RCHRES  11  13 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME RCHRES  11  13 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME RCHRES  11  13 EXTNL  DEWTMP
WDM2    14 WIND     ENGL              SAME RCHRES  11  13 EXTNL  WIND
WDM2    55 SOLR     ENGL              SAME RCHRES  11  13 EXTNL  SOLRAD
WDM2    18 CLOU     ENGL              SAME RCHRES  11  13 EXTNL  CLOUD
WDM2     5 EVAP     ENGL              SAME RCHRES  11  13 EXTNL  POTEV
*** Met Seg CAOMAM
WDM2   202 PREC     ENGL              SAME RCHRES  14  18 EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME RCHRES  14  18 EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME RCHRES  14  18 EXTNL  DEWTMP
WDM2    14 WIND     ENGL              SAME RCHRES  14  18 EXTNL  WIND
WDM2    55 SOLR     ENGL              SAME RCHRES  14  18 EXTNL  SOLRAD
WDM2    18 CLOU     ENGL              SAME RCHRES  14  18 EXTNL  CLOUD
```

```
WDM2    10 EVAP     ENGL              SAME RCHRES  14  18 EXTNL  POTEV
*** Met Seg SALIENTE
WDM2   104 PREC     ENGL              SAME RCHRES  10     EXTNL  PREC
WDM2    13 ATEM     ENGL              SAME RCHRES  10     EXTNL  GATMP
WDM2    17 DEWP     ENGL              SAME RCHRES  10     EXTNL  DEWTMP
WDM2    14 WIND     ENGL              SAME RCHRES  10     EXTNL  WIND
WDM2    55 SOLR     ENGL              SAME RCHRES  10     EXTNL  SOLRAD
WDM2    18 CLOU     ENGL              SAME RCHRES  10     EXTNL  CLOUD
WDM2     4 EVAP     ENGL              SAME RCHRES  10     EXTNL  POTEV
END EXT SOURCES

SCHEMATIC
<-Volume->                  <--Area-->     <-Volume->  <ML#> ***
<sb>
<Name>   x                  <-factor->     <Name>   x        ***
x x
PERLND  11                           0     RCHRES   1      2
IMPLND  11                         342     RCHRES   1      1
PERLND  17                          27     RCHRES   1      2
PERLND  12                         694     RCHRES   1      2
PERLND  13                        9931     RCHRES   1      2
PERLND  14                         613     RCHRES   1      2

PERLND  15                          47     RCHRES   1      2
PERLND  16                           0     RCHRES   1      2
PERLND  21                           0     RCHRES   2      2
IMPLND  21                           7     RCHRES   2      1
PERLND  22                         198     RCHRES   2      2
PERLND  23                        1134     RCHRES   2      2
PERLND  24                          37     RCHRES   2      2
PERLND  25                           5     RCHRES   2      2
PERLND  26                           0     RCHRES   2      2
RCHRES   1                                 RCHRES   2      3
PERLND  71                           0     RCHRES   7      2
IMPLND  71                           7     RCHRES   7      1
PERLND  72                         245     RCHRES   7      2
PERLND  73                        1517     RCHRES   7      2
PERLND  74                         101     RCHRES   7      2
PERLND  31                           0     RCHRES   3      2
IMPLND  31                          57     RCHRES   3      1
PERLND  32                        1075     RCHRES   3      2
PERLND  33                        8313     RCHRES   3      2
PERLND  34                         430     RCHRES   3      2
PERLND  35                          15     RCHRES   3      2
PERLND  36                           0     RCHRES   3      2
RCHRES   2                                 RCHRES   3      3
PERLND  41                           0     RCHRES   4      2
IMPLND  41                         130     RCHRES   4      1
PERLND  47                           2     RCHRES   4      2
PERLND  42                         472     RCHRES   4      2
PERLND  43                        6027     RCHRES   4      2
PERLND  44                         848     RCHRES   4      2
PERLND  45                          20     RCHRES   4      2
RCHRES   3                                 RCHRES   4      3
PERLND  81                           0     RCHRES   8      2
IMPLND  81                           9     RCHRES   8      1
PERLND  82                          54     RCHRES   8      2
```

PERLND	83	1876	RCHRES	8	2
PERLND	84	363	RCHRES	8	2
PERLND	86	0	RCHRES	8	2
RCHRES	7		RCHRES	8	3
PERLND	101	0	RCHRES	10	2
IMPLND	101	35	RCHRES	10	1
PERLND	107	27	RCHRES	10	2
PERLND	102	262	RCHRES	10	2
PERLND	103	5004	RCHRES	10	2
PERLND	104	558	RCHRES	10	2
PERLND	105	30	RCHRES	10	2
PERLND	91	0	RCHRES	9	2
IMPLND	91	305	RCHRES	9	1
PERLND	92	393	RCHRES	9	2
PERLND	93	4875	RCHRES	9	2
PERLND	94	618	RCHRES	9	2
PERLND	95	32	RCHRES	9	2
RCHRES	8		RCHRES	9	3
PERLND	111	0	RCHRES	11	2
IMPLND	111	299	RCHRES	11	1
PERLND	117	413	RCHRES	11	2
PERLND	112	1124	RCHRES	11	2
PERLND	113	10865	RCHRES	11	2
PERLND	114	5256	RCHRES	11	2
PERLND	115	99	RCHRES	11	2
RCHRES	10		RCHRES	11	3
PERLND	121	0	RCHRES	12	2
IMPLND	121	20	RCHRES	12	1
PERLND	122	178	RCHRES	12	2
PERLND	123	4287	RCHRES	12	2
PERLND	124	1626	RCHRES	12	2
PERLND	125	44	RCHRES	12	2
PERLND	126	0	RCHRES	12	2
RCHRES	11		RCHRES	12	3
PERLND	161	0	RCHRES	16	2
IMPLND	161	67	RCHRES	16	1
PERLND	167	106	RCHRES	16	2
PERLND	162	512	RCHRES	16	2
PERLND	163	8809	RCHRES	16	2
PERLND	164	598	RCHRES	16	2
PERLND	165	10	RCHRES	16	2
PERLND	171	0	RCHRES	17	2
IMPLND	171	136	RCHRES	17	1
PERLND	177	166	RCHRES	17	2
PERLND	172	1236	RCHRES	17	2
PERLND	173	10067	RCHRES	17	2
PERLND	174	1300	RCHRES	17	2
PERLND	175	22	RCHRES	17	2
RCHRES	16		RCHRES	17	3
PERLND	181	0	RCHRES	18	2
IMPLND	181	10	RCHRES	18	1
PERLND	182	15	RCHRES	18	2
PERLND	183	1366	RCHRES	18	2
PERLND	184	44	RCHRES	18	2
PERLND	186	0	RCHRES	18	2
RCHRES	17		RCHRES	18	3
PERLND	131	0	RCHRES	13	2

```
IMPLND 131                          15     RCHRES  13       1
PERLND 132                          44     RCHRES  13       2
PERLND 133                        1606     RCHRES  13       2
PERLND 134                         128     RCHRES  13       2
PERLND 135                          12     RCHRES  13       2
PERLND 136                           0     RCHRES  13       2
RCHRES  12                                 RCHRES  13       3
PERLND 141                           0     RCHRES  14       2
IMPLND 141                          16     RCHRES  14       1
PERLND 142                         101     RCHRES  14       2
PERLND 143                        2140     RCHRES  14       2
PERLND 144                          91     RCHRES  14       2
PERLND 145                           5     RCHRES  14       2
PERLND 146                           0     RCHRES  14       2
RCHRES  13                                 RCHRES  14       3
PERLND 153                         348     RCHRES  15       2
PERLND 154                           5     RCHRES  15       2
PERLND 156                           0     RCHRES  15       2
RCHRES  18                                 RCHRES  15       3
RCHRES  14                                 RCHRES  15       3
PERLND  51                           0     RCHRES   5       2
IMPLND  51                         242     RCHRES   5       1
PERLND  52                          20     RCHRES   5       2
PERLND  53                        2706     RCHRES   5       2
PERLND  54                        1243     RCHRES   5       2
PERLND  55                          20     RCHRES   5       2
PERLND  56                           0     RCHRES   5       2
RCHRES   4                                 RCHRES   5       3
RCHRES   9                                 RCHRES   5       3
PERLND  61                           0     RCHRES   6       2
IMPLND  61                          19     RCHRES   6       1
PERLND  62                         343     RCHRES   6       2
PERLND  63                        4361     RCHRES   6       2
PERLND  64                         373     RCHRES   6       2
PERLND  65                          32     RCHRES   6       2
PERLND  66                           0     RCHRES   6       2
RCHRES  15                                 RCHRES   6       3

RCHRES   5                                 RCHRES   6       3
END SCHEMATIC

EXT TARGETS
<-Volume-> <-Grp> <-Member-><--Mult-->Tran <-Volume-> <Member> Tsys Aggr
Amd ***
<Name>   x        <Name> x x<-factor->strg <Name>   x <Name>qf  tem strg
strg***
PERLND  11 SEDMNT SOSED  1 1          AVER WDM1  1034 SOSED  1 ENGL AGGR
REPL
PERLND  17 SEDMNT SOSED  1 1          AVER WDM1  1035 SOSED  1 ENGL AGGR
REPL
PERLND  17 PQUAL  SOQUAL 1 1          AVER WDM1  1109 SOQUAL 1 ENGL AGGR
REPL
PERLND  12 SEDMNT SOSED  1 1          AVER WDM1  1036 SOSED  1 ENGL AGGR
REPL
PERLND  13 SEDMNT SOSED  1 1          AVER WDM1  1037 SOSED  1 ENGL AGGR
REPL
```

```
PERLND  14 SEDMNT SOSED  1 1          AVER WDM1  1038 SOSED  1 ENGL AGGR
REPL
PERLND  15 SEDMNT SOSED  1 1          AVER WDM1  1039 SOSED  1 ENGL AGGR
REPL
IMPLND  11 SOLIDS SOSLD  1 1          AVER WDM1  1074 SOSLD  1 ENGL AGGR
REPL
PERLND  42 SEDMNT SOSED  1 1          AVER WDM1  1081 SOSED  1 ENGL AGGR
REPL
PERLND  51 SEDMNT SOSED  1 1          AVER WDM1  1045 SOSED  1 ENGL AGGR
REPL
PERLND  52 SEDMNT SOSED  1 1          AVER WDM1  1046 SOSED  1 ENGL AGGR
REPL
PERLND  53 SEDMNT SOSED  1 1          AVER WDM1  1047 SOSED  1 ENGL AGGR
REPL
PERLND  54 SEDMNT SOSED  1 1          AVER WDM1  1048 SOSED  1 ENGL AGGR
REPL
PERLND  55 SEDMNT SOSED  1 1          AVER WDM1  1049 SOSED  1 ENGL AGGR
REPL
IMPLND  51 SOLIDS SOSLD  1 1          AVER WDM1  1076 SOSLD  1 ENGL AGGR
REPL
PERLND  22 SEDMNT SOSED  1 1          AVER WDM1  1082 SOSED  1 ENGL AGGR
REPL
PERLND  31 SEDMNT SOSED  1 1          AVER WDM1  1040 SOSED  1 ENGL AGGR
REPL
PERLND  32 SEDMNT SOSED  1 1          AVER WDM1  1041 SOSED  1 ENGL AGGR
REPL
PERLND  33 SEDMNT SOSED  1 1          AVER WDM1  1042 SOSED  1 ENGL AGGR
REPL
PERLND  34 SEDMNT SOSED  1 1          AVER WDM1  1043 SOSED  1 ENGL AGGR
REPL
PERLND  35 SEDMNT SOSED  1 1          AVER WDM1  1044 SOSED  1 ENGL AGGR
REPL
IMPLND  31 SOLIDS SOSLD  1 1          AVER WDM1  1075 SOSLD  1 ENGL AGGR
REPL
PERLND  92 SEDMNT SOSED  1 1          AVER WDM1  1083 SOSED  1 ENGL AGGR
REPL
PERLND  62 SEDMNT SOSED  1 1          AVER WDM1  1084 SOSED  1 ENGL AGGR
REPL
PERLND  72 SEDMNT SOSED  1 1          AVER WDM1  1085 SOSED  1 ENGL AGGR
REPL
PERLND 122 SEDMNT SOSED  1 1          AVER WDM1  1086 SOSED  1 ENGL AGGR
REPL
PERLND 125 SEDMNT SOSED  1 1          AVER WDM1  1087 SOSED  1 ENGL AGGR
REPL
PERLND 171 SEDMNT SOSED  1 1          AVER WDM1  1068 SOSED  1 ENGL AGGR
REPL
PERLND 177 SEDMNT SOSED  1 1          AVER WDM1  1069 SOSED  1 ENGL AGGR
REPL
PERLND 172 SEDMNT SOSED  1 1          AVER WDM1  1070 SOSED  1 ENGL AGGR
REPL
PERLND 173 SEDMNT SOSED  1 1          AVER WDM1  1071 SOSED  1 ENGL AGGR
REPL
PERLND 174 SEDMNT SOSED  1 1          AVER WDM1  1072 SOSED  1 ENGL AGGR
REPL
PERLND 175 SEDMNT SOSED  1 1          AVER WDM1  1073 SOSED  1 ENGL AGGR
REPL
```

