TOWARD SUSTAINABLE RESERVOIR DESIGN: APPLICATION OF DE NOVO PROGRAMMING

BY

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ABSTRACT

Motivation to provide sustainable development for the benefit of present and future generations has led engineers to search for improved design techniques which address all system impacts. The construction of multipurpose reservoirs is a good example of the difficulty in achieving sustainable development given the grand scale, and complex nature of project impacts on society, environment, and the economy. Sustainability of reservoirs implies a need for the control and adjustment of reservoir design and operation characteristics, resulting in optimal, or near optimal system performance throughout the life time of the reservoir. This work focuses on Milan Zeleny's de novo programming, a system design approach which links system flexibility, efficiency, and optimal system design. It is shown that within multiobjective decision making framework, de novo programming may allow the decision maker to achieve an ideal or metaoptimal system performance, or improve the performance of compromise solutions, through the modification or shaping of the feasible region of decision alternatives. As a result, this method shifts the traditional approach of optimization, from optimization of a given reservoir system, to the design of the optimal reservoir system. If the formulation of system impacts is possible at the design stage, de novo programming may be used as a tool for sustainable reservoir design.

1. INTRODUCTION

Sections 1.1 through 1.3 describe the purpose, problem, and scope of the work contained thereafter. The remaining chapters are organized in a manner which will allow the reader to become familiar with de novo programming prior to its application to a reservoir design problem. The remaining chapters concentrate on the results of de novo programming, its suitability to reservoir design, and water resources planning in general.

1.1 Purpose

A systems approach in water resources decision making results in a well organized framework of mathematical techniques in generating optimal, or best compromise decisions. It requires the definition and understanding of system components and their relationship with the decision makers' objectives. In a conflicting objective environment, the systems approach extends to include mathematical techniques for selecting preferable decision alternatives among a predetermined set of feasible compromise solutions. It has been proven to be a successful decision making tool, although in many practical cases the high complexity of the system, computer hardware limitations, and limited user knowledge of solution techniques, have hindered its application.

The first purpose of this thesis stems from the traditional approach to optimization in the field of water resources planning. Mainly that of intense focus on the optimization of predetermined systems of constraints and objectives. The de novo programming approach stresses the importance of optimal system design and has not been applied in this field. Therefore, the first purpose is to apply de novo programming to a water resources planning problem and to evaluate its potential as an optimization approach.

Water shortages through over allocating existing supplies, poor management, planning, and development of watersheds, has focused the attention of engineers on the evaluation of existing planning and management methods. Through collective discussions regarding changes that should be made to existing practices, a new water resources development objective has evolved: sustainable development. Research on this topic continues to generate discussions regarding sustainable objectives, guide lines, or constraints for water resources development. Although a precise definition of sustainable development does not exist, the most widely used definition for sustainable water resources development is that which satisfies the need of the present generation, without compromising future generations to meet their own needs, World Commission on Environment and Development, (WCED, 1987).

Sustainable reservoir design is an objective without existing methodology, Lele (1991), Dovers & Handmer (1993). Sustainability implies the need for complete data information systems, available prior to the selection of a project alternative, and new tools for solving existing problems. These characteristics generated the second purpose for this work, to investigate the use of de novo programming as a tool for sustainable reservoir design. The next two sections introduce the water resources planning problem, state the method that will be used to evaluate de novo programming, and describe the direction with which de novo programming may be used in future water resources planning studies.

1.2 Problem

The single most effective method of water management is attained through the development and operation of reservoirs. Reservoirs are operated to provide many benefits such as hydropower generation, domestic and industrial water supply, recreation, irrigation, and low flow augmentation downstream of the reservoir. Many of these benefits exist in conflict with each other and have a wide range of social and environmental effects.

There does not exist a single reservoir problem type, rather a system of problems (Simonovic 1992). A number of potential problems may arise throughout the life time of a reservoir. The reservoir active storage may be lost with time due to sedimentation of river bed material, evapo-transpiration losses may increase with potential climate change, and sub-optimal operation of the reservoir may result in revenue losses in hydropower generation, lower reservoir levels during months of high recreational activity on the reservoir lake, insufficient reservoir outflows for the provision of downstream biological and aquatic life, as well as high reservoir pollution levels. The extent of potential reservoir problem types is vast.

The most basic reservoir problem is that of reservoir active storage design. The reservoir active storage determines the reservoir size, and therefore impacts the level of flood storage, power generation potential, water availability in drought years, the amount of upstream flooding, people relocated, as well as effects on animal migration, vegetation growth, and other effects on the local ecosystem. The designed reservoir storage must be sufficient to meet the imposed demand for water at one or more locations downstream of the reservoir, at a specific time. The selection of a suitable reservoir active storage is further complicated when the number of demand types and objectives is increased.

The problem selected for the application and evaluation of de novo programming, is that of the design of reservoir active storage in a multiobjective environment. The reservoir active storage is defined as that which will satisfy a cumulative demand for water, on the reservoir, throughout its