```
IMPLND 171 SOLIDS SOSLD  1 1          AVER WDM1  1080 SOSLD  1 ENGL AGGR
REPL
PERLND 161 SEDMNT SOSED  1 1          AVER WDM1  1062 SOSED  1 ENGL AGGR
REPL
PERLND 167 SEDMNT SOSED  1 1          AVER WDM1  1063 SOSED  1 ENGL AGGR
REPL
PERLND 162 SEDMNT SOSED  1 1          AVER WDM1  1064 SOSED  1 ENGL AGGR
REPL
PERLND 163 SEDMNT SOSED  1 1          AVER WDM1  1065 SOSED  1 ENGL AGGR
REPL
PERLND 164 SEDMNT SOSED  1 1          AVER WDM1  1066 SOSED  1 ENGL AGGR
REPL
PERLND 165 SEDMNT SOSED  1 1          AVER WDM1  1067 SOSED  1 ENGL AGGR
REPL
IMPLND 161 SOLIDS SOSLD  1 1          AVER WDM1  1079 SOSLD  1 ENGL AGGR
REPL
PERLND 101 SEDMNT SOSED  1 1          AVER WDM1  1050 SOSED  1 ENGL AGGR
REPL
PERLND 107 SEDMNT SOSED  1 1          AVER WDM1  1051 SOSED  1 ENGL AGGR
REPL
PERLND 102 SEDMNT SOSED  1 1          AVER WDM1  1052 SOSED  1 ENGL AGGR
REPL
PERLND 103 SEDMNT SOSED  1 1          AVER WDM1  1053 SOSED  1 ENGL AGGR
REPL
PERLND 104 SEDMNT SOSED  1 1          AVER WDM1  1054 SOSED  1 ENGL AGGR
REPL
PERLND 105 SEDMNT SOSED  1 1          AVER WDM1  1055 SOSED  1 ENGL AGGR
REPL
IMPLND 101 SOLIDS SOSLD  1 1          AVER WDM1  1077 SOSLD  1 ENGL AGGR
REPL
PERLND 111 SEDMNT SOSED  1 1          AVER WDM1  1056 SOSED  1 ENGL AGGR
REPL
PERLND 117 SEDMNT SOSED  1 1          AVER WDM1  1057 SOSED  1 ENGL AGGR
REPL
PERLND 112 SEDMNT SOSED  1 1          AVER WDM1  1058 SOSED  1 ENGL AGGR
REPL
PERLND 112 PQUAL  POQUAL 1 1          AVER WDM1  1110 POQUAL 1 ENGL AGGR
REPL
PERLND 112 PQUAL  SOQUAL 1 1          AVER WDM1  1111 SOQUAL 1 ENGL AGGR
REPL
PERLND 113 SEDMNT SOSED  1 1          AVER WDM1  1059 SOSED  1 ENGL AGGR
REPL
PERLND 114 SEDMNT SOSED  1 1          AVER WDM1  1060 SOSED  1 ENGL AGGR
REPL
PERLND 115 SEDMNT SOSED  1 1          AVER WDM1  1061 SOSED  1 ENGL AGGR
REPL
IMPLND 111 SOLIDS SOSLD  1 1          AVER WDM1  1078 SOSLD  1 ENGL AGGR
REPL
RCHRES   1 HYDR   RO     1 1          AVER WDM1  1001 FLOW   1 ENGL AGGR
REPL
RCHRES   1 SEDTRN SSED   4 1          AVER WDM1  1010 SSED4  1 ENGL AGGR
REPL
RCHRES   1 HYDR   TAU    1 1          AVER WDM1  1011 TAU    1 ENGL AGGR
REPL
RCHRES   1 NUTRX  DNUST  2 1          AVER WDM1  1116 DNUST2 1 ENGL AGGR
REPL
```

```
RCHRES   1 NUTRX  DNUST  1 1          AVER WDM1  1117 DNUST1 1 ENGL AGGR
REPL
RCHRES   1 HTRCH  TW     1 1          AVER WDM1  1120 TW     1 ENGL AGGR
REPL
RCHRES   1 NUTRX  DNUST  4 1          AVER WDM1  1122 DNUST4 1 ENGL AGGR
REPL
RCHRES   1 OXRX   DOX    1 1          AVER WDM1  1129 DOX    1 ENGL AGGR
REPL
RCHRES   2 HYDR   TAU    1 1          AVER WDM1  1027 TAU    1 ENGL AGGR
REPL
RCHRES   7 HYDR   RO     1 1          AVER WDM1  1002 FLOW   1 ENGL AGGR
REPL
RCHRES   7 SEDTRN SSED   4 1          AVER WDM1  1012 SSED4  1 ENGL AGGR
REPL
RCHRES   7 HYDR   TAU    1 1          AVER WDM1  1013 TAU    1 ENGL AGGR
REPL
RCHRES   3 HYDR   RO     1 1          AVER WDM1  1003 FLOW   1 ENGL AGGR
REPL
RCHRES   3 SEDTRN SSED   4 1          AVER WDM1  1014 SSED4  1 ENGL AGGR
REPL
RCHRES   3 HYDR   TAU    1 1          AVER WDM1  1015 TAU    1 ENGL AGGR
REPL
RCHRES   8 HYDR   TAU    1 1          AVER WDM1  1026 TAU    1 ENGL AGGR
REPL
RCHRES  10 HYDR   RO     1 1          AVER WDM1  1005 FLOW   1 ENGL AGGR
REPL
RCHRES  10 SEDTRN SSED   4 1          AVER WDM1  1018 SSED4  1 ENGL AGGR
REPL
RCHRES  10 HYDR   TAU    1 1          AVER WDM1  1019 TAU    1 ENGL AGGR
REPL
RCHRES  11 HYDR   RO     1 1          AVER WDM1  1006 FLOW   1 ENGL AGGR
REPL
RCHRES  11 SEDTRN SSED   4 1          AVER WDM1  1020 SSED4  1 ENGL AGGR
REPL
RCHRES  11 HYDR   TAU    1 1          AVER WDM1  1021 TAU    1 ENGL AGGR
REPL
RCHRES  11 HTRCH  TW     1 1          AVER WDM1  1106 TW     1 ENGL AGGR
REPL
RCHRES  11 NUTRX  DNUST  2 1          AVER WDM1  1108 DNUST2 1 ENGL AGGR
REPL

RCHRES  11 NUTRX  DNUST  1 1          AVER WDM1  1113 DNUST1 1 ENGL AGGR
REPL
RCHRES  11 NUTRX  DNUST  4 1          AVER WDM1  1124 DNUST4 1 ENGL AGGR
REPL
RCHRES  11 OXRX   DOX    1 1          AVER WDM1  1126 DOX    1 ENGL AGGR
REPL
RCHRES  12 HYDR   TAU    1 1          AVER WDM1  1028 TAU    1 ENGL AGGR
REPL
RCHRES  12 SEDTRN RSED   1 1          AVER WDM1  1096 RSED1  1 ENGL AGGR
REPL
RCHRES  12 SEDTRN RSED   2 1          AVER WDM1  1097 RSED2  1 ENGL AGGR
REPL
RCHRES  12 SEDTRN RSED   3 1          AVER WDM1  1098 RSED3  1 ENGL AGGR
REPL
RCHRES  12 SEDTRN RSED   4 1          AVER WDM1  1099 RSED4  1 ENGL AGGR
REPL
```

```
RCHRES  12 SEDTRN RSED   5 1          AVER WDM1  1100 RSED5  1 ENGL AGGR
REPL
RCHRES  12 SEDTRN RSED   6 1          AVER WDM1  1101 RSED6  1 ENGL AGGR
REPL
RCHRES  12 SEDTRN RSED  10 1          AVER WDM1  1102 RSED10 1 ENGL AGGR
REPL
RCHRES  12 SEDTRN SSED   4 1          AVER WDM1  1103 SSED4  1 ENGL AGGR
REPL
RCHRES  12 HYDR   RO     1 1          AVER WDM1  1104 FLOW   1 ENGL AGGR
REPL
RCHRES  16 HYDR   RO     1 1          AVER WDM1  1007 FLOW   1 ENGL AGGR
REPL
RCHRES  16 SEDTRN SSED   4 1          AVER WDM1  1022 SSED4  1 ENGL AGGR
REPL
RCHRES  16 HYDR   TAU    1 1          AVER WDM1  1023 TAU    1 ENGL AGGR
REPL
RCHRES  17 HYDR   RO     1 1          AVER WDM1  1009 FLOW   1 ENGL AGGR
REPL
RCHRES  17 SEDTRN SSED   4 1          AVER WDM1  1024 SSED4  1 ENGL AGGR
REPL
RCHRES  17 HYDR   TAU    1 1          AVER WDM1  1025 TAU    1 ENGL AGGR
REPL
RCHRES  17 HTRCH  TW     1 1          AVER WDM1  1105 TW     1 ENGL AGGR
REPL
RCHRES  17 NUTRX  DNUST  2 1          AVER WDM1  1112 DNUST2 1 ENGL AGGR
REPL
RCHRES  17 NUTRX  DNUST  1 1          AVER WDM1  1115 DNUST1 1 ENGL AGGR
REPL
RCHRES  17 NUTRX  DNUST  4 1          AVER WDM1  1125 DNUST4 1 ENGL AGGR
REPL
RCHRES  17 OXRX   DOX    1 1          AVER WDM1  1128 DOX    1 ENGL AGGR
REPL
RCHRES  18 HYDR   RO     1 1          AVER WDM1  1008 FLOW   1 ENGL AGGR
REPL
RCHRES  13 HYDR   RO     1 1          AVER WDM1  1031 FLOW   1 ENGL AGGR
REPL
RCHRES  13 SEDTRN SSED   4 1          AVER WDM1  1032 SSED4  1 ENGL AGGR
REPL
RCHRES  13 HYDR   TAU    1 1          AVER WDM1  1033 TAU    1 ENGL AGGR
REPL
RCHRES   5 HYDR   RO     1 1          AVER WDM1  1004 FLOW   1 ENGL AGGR
REPL
RCHRES   5 SEDTRN SSED   4 1          AVER WDM1  1016 SSED4  1 ENGL AGGR
REPL
RCHRES   5 HYDR   TAU    1 1          AVER WDM1  1017 TAU    1 ENGL AGGR
REPL
RCHRES   5 NUTRX  DNUST  2 1          AVER WDM1  1118 DNUST2 1 ENGL AGGR
REPL
RCHRES   5 NUTRX  DNUST  1 1          AVER WDM1  1119 DNUST1 1 ENGL AGGR
REPL
RCHRES   5 HTRCH  TW     1 1          AVER WDM1  1121 TW     1 ENGL AGGR
REPL
RCHRES   5 NUTRX  DNUST  4 1          AVER WDM1  1123 DNUST4 1 ENGL AGGR
REPL
RCHRES   5 OXRX   DOX    1 1          AVER WDM1  1127 DOX    1 ENGL AGGR
REPL
```

```
RCHRES   6 HYDR   RO      1 1          AVER WDM1   101 FLOW   1 ENGL AGGR
REPL
RCHRES   6 HYDR   TAU     1 1          AVER WDM1  1029 TAU    1 ENGL AGGR
REPL
RCHRES   6 SEDTRN RSED  10 1          AVER WDM1  1030 RSED10 1 ENGL AGGR
REPL
RCHRES   6 SEDTRN SSED   4 1          AVER WDM1  1088 SSED4  1 ENGL AGGR
REPL
RCHRES   6 SEDTRN ROSED  4 1          AVER WDM1  1089 ROSED4 1 ENGL AGGR
REPL
RCHRES   6 SEDTRN RSED   1 1          AVER WDM1  1090 RSED1  1 ENGL AGGR
REPL
RCHRES   6 SEDTRN RSED   2 1          AVER WDM1  1091 RSED2  1 ENGL AGGR
REPL
RCHRES   6 SEDTRN RSED   3 1          AVER WDM1  1092 RSED3  1 ENGL AGGR
REPL
RCHRES   6 SEDTRN RSED   4 1          AVER WDM1  1093 RSED4  1 ENGL AGGR
REPL
RCHRES   6 SEDTRN RSED   5 1          AVER WDM1  1094 RSED5  1 ENGL AGGR
REPL
RCHRES   6 SEDTRN RSED   6 1          AVER WDM1  1095 RSED6  1 ENGL AGGR
REPL
END EXT TARGETS

MASS-LINK

  MASS-LINK        2
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-
Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name>
x x  ***
PERLND     PWATER PERO       0.0833333     RCHRES         INFLOW IVOL
PERLND     PEST   POPST  1                 RCHRES         INFLOW IDQAL
1
PERLND     PEST   SOSDPS 1                 RCHRES         INFLOW ISQAL
1 1
PERLND     PEST   SOSDPS 1                 RCHRES         INFLOW ISQAL
2 1
PERLND     PEST   SOSDPS 1                 RCHRES         INFLOW ISQAL
3 1
PERLND     SEDMNT SOSED  1        0.05     RCHRES         INFLOW ISED
1
PERLND     SEDMNT SOSED  1        0.55     RCHRES         INFLOW ISED
2
PERLND     SEDMNT SOSED  1         0.4     RCHRES         INFLOW ISED
3
PERLND     PWTGAS POHT                     RCHRES         INFLOW IHEAT
1
PERLND     PQUAL  POQUAL 1                 RCHRES         INFLOW NUIF1
2
PERLND     PQUAL  POQUAL 2                 RCHRES         INFLOW NUIF1
1
PERLND     PQUAL  POQUAL 3                 RCHRES         INFLOW NUIF1
4
PERLND     PWTGAS PODOXM                   RCHRES         INFLOW OXIF
1
  END MASS-LINK    2
```

```
  MASS-LINK        1
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-
Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name>
x x  ***
IMPLND     IWATER SURO       0.0833333     RCHRES         INFLOW IVOL
IMPLND     SOLIDS SOSLD  1        0.05     RCHRES         INFLOW ISED
1
IMPLND     SOLIDS SOSLD  1        0.55     RCHRES         INFLOW ISED
2
IMPLND     SOLIDS SOSLD  1         0.4     RCHRES         INFLOW ISED
3
IMPLND     IWTGAS SOHT                     RCHRES         INFLOW IHEAT
1
IMPLND     IQUAL  SOQUAL 1                 RCHRES         INFLOW NUIF1
2
IMPLND     IQUAL  SOQUAL 2                 RCHRES         INFLOW NUIF1
1
IMPLND     IQUAL  SOQUAL 3                 RCHRES         INFLOW NUIF1
4
IMPLND     IWTGAS SODOXM                   RCHRES         INFLOW OXIF
1
  END MASS-LINK    1

  MASS-LINK        3
<-Volume-> <-Grp> <-Member-><--Mult-->     <-Target vols> <-Grp> <-
Member->  ***
<Name>            <Name> x x<-factor->     <Name>                <Name>
x x  ***
RCHRES     ROFLOW                          RCHRES         INFLOW
  END MASS-LINK    3
END MASS-LINK

END RUN
```

APPENDIX B
HSPF PARAMETERS
(HYDROLOGY, HYDRAULIC,
SEDIMENTS AND WATER QUALITY)

Table B1. Hydrologic and hydraulic parameters used in HSPF simulation

Name	Description
LZSN (in)	**Lower zone nominal soil moisture storage**
INFILT (in/hr)	**Index to Infiltration Capacity**
LSUR (ft)	Length of overland flow
SLSUR (ft/ft)	Slope of overland flow
KVARY (1/in)	Variable groundwater recession
AGWRC	**Base groundwater recession**
INFEXP	**Exponent in infiltration equation**
INFILD	**Ration of max/mean infiltration capacities**
DEEPFR	Fraction of GW inflow to deep recharge
BASETP	Fraction of remaining ET from baseflow
AGWETP	Fraction of remaining ET from active GW
CEPSC (in)	Interception storage capacity
UZSN (in)	**Upper zone nominal soil moisture storage**
NSUR	Manning's n for overland flow
INTFW	**Interflow inflow parameter**
IRC	**Interflow recession parameter**
LZETP	Lower zone ET parameter
ILS RETSC (in)	Retention storage capacity on impervious land segments
ILS NSUR	Manning's n for overland flow on impervious land segments
ILS LSUR	Length of overland flow on impervious land segments
ILS SLSUR	Slope of overland flow flow on impervious land segments
PETMAX	Temperature below which ET is reduced
PETMIN	Temperature below which ET is set to cero
FTBDSN	WDM data set number for FTABLE
FTABNO	FTABLE number in UCI file
LEN	Stream reach (RCHRES) length
DELTH	Stream reach length change in elevation

Table B2. Suspended sediment parameters used in HSPF simulation

Parameter (Units)	Description
STCOR	Stage correction factor
KS	Routing weighting factor
DB50	Bed sediment diameter
CRRAT	Ratio of maximum to mean flow velocity
VOL	Initial stream channel water volume
SMPF	Supporting management practice factor
KRER	Coefficient in the soil detachment equation
JRER	Exponent in the soil detachment equation
AFFIX (day^{-1})	Daily decrease in sediment attachment rate
COVER	Fraction of land surface which is shielded from erosion by rainfall
NVSI (lb/ac-day)	Rate at which sediment enters detached storage from the atmosphere
KSER	Coefficient in the detached sediment washoff equation
JSER	**Exponent in the detached sediment washoff equation**
KGER	**Scour coefficient for gully erosion**
JGER	**Scour exponent for gully erosion**
KEIM	Coefficient in the solids washoff equation
JEIM	Exponent in the solids washoff equation
ACCSDP (Ton/acre-day)	Rate at which solids accumulate on the land surface
REMSDP (day^{-1})	Fraction of solids storage which is removed each day when there is no runoff
KSAND	**Coefficient in the sand load power function formula**
EXPSND	**Exponent in the sand load power function formula**
TAUCD-SILT (lb/ft^2)	Critical shear stress for deposition
TAUCS-SILT (lb/ft^2)	**Critical shear stress for scour**
M-SILT (lb/ft^2-day)	Erodibility coefficient
TAUCD-CLAY (lb/ft^2)	Critical shear stress for deposition
TAUCS-CLAY (lb/ft^2)	**Critical shear stress for scour**
M-CLAY (lb/ft^2-day)	**Erodibility coefficient**

Table B3. Water quality parameters used in HSPF simulation. (PQUAL module)

Parameter (Units)	Constituent association	Description
POTFW *(qty/ton)*	Sediment (QUALSD)	The wash off potency factor if the constituent is sediment associated.
POTFS *(qty/ton)*	Sediment (QUALSD)	The scour potency factor if the constituent is sediment associated.
SQO *(lbs/acre)*	Overland flow (QUALOF)	Initial Storage of QUALOF on the surface of the pervious land segment.
ACQOP ***(lbs/acre per day)***	**Overland flow (QUALOF)**	**The rate of accumulation of QUALOF**
SQOLIM ***(lbs/acre)***	**Overland flow (QUALOF)**	**The maximum storage of QUALOF**
WSQOP ***(in/hr)***	**Overland flow (QUALOF)**	**The rate of surface runoff which will remove 90 percent of stored QUALOF per hour.**
IOQC *(mg/l)*	Interflow (QUALIF)	Concentration of the constituent in interflow outflow
AOQC *(mg/l)*	Groundwater flow (QUALGW)	Concentration of the constituent in active groundwater outflow.

APPENDIX C
MULTI-OBJECTIVE OPTIMIZATION INTERFACE CODES

APPENDIX C.1 MATLAB INTERFACE TO LINGO AND RANDOM SAMPLE GENERATION

```
clear all
clc
[FileName,PathName] = uigetfile('*.xls','Select Excel-file data ranges
');
nombre=strcat(PathName,FileName);
[ndata, headertext] = xlsread(nombre, 'Rangos');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
prompt = {'Cantidad de modelos:'};
dlg_title = 'Indices de Modelos para LINGO';
num_lines = 1;
def = {'20'};
answer = inputdlg(prompt,dlg_title,num_lines,def);
n = str2num(char(answer));
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
K = menu('Escoger el metodo de
random','uniforme','normal','triangular');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
modelos=ones(n,15);
for i=1:n
 switch K
    case 1 %size(ndata,1)-1
       indices=(ndata(1:15,2)-ndata(1:15,1)).*rand(15,1) ...
               +ndata(1:15,1);
    case 2
       indices=(ndata(1:15,2)-ndata(1:15,1)).*rand(15,1) ...
               +ndata(1:15,1);
    case 3
       indices=(ndata(1:15,2)-ndata(1:15,1)).*rand(15,1) ...
               +ndata(1:15,1);
    otherwise
       error('This is impossible')
 end
      modelos(i,:)=indices;
end
modelos=fix(modelos*1000)/1000; %presicion tres digitos coefficientes
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
a_total=ndata(17,1);
num_eqs=ndata(18,1);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
X1_cond_s=ndata(21,2);
X2_cond_s=ndata(22,2);
X3_cond_s=ndata(23,2);
X4_cond_s=ndata(24,2);
X5_cond_s=ndata(25,2);

X1_cond_i=ndata(21,1);
X2_cond_i=ndata(22,1);
X3_cond_i=ndata(23,1);
X4_cond_i=ndata(24,1);
X5_cond_i=ndata(25,1);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
goal1=ndata(27,1);
goal2=ndata(28,1);
goal3=ndata(29,1);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
[filename, pathname] = uiputfile({'*.xls'},'Save as Aleatorios Models');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
nose = {'X1_E1','X2_E1','X3_E1','X4_E1','X5_E1', ...
        'X1_E2','X2_E2','X3_E2','X4_E2','X5_E2', ...
        'X1_E3','X2_E3','X3_E3','X4_E3','X5_E3'};
xlswrite(strcat(pathname,filename),nose, 'Coeficientes', 'A1:O1');
xlswrite(strcat(pathname,filename),modelos, 'Coeficientes', 'A2');
xlswrite(strcat(pathname,filename),headertext,'Rangos', 'A1');
xlswrite(strcat(pathname,filename),ndata,'Rangos', 'B2');
xlswrite(strcat(pathname,filename),'Xo','Rangos', 'A32');
xlswrite(strcat(pathname,filename),ndata(21:25,1)','Rangos', 'B32');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
[filename, pathname] = uiputfile({'*.lg4'},'Save as Lingo Models');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fid = fopen(strcat(pathname,filename),'wt');
fprintf(fid, 'MODEL:\n');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for i=1:n
fprintf(fid,'\tSUBMODEL ECUACION%d:\n',i);
```

```
if(num_eqs ~= 2)
fprintf(fid,'\tMIN= S11 + S21 + S31;\n');
else
fprintf(fid,'\tMIN= S11 + S21;\n');
end

fprintf(fid,'\tX1 + X2 + X3 + X4 + X5 = %.2f;\n',a_total);
%restricciones de sistema
fprintf(fid,'\tX1 >= %.2f;\n',X1_cond_i);
fprintf(fid,'\tX1 <= %.2f;\n',X1_cond_s);

fprintf(fid,'\tX2 >= %.2f;\n',X2_cond_i);
fprintf(fid,'\tX2 <= %.2f;\n',X2_cond_s);

fprintf(fid,'\tX3 >= %.2f;\n',X3_cond_i);
fprintf(fid,'\tX3 <= %.2f;\n',X3_cond_s);

fprintf(fid,'\tX4 >= %.2f;\n',X4_cond_i);
fprintf(fid,'\tX4 <= %.2f;\n',X4_cond_s);

fprintf(fid,'\tX5 >= %.2f;\n',X5_cond_i);
fprintf(fid,'\tX5 <= %.2f;\n',X5_cond_s);

%restricciones de meta
fprintf(fid,'\t- S11 + %.3f * X1 + %.3f * X2 + %.3f * X3 + %.3f * X4 +
%.3f * X5 + S12 = %.2f ;\n' ...

,modelos(i,1),modelos(i,2),modelos(i,3),modelos(i,4),modelos(i,5),goal1)
;
fprintf(fid,'\t- S21 + %.3f * X1 + %.3f * X2 + %.3f * X3 + %.3f * X4 +
%.3f * X5 + S22 = %.2f ;\n' ...

,modelos(i,6),modelos(i,7),modelos(i,8),modelos(i,9),modelos(i,10),goal2
);
if(num_eqs ~= 2)
```

```
fprintf(fid,'\t- S31 + %.3f * X1 + %.3f * X2 + %.3f * X3 + %.3f * X4 +
%.3f * X5 + S32 = %.2f ;\n' ...

,modelos(i,11),modelos(i,12),modelos(i,13),modelos(i,14),modelos(i,15),g
oal3);
end
fprintf(fid,'\tENDSUBMODEL\n\n');
   %%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%


fprintf(fid,'\tCALC:\n');
fprintf(fid,'\t @SOLVE(ECUACION%d);\n',i);
if( i == 1)
fprintf(fid,'\t   \t@WRITE("\t\tN\t\t","X1\t\t   ","X2\t\t      ","X3\t\t
","X4\t\t ","X5\t\t ");\n');
if(num_eqs == 2)
fprintf(fid,'\t     \t@WRITE("S11\t\t          ","S21\t\t     ","S12\t\t
","S22\t\t");\n');
else
fprintf(fid,'\t   \t@WRITE("S11\t\t     ","S21\t\t","S31\t\t   ","S12\t\t
","S22\t\t","S32\t\t");\n');
end
fprintf(fid,'\t \t@WRITE(@NEWLINE( 1));\n');
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf(fid,'\t \t@WRITE(@FORMAT(%d, "8.0f"),@FORMAT(X1, "11.4f"),',i);
fprintf(fid,'@FORMAT(X2,"11.4f"),@FORMAT(X3,"11.4f"));\n');
fprintf(fid,'\t \t@WRITE(@FORMAT(X4, "11.4f"),');
fprintf(fid,'@FORMAT(X5,"11.4f"));\n');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf(fid,'\t \t@WRITE(@FORMAT( S11, "11.4f"),');
if(num_eqs ~= 2)
fprintf(fid,'@FORMAT(S21,"11.4f"),@FORMAT(S31,"11.4f"));\n');
else
fprintf(fid,'@FORMAT(S21,"11.4f"));\n');
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf(fid,'\t \t@WRITE(@FORMAT( S12, "11.4f"),');
if(num_eqs ~= 2)
```

```
fprintf(fid,'@FORMAT(S22,"11.4f"),@FORMAT(S32,"11.4f"));\n');
else
fprintf(fid,'@FORMAT(S22,"11.4f"));\n');
end
fprintf(fid,'\t \t@WRITE(@NEWLINE( 1));\n');
fprintf(fid,'\tENDCALC\n\n');
end
fprintf(fid, 'END\n');
fclose(fid);
```

APPENDIX C.2 MATLAB FGOALATTAIN FUNCTION AND RANDOM SAMPLE GENERATION

```
clear all;
clc;
%programa para DOS funciones multiobjetivos
[FileName,PathName] = uigetfile('*.xls','Select the Excel-file
aleatorios');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
[ndata, headertext] = xlsread(strcat(PathName,FileName),
'Coeficientes');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
[ndata2, headertext2] = xlsread(strcat(PathName,FileName), 'Rangos');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
prompt = {'Enter filename of function generator:', ...
          'Enter filename of parameter generator:', ...
          'Enter filename of main multiobjetivo:'};
dlg_title = 'Input filenames';
num_lines = 1;
def = {'f_fgoalattain','p_fgoalattain','main_fgoalattain'};
answer = inputdlg(prompt,dlg_title,num_lines,def);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
dname = uigetdir('C:\');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
main_multi=strcat(char(answer(3)),'.m');
fid_main = fopen(strcat(dname,'\',main_multi),'w+');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
prompt={'Enter the WEIGHT:',...
        'Enter the MAXFUNEVALS:',...
        'Enter the MAXITER:',...
        'Enter the GOALSEXACTACHIEVE:'};
name='Input Data Options';
numlines=1;
if ndata2(18,1) == 2
defaultanswer={'[0 0]','500','1e3','0'};
else
defaultanswer={'[0 0 0]','500','1e3','0'};
```

```
end
answer3=inputdlg(prompt,name,numlines,defaultanswer);
weight=char(answer3(1));
maxfunevals=str2num(char(answer3(2)));
maxiter=str2num(char(answer3(3)));
goalsexact=str2num(char(answer3(4)));
fprintf(fid_main,'tic\n');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
for i=1:size(ndata,1)
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% main multiobjetivo
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
pf_multi=strcat(char(answer(2)),num2str(i));
if ndata2(18,1) == 2
fprintf(fid_main,'[x,s11,s21,s12,s22,output]=%s;\n',pf_multi);
fprintf(fid_main,'matriz_x(%d,:)=x;\n',i);
fprintf(fid_main,'matriz_s(%d,:)=[s11 s21 s12 s22 output.iterations
output.funcCount];\n',i);
else
fprintf(fid_main,'[x,s11,s21,s31,s12,s22,s32,output]=%s;\n',pf_multi);
fprintf(fid_main,'matriz_x(%d,:)=x;\n',i);
fprintf(fid_main,'matriz_s(%d,:)=[s11 s21 s31 s12 s22 s32
output.iterations output.funcCount];\n',i);
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% parameter multiobjetivo
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
p_multi=strcat(char(answer(2)),num2str(i),'.m');
fid_p = fopen(strcat(dname,'\',p_multi),'w+');
if ndata2(18,1) == 2
fprintf(fid_p,'function [x,s11,s21,s12,s22,output]=%s;\n',pf_multi);
else
fprintf(fid_p,'function
[x,s11,s21,s31,s12,s22,s32,output]=%s;\n',pf_multi);
end
fprintf(fid_p,'%Problema multiobjetivo\n');
fprintf(fid_p,'%Subrutina fgoalattain para solución de problemas
multiobjetivo\n');
```

```
fprintf(fid_p,'%Punto de arranque del algoritmo\n');
if(mod(i,10) == 0)
fprintf(fid_p,'fprintf(''Modelo = %i\\n'');\n',i);
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% Punto de Arranque
fprintf(fid_p,'x0=[%.2f,%.2f,%.2f,%.2f,%.2f];\n\n',ndata2(31,1),ndata2(3
1,2), ...
              ndata2(31,3),ndata2(31,4),ndata2(31,5));
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%  Objetivos de Inequalidades
fprintf(fid_p,'A = [-1     0       0       0          0;\n');
fprintf(fid_p,'     0      -1      0       0          0;\n');
fprintf(fid_p,'     0      0       -1      0          0;\n');
fprintf(fid_p,'     0      0       0       -1         0;\n');
fprintf(fid_p,'     0      0       0       0         -1];\n');
fprintf(fid_p,'b = [%.2f;%.2f;%.2f;%.2f;%.2f];\n',-1*ndata2(21,1),-
1*ndata2(22,1), ...
              -1*ndata2(23,1),-1*ndata2(24,1),-1*ndata2(25,1));
fprintf(fid_p,'\n');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% Objetivos de igualdades
fprintf(fid_p,'Aeq=[ 1 1 1 1 1];\n');
fprintf(fid_p,'beq=%.2f;\n',ndata2(17,1));
fprintf(fid_p,'\n');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% Range lb <= x <= ub
fprintf(fid_p,'lb=[%.2f;%.2f;%.2f;%.2f;%.2f];\n',ndata2(21,1),ndata2(22,
1), ...
                          ndata2(23,1),ndata2(24,1),ndata2(25,1));
fprintf(fid_p,'ub=[%.2f;%.2f;%.2f;%.2f;%.2f];\n',ndata2(21,2),ndata2(22,
2), ...
                          ndata2(23,2),ndata2(24,2),ndata2(25,2));
fprintf(fid_p,'\n');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% Solve fgoalattain constraint problem
if ndata2(18,1) == 2
```

```
fprintf(fid_p,'goal = [%.2f %.2f];\n',ndata2(27,1),ndata2(28,1));   %
Set goal values
else
fprintf(fid_p,'goal = [%.2f %.2f %.2f];\n',ndata2(27,1), ...
              ndata2(28,1),ndata2(29,1));   % Set goal values
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% Weight
%fprintf(fid_p,'weight = abs(goal);');    % Set weight for same
percentage
fprintf(fid_p,'weight =%s;\n',weight);    % Set weight for same
percentage
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf(fid_p,'options =
optimset(''MaxFunEvals'',%i,''MaxIter'',%i,''GoalsExactAchieve'',%i);',
...
               maxfunevals,maxiter,goalsexact);
fprintf(fid_p,'\n\n');
fprintf(fid_p, ...
'[x,fval,attainfactor,exitflag,output]=fgoalattain(@%s,x0,goal,weight,A,
b,Aeq,beq,lb,ub,[],options);' ...
                        ,strcat(char(answer(1)),num2str(i)));
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% VARIABLES LIBRES
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf(fid_p,'\n\n');
fprintf(fid_p,'s11=fval(1)-goal(1);\n');
fprintf(fid_p,'if(s11 > 0)\n');
fprintf(fid_p,'  s12=0;\n');
fprintf(fid_p,'else\n');
fprintf(fid_p,'  s12=abs(s11);\n');
fprintf(fid_p,'  s11=0;\n');
fprintf(fid_p,'end\n');
fprintf(fid_p,'s21=fval(2)-goal(2);\n');
fprintf(fid_p,'if(s21 > 0)\n');
fprintf(fid_p,'  s22=0; \n');
fprintf(fid_p,'else\n');
fprintf(fid_p,'  s22=abs(s21);\n');
```

```
fprintf(fid_p,'  s21=0;\n');
fprintf(fid_p,'end\n');
if ndata2(18,1) == 3
fprintf(fid_p,'s31=fval(3)-goal(3);\n');
fprintf(fid_p,'if(s31 > 0)\n');
fprintf(fid_p,'  s32=0; \n');
fprintf(fid_p,'else\n');
fprintf(fid_p,'  s32=abs(s31);\n');
fprintf(fid_p,'  s31=0;\n');
fprintf(fid_p,'end\n');
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% function multiobjetivo
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf(fid_p,'%%Información para fminmax\n');
fprintf(fid_p,'%%Función multiobjetivo\n');
fprintf(fid_p,'function f =
%s(x)\n',strcat(char(answer(1)),num2str(i)));
fprintf(fid_p,'f(1)= %f*x(1)+%f*x(2)+%f*x(3)+%f*x(4)+%f*x(5);\n', ...
             ndata(i,1),ndata(i,2),ndata(i,3),ndata(i,4),ndata(i,5));
fprintf(fid_p,'f(2)= %f*x(1)+%f*x(2)+%f*x(3)+%f*x(4)+%f*x(5);\n', ...
             ndata(i,6),ndata(i,7),ndata(i,8),ndata(i,9),ndata(i,10));
if ndata2(18,1) == 3
fprintf(fid_p,'f(3)= %f*x(1)+%f*x(2)+%f*x(3)+%f*x(4)+%f*x(5);\n', ...

ndata(i,11),ndata(i,12),ndata(i,13),ndata(i,14),ndata(i,15));
end
fclose(fid_p);
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% main multiobjetivo
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
fprintf(fid_main,'t_computo = (toc)/60;\n');
fprintf(fid_main,'fprintf(''Tiempo de computo =
%%f\\n'',t_computo);\n');
fprintf(fid_main,'[file,path] = uiputfile(''*.xls'',''Save As to
Excel'');\n');
fprintf(fid_main,'tic\n');
```

```
fprintf(fid_main,'n=(1:%i)'';\n',size(ndata,1));
fprintf(fid_main,'xlswrite(strcat(path,file),n,''Sheet1'', ''A2'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''N''),''Sheet1'',
''A1'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''X1''),''Sheet1'',
''B1'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''X2''),''Sheet1'',
''C1'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''X3''),''Sheet1'',
''D1'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''X4''),''Sheet1'',
''E1'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''X5''),''Sheet1'',
''F1'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''S11''),''Sheet1''
, ''G1'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''S21''),''Sheet1''
, ''H1'')\n');
if ndata2(18,1) == 2
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''S12''),''Sheet1''
, ''I1'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''S22''),''Sheet1''
, ''J1'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''ITER''),''Sheet1'
', ''K1'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''FUNC''),''Sheet1'
', ''L1'')\n');
else
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''S31''),''Sheet1''
, ''I1'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''S12''),''Sheet1''
, ''J1'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''S22''),''Sheet1''
, ''K1'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''S32''),''Sheet1''
, ''L1'')\n');
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''ITER''),''Sheet1'
', ''M1'')\n');
```

```
fprintf(fid_main,'xlswrite(strcat(path,file),cellstr(''FUNC''),''Sheet1'
', ''N1'')\n');
end
fprintf(fid_main,'xlswrite(strcat(path,file),matriz_x,''Sheet1'',''B2'')
\n');
fprintf(fid_main,'xlswrite(strcat(path,file),matriz_s,''Sheet1'',''G2'')
\n');
fprintf(fid_main,'t_guardar = (toc)/60;\n');
fprintf(fid_main,'fprintf(''Tiempo de guardar =
%%f\\n'',t_guardar);\n');
fclose(fid_main);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%% main multiobjetivo
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
cd(dname)
```

APPENDIX C.3 MATLAB PLOT RESULTS

```
close all
clear all
clc
[FileName,PathName] = uigetfile('*.xls','Select the model results Excel-file');
nombre=strcat(PathName,FileName);
[ndata, headertext] = xlsread(nombre);
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%
% cant x1
figure(1)
subplot(5,1,1);
hist(ndata(:,2))
title('Todas las soluciones')
ylabel('X1')
% cant x2
subplot(5,1,2);
hist(ndata(:,3))
ylabel('X2')
% cant x3
subplot(5,1,3);
hist(ndata(:,4))
ylabel('X3')
% cant x4
subplot(5,1,4);
hist(ndata(:,5))
ylabel('X4')
% cant x5
subplot(5,1,5);
hist(ndata(:,6))
ylabel('X5')
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%
% prompt = {'Entre la precision mayor que 0:'};
% dlg_title = 'Precision S11-S21';
% num_lines = 1;
% def = {'.1'};
```

```
% answer = inputdlg(prompt,dlg_title,num_lines,def);
% presic=str2num(char(answer));
presic=0;
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%
% encuentra los s11=s21=0
% column 7 = s11
% column 8 = s21
%s11=s21=s31=0
indices=find(ndata(:,7) <= presic  & ndata(:,8) <= presic & ...
        ndata(:,9) <= presic);
%s11=s21=0 y s31=?
indices2=find(ndata(:,7) <= presic  & ndata(:,8) <= presic & ...
        ndata(:,9) > presic);
%s11=s31=0 y s21=?
indices3=find(ndata(:,7) <= presic  & ndata(:,8) > presic & ...
        ndata(:,9) <= presic);
%s21=s31=0 y s11=?
indices4=find(ndata(:,7) > presic  & ndata(:,8) <= presic & ...
        ndata(:,9) <= presic);

label2 = {'N    ','X1   ','X2   ','X3   ','X4   ','X5   ', ...
      'S11  ','S21  ','S31  ','S12  ','S22  ','S32  ', ...
      'iters','funcC'};
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%
xlswrite(strcat(PathName,FileName),label2, 's11_s21_s31_0','A1:N1');
if(size(indices,1) ~= 0 )
xlswrite(strcat(PathName,FileName),ndata(indices,:), 's11_s21_s31_0', 'A2');
end

xlswrite(strcat(PathName,FileName),label2, 's11_s21_0','A1:N1');
if(size(indices2,1) ~= 0 )
xlswrite(strcat(PathName,FileName),ndata(indices2,:), 's11_s21_0', 'A2');
end

xlswrite(strcat(PathName,FileName),label2, 's11_s31_0','A1:N1');
```

```
if(size(indices3,1) ~= 0 )
xlswrite(strcat(PathName,FileName),ndata(indices3,:), 's11_s31_0', 'A2');
end

xlswrite(strcat(PathName,FileName),label2, 's21_s31_0','A1:N1');
if(size(indices4,1) ~= 0 )
xlswrite(strcat(PathName,FileName),ndata(indices4,:), 's21_s31_0', 'A2');
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%%%%%%
if (~isempty(indices))
figure(2)
plotmatrix(ndata(indices,2:6),'*r')
title('Scatter plot de las soluciones factibles')
end

[FileName2,PathName2] = uigetfile('*.xls','Select aleatorios Excel-file');
nombre2=strcat(PathName2,FileName2);
[ndata2, headertext2] = xlsread(nombre2,'Coeficientes');
xlswrite(strcat(PathName,FileName),'N', 'aleatorios', 'A1');
xlswrite(strcat(PathName,FileName),headertext2, 'aleatorios', 'B1:P1');
if(size(indices,1) ~= 0 )
xlswrite(strcat(PathName,FileName),indices, 'aleatorios', 'A2');
xlswrite(strcat(PathName,FileName),ndata2(indices,:),'aleatorios','B2');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% la estadistica de los aleatorios s11=s21=s31=0
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
xlswrite(strcat(PathName,FileName),cellstr('max='),'stat_s11_s21_s31','A1');
xlswrite(strcat(PathName,FileName),cellstr('min='),'stat_s11_s21_s31','A2');
xlswrite(strcat(PathName,FileName),cellstr('mean='),'stat_s11_s21_s31','A3');
xlswrite(strcat(PathName,FileName),cellstr('median='),'stat_s11_s21_s31','A4');
xlswrite(strcat(PathName,FileName),cellstr('std='),'stat_s11_s21_s31','A5');
xlswrite(strcat(PathName,FileName),cellstr('CV='),'stat_s11_s21_s31','A6');
xlswrite(strcat(PathName,FileName),max(ndata2(indices,1:15),[],1),'stat_s11_s21_s31','B1');
xlswrite(strcat(PathName,FileName),min(ndata2(indices,1:15),[],1),'stat_s11_s21_s31','B2');
xlswrite(strcat(PathName,FileName),mean(ndata2(indices,1:15)),'stat_s11_s21_s31','B3');
xlswrite(strcat(PathName,FileName),median(ndata2(indices,1:15),1),'stat_s11_s21_s31','B4');
```

```
xlswrite(strcat(PathName,FileName),std(ndata2(indices,1:15),0,1),'stat_s11_s21_s31','B5');
CV=std(ndata2(indices,1:15),0,1)./median(ndata2(indices,1:15),1);
xlswrite(strcat(PathName,FileName),CV,'stat_s11_s21_s31','B6');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% la estadistica de las soluciones s11=s21=s31=0
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
xlswrite(strcat(PathName,FileName),cellstr('max='),'stat_s11_s21_s31','A8');
xlswrite(strcat(PathName,FileName),cellstr('min='),'stat_s11_s21_s31','A9');
xlswrite(strcat(PathName,FileName),cellstr('mean='),'stat_s11_s21_s31','A10');
xlswrite(strcat(PathName,FileName),cellstr('median='),'stat_s11_s21_s31','A11');
xlswrite(strcat(PathName,FileName),cellstr('std='),'stat_s11_s21_s31','A12');
xlswrite(strcat(PathName,FileName),cellstr('CV='),'stat_s11_s21_s31','A13');
xlswrite(strcat(PathName,FileName),max(ndata(indices,2:12),[],1),'stat_s11_s21_s31','B8');
xlswrite(strcat(PathName,FileName),min(ndata(indices,2:12),[],1),'stat_s11_s21_s31','B9');
xlswrite(strcat(PathName,FileName),mean(ndata(indices,2:12)),'stat_s11_s21_s31','B10');
xlswrite(strcat(PathName,FileName),median(ndata(indices,2:12),1),'stat_s11_s21_s31','B11');
xlswrite(strcat(PathName,FileName),std(ndata(indices,2:12),0,1),'stat_s11_s21_s31','B12');
CV=std(ndata(indices,2:12),0,1)./median(ndata(indices,2:12),1);
xlswrite(strcat(PathName,FileName),CV,'stat_s11_s21_s31','B13');
end
if(size(indices2,1) ~= 0 )
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% la estadistica de los aleatorios s11=s21=0
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
xlswrite(strcat(PathName,FileName),cellstr('max='),'stat_s11_s21','A1');
xlswrite(strcat(PathName,FileName),cellstr('min='),'stat_s11_s21','A2');
xlswrite(strcat(PathName,FileName),cellstr('mean='),'stat_s11_s21','A3');
xlswrite(strcat(PathName,FileName),cellstr('median='),'stat_s11_s21','A4');
xlswrite(strcat(PathName,FileName),cellstr('std='),'stat_s11_s21','A5');
xlswrite(strcat(PathName,FileName),cellstr('CV='),'stat_s11_s21','A6');
xlswrite(strcat(PathName,FileName),max(ndata2(indices2,1:15),[],1),'stat_s11_s21','B1');
xlswrite(strcat(PathName,FileName),min(ndata2(indices2,1:15),[],1),'stat_s11_s21','B2');
xlswrite(strcat(PathName,FileName),mean(ndata2(indices2,1:15)),'stat_s11_s21','B3');
xlswrite(strcat(PathName,FileName),median(ndata2(indices2,1:15),1),'stat_s11_s21','B4');
xlswrite(strcat(PathName,FileName),std(ndata2(indices2,1:15),0,1),'stat_s11_s21','B5');
CV=std(ndata2(indices,1:15),0,1)./median(ndata2(indices2,1:15),1);
xlswrite(strcat(PathName,FileName),CV,'stat_s11_s21','B6');
```

```
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% la estadistica de las soluciones s11=s21=0
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
xlswrite(strcat(PathName,FileName),cellstr('max='),'stat_s11_s21','A8');
xlswrite(strcat(PathName,FileName),cellstr('min='),'stat_s11_s21','A9');
xlswrite(strcat(PathName,FileName),cellstr('mean='),'stat_s11_s21','A10');
xlswrite(strcat(PathName,FileName),cellstr('median='),'stat_s11_s21','A11');
xlswrite(strcat(PathName,FileName),cellstr('std='),'stat_s11_s21','A12');
xlswrite(strcat(PathName,FileName),cellstr('CV='),'stat_s11_s21','A13');
xlswrite(strcat(PathName,FileName),max(ndata(indices2,2:12),[],1),'stat_s11_s21','B8');
xlswrite(strcat(PathName,FileName),min(ndata(indices2,2:12),[],1),'stat_s11_s21','B9');
xlswrite(strcat(PathName,FileName),mean(ndata(indices2,2:12)),'stat_s11_s21','B10');
xlswrite(strcat(PathName,FileName),median(ndata(indices2,2:12),1),'stat_s11_s21','B11');
xlswrite(strcat(PathName,FileName),std(ndata(indices2,2:12),0,1),'stat_s11_s21','B12');
CV=std(ndata(indices,2:12),0,1)./median(ndata(indices2,2:12),1);
xlswrite(strcat(PathName,FileName),CV,'stat_s11_s21','B13');
end
if(size(indices3,1) ~= 0 )
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% la estadistica de los aleatorios s11=s31=0
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
xlswrite(strcat(PathName,FileName),cellstr('max='),'stat_s11_s31','A1');
xlswrite(strcat(PathName,FileName),cellstr('min='),'stat_s11_s31','A2');
xlswrite(strcat(PathName,FileName),cellstr('mean='),'stat_s11_s31','A3');
xlswrite(strcat(PathName,FileName),cellstr('median='),'stat_s11_s31','A4');
xlswrite(strcat(PathName,FileName),cellstr('std='),'stat_s11_s31','A5');
xlswrite(strcat(PathName,FileName),cellstr('CV='),'stat_s11_s31','A6');
xlswrite(strcat(PathName,FileName),max(ndata2(indices3,1:15),[],1),'stat_s11_s31','B1');
xlswrite(strcat(PathName,FileName),min(ndata2(indices3,1:15),[],1),'stat_s11_s31','B2');
xlswrite(strcat(PathName,FileName),mean(ndata2(indices3,1:15)),'stat_s11_s31','B3');
xlswrite(strcat(PathName,FileName),median(ndata2(indices3,1:15),1),'stat_s11_s31','B4');
xlswrite(strcat(PathName,FileName),std(ndata2(indices3,1:15),0,1),'stat_s11_s31','B5');
CV=std(ndata2(indices,1:15),0,1)./median(ndata2(indices3,1:15),1);
xlswrite(strcat(PathName,FileName),CV,'stat_s11_s31','B6');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% la estadistica de las soluciones s11=s31=0
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
```

```
xlswrite(strcat(PathName,FileName),cellstr('max='),'stat_s11_s31','A8');
xlswrite(strcat(PathName,FileName),cellstr('min='),'stat_s11_s31','A9');
xlswrite(strcat(PathName,FileName),cellstr('mean='),'stat_s11_s31','A10');
xlswrite(strcat(PathName,FileName),cellstr('median='),'stat_s11_s31','A11');
xlswrite(strcat(PathName,FileName),cellstr('std='),'stat_s11_s31','A12');
xlswrite(strcat(PathName,FileName),cellstr('CV='),'stat_s11_s31','A13');
xlswrite(strcat(PathName,FileName),max(ndata(indices3,2:12),[],1),'stat_s11_s31','B8');
xlswrite(strcat(PathName,FileName),min(ndata(indices3,2:12),[],1),'stat_s11_s31','B9');
xlswrite(strcat(PathName,FileName),mean(ndata(indices3,2:12)),'stat_s11_s31','B10');
xlswrite(strcat(PathName,FileName),median(ndata(indices3,2:12),1),'stat_s11_s31','B11');
xlswrite(strcat(PathName,FileName),std(ndata(indices3,2:12),0,1),'stat_s11_s31','B12');
CV=std(ndata(indices,2:12),0,1)./median(ndata(indices3,2:12),1);
xlswrite(strcat(PathName,FileName),CV,'stat_s11_s31','B13');
end
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% la estadistica de los aleatorios s21=s31=0
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
if(size(indices4,1) ~= 0 )
xlswrite(strcat(PathName,FileName),cellstr('max='),'stat_s21_s31','A1');
xlswrite(strcat(PathName,FileName),cellstr('min='),'stat_s21_s31','A2');
xlswrite(strcat(PathName,FileName),cellstr('mean='),'stat_s21_s31','A3');
xlswrite(strcat(PathName,FileName),cellstr('median='),'stat_s21_s31','A4');
xlswrite(strcat(PathName,FileName),cellstr('std='),'stat_s21_s31','A5');
xlswrite(strcat(PathName,FileName),cellstr('CV='),'stat_s21_s31','A6');
xlswrite(strcat(PathName,FileName),max(ndata2(indices4,1:15),[],1),'stat_s21_s31','B1');
xlswrite(strcat(PathName,FileName),min(ndata2(indices4,1:15),[],1),'stat_s21_s31','B2');
xlswrite(strcat(PathName,FileName),mean(ndata2(indices4,1:15)),'stat_s21_s31','B3');
xlswrite(strcat(PathName,FileName),median(ndata2(indices4,1:15),1),'stat_s21_s31','B4');
xlswrite(strcat(PathName,FileName),std(ndata2(indices4,1:15),0,1),'stat_s21_s31','B5');
CV=std(ndata2(indices,1:15),0,1)./median(ndata2(indices4,1:15),1);
xlswrite(strcat(PathName,FileName),CV,'stat_s21_s31','B6');
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% la estadistica de las soluciones s21=s31=0
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
xlswrite(strcat(PathName,FileName),cellstr('max='),'stat_s21_s31','A8');
xlswrite(strcat(PathName,FileName),cellstr('min='),'stat_s21_s31','A9');
xlswrite(strcat(PathName,FileName),cellstr('mean='),'stat_s21_s31','A10');
```

```
xlswrite(strcat(PathName,FileName),cellstr('median='),'stat_s21_s31','A11');
xlswrite(strcat(PathName,FileName),cellstr('std='),'stat_s21_s31','A12');
xlswrite(strcat(PathName,FileName),cellstr('CV='),'stat_s21_s31','A13');
xlswrite(strcat(PathName,FileName),max(ndata(indices4,2:12),[],1),'stat_s21_s31','B8');
xlswrite(strcat(PathName,FileName),min(ndata(indices4,2:12),[],1),'stat_s21_s31','B9');
xlswrite(strcat(PathName,FileName),mean(ndata(indices4,2:12)),'stat_s21_s31','B10');
xlswrite(strcat(PathName,FileName),median(ndata(indices4,2:12),1),'stat_s21_s31','B11');
xlswrite(strcat(PathName,FileName),std(ndata(indices4,2:12),0,1),'stat_s21_s31','B12');
CV=std(ndata(indices,2:12),0,1)./median(ndata(indices4,2:12),1);
xlswrite(strcat(PathName,FileName),CV,'stat_s21_s31','B13');
end
```

APPENDIX D
Multi-objective Optimization Approach Results by Scenario

SCENARIO 1

Table D.1.1 Optimal land use values and goal achievement by nutrient.

Sub-watershed	Algorithm	Land Use Optimal Values (Ha)					Average Goal Achievement[1]	
		Forest (X_1)	Agriculture (X_2)	Urban (X_3)	Pasture (X_4)	Rangeland (X_5)	Nutrient	Value (Kg/yr)
RGA							TP	528.75
	Goal Programming	14,689.44	1,416.55	978.35	35.80	1,452.43	TN	54,915.54
							TS	1,682.74
							TP	591.40
	Fgoalattain	14,699.20	1,363.46	948.75	78.47	1,482.74	TN	55,345.65
							TS	1,734.63
CAONILLAS							TP	371.48
	Goal Programming	8,159.56	710.79	409.05	197.29	2,792.17	TN	18,878.51
							TS	378.07
							TP	358.69
	Fgoalattain	8,160.01	733.11	414.81	198.26	2,762.51	TN	18,524.74
							TS	353.35
LIMON							TP	517.52
	Goal Programming	7,682.52	763.40	174.80	104.70	654.61	TN	1,418.70
							TS	155.36
							TP	526.36
	Fgoalattain	7,676.69	728.02	187.90	110.97	676.28	TN	1,987.99
							TS	168.66

[1] Positive value means an underachievement in the proposed goal;
Barrenland is not included in the optimal value but is considered

Table D.1.2 Land uses optimization values summarize (Scenario 1)

Sub-watershed	Land Use	2005	2025			
		Actual Value (Ha)	Lower Bound (Ha)	Upper Bound (Ha)	Interval (Ha)	Mid. Value (Ha)
RGA	Forest	14,653.1	14,689.4	14,699.2	9.8	14,694.3
	Agriculture	1,286.3	1,363.5	1,416.6	53.1	1,390.1
	Urban	883.7	948.8	978.4	29.6	963.6
	Pasture	11.7	35.8	78.5	42.7	57.2
	Rangeland	1,713.3	1,452.4	1,482.7	30.3	1,467.6
CAONILLAS	Forest	8,155.7	8,159.6	8,160.1	0.5	8,159.9
	Agriculture	643	710.8	733.1	22.3	721.9
	Urban	283.7	409.1	414.8	5.7	411.9
	Pasture	180.9	197.3	198.3	1.0	197.9
	Rangeland	2,970.9	2,762.5	2,792.2	29.7	2777.4
LIMON	Forest	7,627.0	7,676.7	7,682.5	5.8	7,679.6
	Agriculture	694.7	728	763.4	35.4	745.7
	Urban	165.2	174.8	187.9	13.1	181.35
	Pasture	102.3	104.7	110.9	6.2	107.8
	Rangeland	784.9	654.6	676.3	21.7	665.45

Table D.1.3 Land use probable conversion based on mean optimization modeling output. SCENARIO 1 (Forest conservation + agriculture and urban growth)

Land use	Subwatershed land conversion (Ha)			TOTAL
	RGA	Caonillas	Limon	
Forest	38.3 (0.26%)	4.1 (0.05%)	52.5 (0.69%)	94.9
Agriculture	104.0 (8.09%)	78.9 (12.28%)	50.9 (7.34%)	233.8
Urban	79.6 (9.00%)	128.2 (45.20%)	16.1 (9.76%)	223.9
Pasture	45.4 (388.3%)	16.9 (9.33%)	5.51 (5.4%)	67.8
Rangeland	245.4 (-14.33%)	193.6 (-6.52%)	119.42 (-15.2%)	558.4
Barrenland	24.5 (-40.8%)	34.1 (-50.1%)	5.6 (-50.9%)	
Water	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0

Table D.1.4 Total phosphorus average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Kg/Ha*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[0.07 , 0.29]	0.13	[0.05 , 0.27]	0.13	[0.06 , 0.25]	0.13
Agriculture	[0.32 , 2.56]	1.07	[0.32 , 1.59]	0.89	[0.37 , 1.59]	0.88
Urban	[1.42 , 3.79]	2.33	[1.39 , 3.26]	2.26	[0.67 , 1.89]	1.26
Pasture	[0.25 , 2.68]	1.44	[0.18 , 1.60]	0.87	[0.14 , 1.34]	0.72
Rangeland	[0.08 , 0.38]	0.22	[0.06 , 0.29]	0.16	[0.08 , 0.36]	0.22

Table D.1.5 Total nitrogen average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Kg/Ha*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[1.71 , 3.87]	2.76	[1.65 , 4.70]	3.16	[3.12 , 4.21]	3.49
Agriculture	[5.86 , 31.17]	18.61	[5.67 , 28.50]	17.04	[21.69 , 33.51]	26.02
Urban	[6.84 , 11.78]	9.33	[6.14 , 10.79]	8.48	[8.55 , 12.64]	10.56
Pasture	[7.34 , 24.45]	15.93	[6.87 , 24.94]	15.89	[11.46 , 24.05]	17.52
Rangeland	[2.12 , 4.34]	3.24	[2.26 , 5.98]	4.07	[3.64 , 5.13]	4.34

Table D.1.6 Total sediments average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Ton/acre*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[0.0049 , 0.0190]	0.0117	[0.0036 , 0.0049]	0.0044	[0.0028 , 0.0057]	0.0043
Agriculture	[0.1238 , 0.5577]	0.3257	[0.4039 , 0.5378]	0.4705	[0.0955 , 0.2525]	0.1735
Urban	[0.0142 , 0.3096]	0.1607	[0.0170 , 0.0231]	0.0200	[0.0170 , 0.0198]	0.0184
Pasture	[0.0142 , 0.0247]	0.0196	[0.0259 , 0.0348]	0.0305	[0.0348 , 0.0631]	0.0503
Rangeland	[0.0065 , 0.0219]	0.0143	[0.0089 , 0.0101]	0.0095	[0.0057 , 0.0117]	0.0087

SCENARIO 2

Table D.2.1 Optimal land use values and goal achievement by nutrient.

Sub-watershed	Algorithm	Land Use Optimal Values (Ha)					Average Goal Achievement(1)	
		Forest (X_1)	Agriculture (X_2)	Urban (X_3)	Pasture (X_4)	Rangeland (X_5)	Nutrient	Value (Kg/yr)
RGA							TP	451.63
	Goal Programming	14,690.35	1,325.04	1,067.22	13.60	1,476.36	TN	56,096.66
							TS	1,721.79
							TP	537.29
	Fgoalattain	14,700.00	1,338.94	1,003.68	17.02	1,512.99	TN	56,124.62
							TS	1,727.99
CAONILLAS							TP	418.86
	Goal Programming	8,159.72	669.49	409.55	188.40	2,841.70	TN	19,420.71
							TS	421.81
							TP	401.15
	Fgoalattain	8,160.00	669.64	417.07	188.47	2,833.68	TN	19,375.98
							TS	421.31
LIMON							TP	446.15
	Goal Programming	7,695.15	721.04	205.06	105.77	653.07	TN	2,015.90
							TS	163.43
							TP	445.87
	Fgoalattain	7,682.37	720.53	205.72	106.14	664.70	TN	1,973.95
							TS	162.43

(1) Positive value means an underachievement in the proposed goal;
Barrenland is not included in the optimal value but is considered

Table D.2.2 Land uses optimization values summarize (Scenario 2)

Sub-watershed	Land Use	2005	2025			
		Actual Value (Ha)	Lower Bound (Ha)	Upper Bound (Ha)	Interval (Ha)	Mid. Value (Ha)
RGA	Forest	14,653.1	14,690.35	14,700.00	9.65	14,695.18
	Agriculture	1,286.3	1,325.04	1,338.94	13.9	1,331.99
	Urban	883.7	1,003.68	1,067.22	63.54	1,035.45
	Pasture	11.7	13.60	17.02	3.42	15.31
	Rangeland	1,713.3	1,476.36	1,512.99	36.63	1,494.675
CAONILLAS	Forest	8,155.7	8,159.72	8,160.00	0.28	8,159.86
	Agriculture	643	669.49	669.64	0.15	669.565
	Urban	283.7	409.55	417.07	7.52	413.31
	Pasture	180.9	188.40	188.47	0.07	188.435
	Rangeland	2,970.9	2,833.68	2,841.70	8.02	2,837.69
LIMON	Forest	7,627.0	7,682.37	7,695.15	12.78	7,688.76
	Agriculture	694.7	720.53	721.04	0.51	720.785
	Urban	165.2	205.06	205.72	0.66	205.39
	Pasture	102.3	105.77	106.14	0.37	105.955
	Rangeland	784.9	653.07	664.70	11.63	658.885

Table D.2.3 Land use probable conversion based on mean optimization modeling output. SCENARIO 2 (Forest conservation + urban growth priority)

Land use	Subwatershed land conversion (Ha)			TOTAL
	RGA	Caonillas	Limon	
Forest	42.2 (0.29%)	4.2 (0.05%)	61.7 (0.81%)	108.1
Agriculture	46.0 (3.58%)	26.6 (4.1%)	26.1 (3.75%)	98.7
Urban	151.5 (17.1%)	129.6 (45.68%)	40.2 (24.31%)	321.3
Pasture	3.6 (30.8%)	7.5 (4.2%)	3.6 (3.54%)	14.7
Rangeland	218.3 (-12.8%)	133.2 (-4.48%)	126.0 (-16.05%)	477.5
Barrenland	25.0 (-41.7%)	34.7 (-51.0%)	5.6 (-50.9%)	
Water	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0

Table D.2.4 Total phosphorus average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Kg/Ha*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[0.07 , 0.29]	0.13	[0.05 , 0.27]	0.13	[0.06 , 0.25]	0.14
Agriculture	[0.32 , 2.56]	1.07	[0.32 , 1.59]	0.88	[0.37 , 1.58]	0.88
Urban	[1.42 , 3.79]	2.33	[1.39 , 3.26]	2.25	[0.66 , 1.89]	1.25
Pasture	[0.25 , 2.68]	1.44	[0.18 , 1.60]	0.88	[0.14 , 1.34]	0.73
Rangeland	[0.08 , 0.38]	0.22	[0.06 , 0.29]	0.16	[0.08 , 0.36]	0.21

Table D.2.5 Total nitrogen average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Kg/Ha*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[1.71 , 3.87]	2.76	[1.64 , 4.70]	3.17	[3.12 , 4.20]	3.51
Agriculture	[5.86 , 31.16]	18.58	[5.70 , 28.52]	16.87	[21.68 , 33.38]	25.95
Urban	[6.84 , 11.78]	9.34	[6.13 , 10.79]	8.45	[8.55 , 12.64]	10.60
Pasture	[7.34 , 24.48]	15.88	[6.89 , 24.95]	15.89	[11.43 , 23.94]	17.30
Rangeland	[2.12 , 4.34]	3.25	[2.26 , 5.98]	4.11	[3.63 , 5.14]	4.34

Table D.2.6 Total sediments average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Ton/acre*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[0.0049 , 0.0190]	0.0117	[0.0036 , 0.0049]	0.0044	[0.0028 , 0.0057]	0.0042
Agriculture	[0.1238 , 0.5577]	0.3258	[0.4041 , 0.5374]	0.4714	[0.0955 , 0.2529]	0.1795
Urban	[0.0142 , 0.3096]	0.1607	[0.0170 , 0.0231]	0.0201	[0.0170 , 0.0198]	0.0186
Pasture	[0.0142 , 0.0247]	0.0196	[0.0259 , 0.0348]	0.0304	[0.0348 , 0.0627]	0.0491
Rangeland	[0.0065 , 0.0219]	0.0143	[0.0089 , 0.0101]	0.0095	[0.0057 , 0.0117]	0.0087

SCENARIO 3

Table D.3.1 Optimal land use values and goal achievement by nutrient.

Sub-watershed	Algorithm	Land Use Optimal Values (Ha)					Average Goal Achievement(1)	
		Forest (X_1)	Agriculture (X_2)	Urban (X_3)	Pasture (X_4)	Rangeland (X_5)	Nutrient	Value (Kg/yr)
RGA							TP	576.68
	Goal Programming	14,691.42	1,470.44	949.02	10.24	1,451.46	TN	54,588.88
							TS	1,651.42
							TP	637.57
	Fgoalattain	14,699.90	1,392.52	952.23	16.68	1,511.29	TN	55,643.83
							TS	1,712.21
CAONILLAS							TP	551.85
	Goal Programming	8,159.98	756.48	308.80	188.45	2,855.16	TN	18,805.03
							TS	325.14
							TP	548.37
	Fgoalattain	8,160.00	763.92	307.85	188.38	2,848.71	TN	18,708.32
							TS	316.00
LIMON							TP	514.65
	Goal Programming	7,677.18	771.85	171.86	103.39	655.75	TN	1,247.98
							TS	151.74
							TP	533.72
	Fgoalattain	7,680.13	732.40	180.52	106.34	680.01	TN	2,005.98
							TS	167.66

(1) Positive value means an underachievement in the proposed goal;
Barrenland is not included in the optimal value but is considered

Table D.3.2 Land uses optimization values summarize (Scenario 3)

Sub-watershed	Land Use	2005	2025			
		Actual Value (Ha)	Lower Bound (Ha)	Upper Bound (Ha)	Interval (Ha)	Mid. Value (Ha)
RGA	Forest	14,653.1	14,691.42	14,699.90	8.48	14,695.66
	Agriculture	1,286.3	1,392.52	1,470.44	77.92	1,431.48
	Urban	883.7	949.02	952.23	3.21	950.625
	Pasture	11.7	10.24	16.68	6.44	13.46
	Rangeland	1,713.3	1,451.46	1,511.29	59.83	1,481.375
CAONILLAS	Forest	8,155.7	8,159.98	8,160.00	0.02	8,159.99
	Agriculture	643	756.48	763.92	7.44	760.2
	Urban	283.7	307.85	308.80	0.95	308.325
	Pasture	180.9	188.38	188.45	0.07	188.415
	Rangeland	2,970.9	2,848.71	2,855.16	6.45	2,851.935
LIMON	Forest	7,627.0	7,677.18	7,680.13	2.95	7,678.655
	Agriculture	694.7	732.40	771.85	39.45	752.125
	Urban	165.2	171.86	180.52	8.66	176.19
	Pasture	102.3	103.39	106.34	2.95	104.865
	Rangeland	784.9	655.75	680.01	24.26	667.88

Table D.3.3 Land use probable conversion based on mean optimization modeling output. SCENARIO 3 (Forest conservation + agriculture growth priority)

Land use	Subwatershed land conversion (Ha)			**TOTAL**
	RGA	Caonillas	Limon	
Forest	42.7 (0.29%)	4.3 (0.05%)	51.6 (0.68%)	98.6
Agriculture	145.5 (11.31%)	117.2 (18.23%)	57.4 (8.26%)	320.1
Urban	66.7 (7.54%)	24.6 (8.68%)	11.0 (6.63%)	102.3
Pasture	1.8 (15.0%)	7.5 (4.2%)	2.5 (2.48%)	11.8
Rangeland	231.6 (-13.5%)	119.0 (-4.00%)	117.0 (-14.91%)	467.6
Barrenland	25.1 (-41.8%)	34.6 (-50.9%)	5.5 (-50.0%)	
Water	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0

Table D.3.4 Total phosphorus average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Kg/Ha*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[0.07 , 0.28]	0.13	[0.05 , 0.27]	0.13	[0.06 , 0.25]	0.13
Agriculture	[0.32 , 2.55]	1.08	[0.32 , 1.59]	0.88	[0.37 , 1.58]	0.89
Urban	[1.42 , 3.80]	2.33	[1.39 , 3.26]	2.26	[0.67 , 1.89]	1.26
Pasture	[0.25 , 2.68]	1.43	[0.18 , 1.60]	0.88	[0.14 , 1.33]	0.75
Rangeland	[0.08 , 0.38]	0.22	[0.06 , 0.29]	0.16	[0.08 , 0.36]	0.22

Table D.3.5 Total nitrogen average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Kg/Ha*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[1.71 , 3.87]	2.77	[1.64 , 4.70]	3.16	[3.12 , 4.25]	3.49
Agriculture	[5.80 , 31.20]	18.69	[5.69 , 28.52]	16.84	[21.68 , 33.42]	25.96
Urban	[6.85 , 11.81]	9.30	[6.13 , 10.79]	8.44	[8.55 , 12.59]	10.50
Pasture	[7.34 , 24.31]	16.20	[6.89 , 24.95]	15.87	[11.44 , 24.09]	17.56
Rangeland	[2.12 , 4.33]	3.21	[2.26 , 5.98]	4.11	[3.63 , 5.13]	4.34

Table D.3.6 Total sediments average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Ton/acre*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[0.0049 , 0.0190]	0.0118	[0.0036 , 0.0049]	0.0044	[0.0028 , 0.0057]	0.0043
Agriculture	[0.1238 , 0.5577]	0.3255	[0.4043 , 0.5370]	0.4723	[0.0955 , 0.2525]	0.1735
Urban	[0.0142 , 0.3096]	0.1606	[0.0170 , 0.0231]	0.0202	[0.0170 , 0.0198]	0.0184
Pasture	[0.0142 , 0.0247]	0.0196	[0.0259 , 0.0348]	0.0304	[0.0348 , 0.0631]	0.0503
Rangeland	[0.0065 , 0.0219]	0.0143	[0.0089 , 0.0101]	0.0095	[0.0057 , 0.0117]	0.0087

SCENARIO 11

Table D.4.1 Optimal land use values and goal achievement by nutrient.

Sub-watershed	Algorithm	Land Use Optimal Values (Ha)					Average Goal Achievement[1]	
		Forest (X_1)	Agriculture (X_2)	Urban (X_3)	Pasture (X_4)	Rangeland (X_5)	Nutrient	Value (Kg/yr)
RGA							TP	158,105
	Goal Programming	14,700.00	1,389.33	989.82	19.88	1,371.44	TN	3,850,230
							TS	1,584
							TP	158,270
	Fgoalattain	14,700.00	1,469.83	1,010.69	19.88	1,472.81	TN	3,851,607
							TS	1,656
CAONILLAS							TP	87,712
	Goal Programming	8,160.00	734.08	430.53	198.40	2,745.86	TN	3,764,204
							TS	350
							TP	87,712
	Fgoalattain	8,160.00	734.08	430.53	198.40	2,745.86	TN	3,764,204
							TS	350
LIMON							TP	64,211
	Goal Programming	7,671.69	737.26	164.71	102.35	626.74	TN	4,600,700
							TS	144
							TP	64,218
	Fgoalattain	7,685.20	787.59	189.39	111.64	670.53	TN	4,601,588
							TS	163

[1] **Positive value means an underachievement in the proposed goal;**
Barrenland is not included in the optimal value but is considered

Table D.4.2 Land uses optimization values summarize (Scenario 11)

Sub-watershed	Land Use	2005	2025			
		Actual Value (Ha)	Lower Bound (Ha)	Upper Bound (Ha)	Interval (Ha)	Mid. Value (Ha)
RGA	Forest	14,653.1	14,700.0	14,700.0	0.0	14,700.0
	Agriculture	1,286.3	1,389.3	1,469.8	80.5	1,429.6
	Urban	883.7	989.8	1,010.7	20.9	1,000.3
	Pasture	11.7	19.9	19.9	0.0	19.9
	Rangeland	1,713.3	1,371.4	1,472.8	101.4	1,422.1
CAONILLAS	Forest	8,155.7	8,160.0	8,160.0	0.0	8,160.0
	Agriculture	643	734.1	734.1	0.0	734.1
	Urban	283.7	430.5	430.5	0.0	430.5
	Pasture	180.9	198.4	198.4	0.0	198.4
	Rangeland	2,970.9	2,745.9	2,745.9	0.0	2,745.9
LIMON	Forest	7,627.0	7,671.7	7,685.2	13.5	7,678.5
	Agriculture	694.7	737.3	787.6	50.3	762.5
	Urban	165.2	164.7	189.4	24.7	177.1
	Pasture	102.3	102.4	111.6	9.2	107.0
	Rangeland	784.9	626.7	670.5	43.8	648.6

Table D.4.3 Land use probable conversion based on mean optimization modeling output. SCENARIO 11 (Forest conservation + agriculture and urban growth)

Land use	Subwatershed land conversion (Ha)			TOTAL
	RGA	Caonillas	Limon	
Forest	47.0 (0.32%)	4.3 (0.05%)	58.1 (0.76%)	109.4
Agriculture	143.6 (11.2%)	91.1 (14.2%)	67.7 (9.7%)	302.4
Urban	116.3 (13.2%)	146.8 (51.8%)	11.8 (7.2%)	274.9
Pasture	8.2 (69.9%)	17.5 (9.7%)	4.7 (4.6%)	30.4
Rangeland	290.9 (-17.0%)	225.0 (-7.6%)	136.2 (-17.4%)	652.1
Barrenland	24.2 (-40.3%)	34.7 (-51.0%)	6.1 (-55.5%)	
Water	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0

Table D.4.4. Total phosphorus average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Kg/Ha*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[0.07 , 0.35]	0.21	[0.05 , 0.27]	0.16	[0.06 , 0.26]	0.16
Agriculture	[0.32 , 2.91]	1.65	[0.32 , 1.59]	0.97	[0.37 , 1.59]	1.00
Urban	[1.42 , 3.81]	2.62	[1.39 , 3.26]	2.33	[0.66 , 1.89]	1.29
Pasture	[0.25 , 2.69]	1.44	[0.18 , 1.60]	0.87	[0.14 , 1.34]	0.73
Rangeland	[0.08 , 0.38]	0.23	[0.06 , 0.29]	0.18	[0.08 , 0.36]	0.22

Table D.4.5 Total nitrogen average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Kg/Ha*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[1.70 , 3.88]	2.78	[1.64 , 4.70]	3.17	[3.12 , 4.96]	4.04
Agriculture	[5.75 , 31.20]	18.62	[5.66 , 28.49]	17.20	[21.66 , 33.53]	27.52
Urban	[6.82 , 11.83]	9.38	[6.12 , 10.79]	8.50	[8.54 , 12.64]	10.56
Pasture	[7.20 , 24.63]	16.15	[6.86 , 24.94]	16.14	[11.35 , 24.13]	17.69
Rangeland	[2.12 , 4.36]	3.22	[2.25 , 5.97]	4.08	[3.63 , 5.16]	4.40

Table D.4.6 Total sediments average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Ton/acre*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[0.0049 , 0.0190]	0.0118	[0.0036 , 0.0049]	0.0044	[0.0028 , 0.0057]	0.0042
Agriculture	[0.1218 , 0.5581]	0.3371	[0.4039 , 0.5383]	0.4701	[0.0951 , 0.2533]	0.1749
Urban	[0.0125 , 0.3116]	0.1617	[0.0170 , 0.0231]	0.0201	[0.0170 , 0.0198]	0.0185
Pasture	[0.0142 , 0.0247]	0.0197	[0.0259 , 0.0348]	0.0305	[0.0348 , 0.0627]	0.0491
Rangeland	[0.0065 , 0.0219]	0.0142	[0.0089 , 0.0101]	0.0095	[0.0057 , 0.0117]	0.0087

SCENARIO 12

Table D.5.1 Optimal land use values and goal achievement by nutrient.

Sub-watershed	Algorithm	Land Use Optimal Values (Ha)					Average Goal Achievement(1)	
		Forest (X_1)	Agriculture (X_2)	Urban (X_3)	Pasture (X_4)	Rangeland (X_5)	Nutrient	Value (Kg/yr)
RGA							TP	157,974
	Goal Programming	14,700.00	1,341.63	1,141.88	17.89	1,370.45	TN	3,851,430
							TS	1,639
							TP	158,179
	Fgoalattain	14,700.00	1,341.63	1,056.91	17.89	1,455.42	TN	3,851,957
							TS	1,670
CAONILLAS							TP	87,770
	Goal Programming	8,160.00	669.60	430.53	188.48	2,820.26	TN	3,765,178
							TS	425
							TP	87,770
	Fgoalattain	8,160.00	669.60	430.53	188.48	2,820.26	TN	3,765,178
							TS	425
LIMON							TP	64,215
	Goal Programming	7,700.00	727.44	213.75	106.63	632.28	TN	4,601,694
							TS	171
							TP	64,214
	Fgoalattain	7,686.25	727.66	213.81	106.66	646.18	TN	4,601,689
							TS	171

(1) Positive value means an underachievement in the proposed goal;
Barrenland is not included in the optimal value but is considered

Table D.5.2. Land uses optimization values summarize (Scenario 12)

Sub-watershed	Land Use	2005	2025			
		Actual Value (Ha)	Lower Bound (Ha)	Upper Bound (Ha)	Interval (Ha)	Mid. Value (Ha)
RGA	Forest	14,653.1	14,700.0	14,700.0	0.0	14,700.0
	Agriculture	1,286.3	1,341.6	1,341.6	0.0	1,341.6
	Urban	883.7	1,056.9	1,141.9	85.0	1,099.4
	Pasture	11.7	17.9	17.9	0.0	17.9
	Rangeland	1,713.3	1,370.5	1,455.4	84.9	1,413.0
CAONILLAS	Forest	8,155.7	8,160.0	8,160.0	0.0	8,160.0
	Agriculture	643	669.6	669.6	0.0	669.6
	Urban	283.7	430.5	430.5	0.0	430.5
	Pasture	180.9	188.5	188.5	0.0	188.5
	Rangeland	2,970.9	2,820.3	2,820.3	0.0	2,820.3
LIMON	Forest	7,627.0	7,686.3	7,700.0	13.7	7,693.2
	Agriculture	694.7	727.4	727.6	0.2	727.5
	Urban	165.2	213.7	213.8	0.1	213.8
	Pasture	102.3	106.6	106.7	0.1	106.7
	Rangeland	784.9	632.3	646.2	13.9	639.3

Table D.5.3. Land use probable conversion based on mean optimization modeling output. SCENARIO 12 (Forest conservation + urban growth priority)

Land use	Subwatershed land conversion (Ha)			**TOTAL**
	RGA	Caonillas	Limon	
Forest	47.0 (0.32%)	4.3 (0.05%)	66.0 (0.87%)	117.3
Agriculture	55.6 (4.3%)	26.6 (4.1%)	32.8 (4.7%)	115.0
Urban	215.4 (24.4%)	146.8 (51.8%)	48.6 (29.4%)	410.8
Pasture	6.2 (52.9%)	7.6 (4.2%)	4.3 (4.2%)	18.1
Rangeland	300.1 (-17.5%)	150.6 (-5.1%)	145.6 (-18.6%)	596.3
Barrenland	24.1 (-40.2%)	34.7 (-51.0%)	6.1 (-55.5%)	
Water	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0

Table D.5.4. Total phosphorus average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Kg/Ha*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[0.07 , 0.35]	0.21	[0.05 , 0.27]	0.16	[0.06 , 0.26]	0.16
Agriculture	[0.32 , 2.91]	1.65	[0.32 , 1.59]	0.97	[0.37 , 1.59]	0.99
Urban	[1.42 , 3.81]	2.62	[1.39 , 3.26]	2.33	[0.66 , 1.89]	1.28
Pasture	[0.25 , 2.69]	1.44	[0.18 , 1.60]	0.87	[0.14 , 1.34]	0.73
Rangeland	[0.08 , 0.38]	0.23	[0.06 , 0.29]	0.18	[0.08 , 0.36]	0.22

Table D.5.5 Total nitrogen average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Kg/Ha*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[1.70 , 3.88]	2.78	[1.64 , 4.70]	3.17	[3.12 , 4.96]	4.03
Agriculture	[5.75 , 31.20]	18.62	[5.66 , 28.49]	17.20	[21.67 , 33.51]	27.65
Urban	[6.82 , 11.83]	9.38	[6.12 , 10.79]	8.50	[8.53 , 12.64]	10.63
Pasture	[7.20 , 24.63]	16.15	[6.86 , 24.94]	16.14	[11.33 , 24.11]	17.90
Rangeland	[2.12 , 4.36]	3.22	[2.25 , 5.97]	4.08	[3.63 , 5.16]	4.38

Table D.5.6 Total sediments average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Ton/acre*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[0.0049 , 0.0190]	0.0118	[0.0036 , 0.0049]	0.0044	[0.0028 , 0.0057]	0.0042
Agriculture	[0.1218 , 0.5581]	0.3371	[0.4039 , 0.5383]	0.4701	[0.0951 , 0.2533]	0.1730
Urban	[0.0125 , 0.3116]	0.1617	[0.0170 , 0.0231]	0.0201	[0.0170 , 0.0198]	0.0184
Pasture	[0.0142 , 0.0247]	0.0197	[0.0259 , 0.0348]	0.0305	[0.0348 , 0.0631]	0.0494
Rangeland	[0.0065 , 0.0219]	0.0142	[0.0089 , 0.0101]	0.0095	[0.0057 , 0.0117]	0.0087

SCENARIO 13

Table D.6.1 Optimal land use values and goal achievement by nutrient.

Sub-watershed	Algorithm	Land Use Optimal Values (Ha)					Average Goal Achievement[1]	
		Forest (X_1)	Agriculture (X_2)	Urban (X_3)	Pasture (X_4)	Rangeland (X_5)	Nutrient	Value (Kg/yr)
RGA							TP	158,133
	Goal Programming	14,700.00	1,533.43	965.97	10.93	1,361.51	TN	3,849,638
							TS	1,549
							TP	158,311
	Fgoalattain	14,700.00	1,402.25	965.97	17.89	1,485.73	TN	3,851,581
							TS	1,655
CAONILLAS							TP	87956
	Goal Programming	8,160.00	765.82	309.50	188.48	2,845.06	TN	3,764,445
							TS	317
							TP	87,956
	Fgoalattain	8,160.00	765.82	309.50	188.48	2,845.06	TN	3,764,445
							TS	317
LIMON							TP	64,210
	Goal Programming	7,696.41	789.70	164.72	102.24	627.02	TN	4,600,651
							TS	143
							TP	64,226
	Fgoalattain	7,676.03	741.57	181.42	106.66	674.86	TN	4,601,605
							TS	162

[1] Positive value means an underachievement in the proposed goal;
Barrenland is not included in the optimal value but is considered

Table D.6.2 Land uses optimization values summarize (Scenario 13)

Sub-watershed	Land Use	2005	2025			
		Actual Value (Ha)	Lower Bound (Ha)	Upper Bound (Ha)	Interval (Ha)	Mid. Value (Ha)
RGA	Forest	14,653.1	14,700	14,700	0.0	14,700.0
	Agriculture	1,286.3	1,402.3	1,533.4	131.1	1,467.9
	Urban	883.7	965.9	965.9	0.0	965.9
	Pasture	11.7	10.9	17.9	7.0	14.4
	Rangeland	1,713.3	1,316.5	1,485.7	169.2	1,401.1
CAONILLAS	Forest	8,155.7	8,160.0	8,160.0	0.0	8,160.0
	Agriculture	643	765.8	765.8	0.0	765.8
	Urban	283.7	309.5	309.5	0.0	309.5
	Pasture	180.9	188.5	188.5	0.0	188.5
	Rangeland	2,970.9	2,845.1	2,845.1	0.0	2,845.1
LIMON	Forest	7,627.0	7,676.1	7,696.4	20.3	7,686.3
	Agriculture	694.7	741.6	789.7	48.1	765.7
	Urban	165.2	164.7	181.4	16.7	173.1
	Pasture	102.3	102.2	106.7	4.5	104.5
	Rangeland	784.9	627.1	674.9	47.8	651.0

Table D.6.3 Land use probable conversion based on mean optimization modeling output. SCENARIO 13 (Forest conservation + agriculture growth priority)

Land use	Subwatershed land conversion (Ha)			TOTAL
	RGA	Caonillas	Limon	
Forest	47.0 (0.32%)	4.3 (0.05%)	59.1 (0.78%)	110.4
Agriculture	181.8 (14.1%)	122.8 (19.1%)	70.9 (10.2%)	375.5
Urban	81.9 (9.3%)	25.8 (9.1%)	7.8 (4.7%)	115.5
Pasture	2.7 (23.2%)	7.6 (4.2%)	2.1 (2.1%)	12.4
Rangeland	289.4 (-16.9%)	125.8 (-4.2%)	133.9 (-17.1%)	549.1
Barrenland	24.0 (-40.0%)	34.7 (-51.0%)	6.0 (-54.5%)	
Water	0.0 (0%)	0.0 (0%)	0.0 (0%)	0.0

Table D.6.4 Total phosphorus average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Kg/Ha*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[0.07 , 0.35]	0.21	[0.05 , 0.27]	0.16	[0.06 , 0.26]	0.16
Agriculture	[0.32 , 2.91]	1.65	[0.32 , 1.59]	0.97	[0.37 , 1.59]	1.00
Urban	[1.42 , 3.81]	2.62	[1.39 , 3.26]	2.33	[0.66 , 1.89]	1.29
Pasture	[0.25 , 2.69]	1.44	[0.18 , 1.60]	0.87	[0.14 , 1.34]	0.73
Rangeland	[0.08 , 0.38]	0.23	[0.06 , 0.29]	0.18	[0.08 , 0.36]	0.22

Table D.6.5 Total nitrogen average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Kg/Ha*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[1.70 , 3.88]	2.78	[1.64 , 4.70]	3.17	[3.12 , 4.96]	4.04
Agriculture	[5.75 , 31.20]	18.62	[5.66 , 28.49]	17.20	[21.66 , 33.53]	27.52
Urban	[6.82 , 11.83]	9.38	[6.12 , 10.79]	8.50	[8.54 , 12.64]	10.56
Pasture	[7.20 , 24.63]	16.15	[6.86 , 24.94]	16.14	[11.35 , 24.13]	17.69
Rangeland	[2.12 , 4.36]	3.22	[2.25 , 5.97]	4.08	[3.63 , 5.16]	4.40

Table D.6.6.Total sediments average optimal land use export coefficients (Normal conditions)

Land use	Export coefficients (Ton/acre*yr)					
	RGA		Caonillas		Limón	
	Initial	Mean optimal	Initial	Mean optimal	Initial	Mean optimal
Forest	[0.0049 , 0.0190]	0.0118	[0.0036 , 0.0049]	0.0044	[0.0028 , 0.0057]	0.0042
Agriculture	[0.1218 , 0.5581]	0.3371	[0.4039 , 0.5383]	0.4701	[0.0951 , 0.2533]	0.1749
Urban	[0.0125 , 0.3116]	0.1617	[0.0170 , 0.0231]	0.0201	[0.0170 , 0.0198]	0.0185
Pasture	[0.0142 , 0.0247]	0.0197	[0.0259 , 0.0348]	0.0305	[0.0348 , 0.0627]	0.0491
Rangeland	[0.0065 , 0.0219]	0.0142	[0.0089 , 0.0101]	0.0095	[0.0057 , 0.0117]	0.0087

APPENDIX E
ENTITY RELATIONAL DATABASE

Table E.1 Entity relational database format

<table>
<tr><th colspan="5">ENTITY <Entity name></th></tr>
<tr><td colspan="3">Layer (s): <name of layer></td><td colspan="2">Info_Table: <name of table></td></tr>
<tr><td colspan="5">Description: <description></td></tr>
<tr><td colspan="3">Project Coordinate System: <Projection+datum></td><td colspan="2">Data_type: <raster or shapefile></td></tr>
<tr><th colspan="5">ATTRIBUTES LIST</th></tr>
<tr><td>Name</td><td>Description</td><td>Type</td><td>Indexed</td><td>Condition</td></tr>
<tr><td><attribute 1></td><td><description 1></td><td><type 1></td><td><in 1></td><td><ob 1></td></tr>
<tr><td><attribute 2></td><td><description 2></td><td><type 2></td><td><in 2></td><td><ob 2></td></tr>
<tr><td>…</td><td>…</td><td>…</td><td>…</td><td>…</td></tr>
</table>

A. AGRICULTURAL MODEL

ENTITY <Entity name>				
Layer (s): *soils.shp*			Info_Table: *soils.dbf*	
Description: Soils layer based on the U.S. Department of Agriculture and Agro-ecological zones (ZAE's) from the National Resources Conservation Service (NRCS)				
Project Coordinate System: UTM NAD 83			Data_type: shape file, polygon	
ATTRIBUTES LIST				
Name	Description	Type	Indexed	Condition
MUSYM	Soils code	Text	NO	Optional
Comment	Soil code description	Text	NO	Optional
Hyd_group1	Hydrological group	Text	NO	Optional
ZAE	Agro-ecological zone	Text	NO	Optional
ZAE_OPT_CO	Boolean Agro-ecological zone	Short Integer	NO	Required

ENTITY <Entity name>				
Layer (s): *landuse.shp*			Info_Table: *landuse.dbf*	
Description: Land Use from the Junta de Planificación de Puerto Rico (1977) and redefinition in 2000 by CSA Group private consultants				
Project Coordinate System: UTM NAD 83			Data_type: shape file, polygon	
ATTRIBUTES LIST				
Name	Description	Type	Indexed	Condition
LU_CODE	Land use numeric code*	Short Integer	NO	Optional
LU_OPT_COD	Boolean Land use numeric code	Short Integer	NO	Required

*1= Urban; 3=Agriculture; 4=Forest; 5=Pasture; 6=Rangeland; 7=Barrenland; 12= waterbodies

ENTITY <Entity name>				
Layer (s): *stream.shp*			Info_Table: *stream.dbf*	
Description: Stream network, including the main rivers in the watershed.				
Project Coordinate System: UTM NAD 83			Data_type: shape file, polyline	
ATTRIBUTES LIST				
Name	Description	Type	Indexed	Condition
ARCID	Segment ID	Short Integer	Yes	Required
SNAME	Streams name	Text	No	Optional

ENTITY <Entity name>				
Layer (s): *rivers_buff.shp*			Info_Table: *rivers_buff.dbf*	
Description: Rivers network buffer at 0.5 Km (by criteria)				
Project Coordinate System: UTM NAD 83			Data_type: shape file, polygon	
ATTRIBUTES LIST				
Name	Description	Type	Indexed	Condition
Id	Default_Id	Short Integer	No	Optional
Buff_river	Buffer code	Short Integer	No	Required

ENTITY <Entity name>				
Layer (s): *subbasins.shp*			Info_Table: *subbasins.dbf*	
Description: Subwatershed division form 1 to 18*				
Project Coordinate System: UTM NAD 83			Data_type: shape file, polygon	
ATTRIBUTES LIST				
Name	Description	Type	Indexed	Condition
DRAINTYPE	Drain type code(1)	Short Integer	No	Optional
BASIN_ID	Basin Id code	Short Integer	Yes	Required
MEANELEV	Subbasin mean elevation	Float	No	Optional

*1 to 18 means: 1-9, RGA watershed; 10-12, Caonillas watershed; 16-18, Limón watershed

B. URBAN OR BUILT-UP MODEL

ENTITY <Entity name>				
Layer (s): *landuse.shp*			Info_Table: *landuse.dbf*	
Description: Land Use from the Junta de Planificación de Puerto Rico (1977) and redefinition in 2000 by CSA Group private consultants				
Project Coordinate System: UTM NAD 83			Data_type: shape file, polygon	
ATTRIBUTES LIST				
Name	Description	Type	Indexed	Condition
LU_CODE	Land use numeric code*	Short Integer	NO	Optional
LU_OPT_COD	Boolean Land use numeric code	Short Integer	NO	Required

*1= Urban; 3=Agriculture; 4=Forest; 5=Pasture; 6=Rangeland; 7=Barrenland; 12= waterbodies

ENTITY <Entity name>				
Layer (s): *subbasins.shp*			Info_Table: *subbasins.dbf*	
Description: Subwatershed division form 1 to 18*				
Project Coordinate System: UTM NAD 83			Data_type: shape file, polygon	
ATTRIBUTES LIST				
Name	Description	Type	Indexed	Condition
DRAINTYPE	Drain type code(1)	Short Integer	No	Optional
BASIN_ID	Basin Id code	Short Integer	Yes	Required
MEANELEV	Subbasin mean elevation	Float	No	Optional

*1 to 18 means: 1-9, RGA watershed; 10-12, Caonillas watershed; 16-18, Limón watershed

ENTITY <Entity name>				
Layer (s): *roads_buffer.shp*			Info_Table: *roads_buffer.dbf*	
Description: Roads network buffer at 200 m (by criteria)				
Project Coordinate System: UTM NAD 83			Data_type: shape file, polygon	
ATTRIBUTES LIST				
Name	Description	Type	Indexed	Condition
Id	Default_Id	Short Integer	No	Optional
Buffer_Op	Buffer_code	Short Integer	No	Required

ENTITY <Entity name>				
Layer (s): *pr dem_utm83.img*			Info_Table: NA	
Description: Puerto Rico digital elevation model				
Project Coordinate System: UTM NAD 83			Data_type: raster	
ATTRIBUTES LIST				
Name	Description	Type	Indexed	Condition

ENTITY <Entity name>				
Layer (s): *Slope.img*			Info_Table: NA	
Description: Raster file containing the slope pattern in the watershed				
Project Coordinate System: UTM NAD 83			Data_type: raster	
ATTRIBUTES LIST				
Name	Description	Type	Indexed	Condition

APPENDIX F
SOCIO-ECONOMIC
COMPILED DATABASE

The next table is a compendium of all the documents and interviews to evaluate the socio-economic conditions at the RGA watershed used as the basis for the Multi-objective Optimization Scenarios formulation.

A. Documents			
1. Territorial Order Plan 1.1 Utuado Municipality (2003) 1.2 Jayuya Municipality (2002)			
2. Ley de Municipios Autónomos de Puerto Rico (1991)			
3. Plan de Usos de Terreno de Puerto Rico; Perfil Regional, Región Central (Junta de Planificación de Puerto Rico)			
4. Ley de Planificación de Puerto Rico; Ley 75 (1975)			
5.Gobernabilidad y municipalización en Puerto Rico (1998)			
B. Interviews			
NAME	AGENCY	DESCRIPTION	DATE
Mr. Félix Aponte	Escuela de Planificación, Universidad de Puerto Rico, Recinto Universitario de Río Piedras	Interview with Mr. Aponte to talk about the planning order plans in Puerto Rico and planning in the country.	
Mr. Luis Seda	Jayuya Municipality, Planning Office	Interview to talk about the Territorial Order Plan in Jayuya and tasks in the Planning Office	
Mr. MiguelMaldonado	Utuado Municipality, Territorial Order Plan	Interview to talk about the Territorial Order Plan in Utuado	
Mr. Pedro Rodríguez	Agronomist, Agriculture Department of Puerto Rico	Interview with emphasys in the actual agriculture conditions of the zone, as well as the projections in this activity.	
Mr. Manuel Cordero	Agronomist, Agriculture Experimental Station	Interview with emphasys in the actual agriculture conditions of the zone, as well as the projections in this activity.	
Mr. Víctor de Jesús	Agriculture Department North Central Region Director	Interview to analyze the past, actual and future projections in the agriculture of the zone.	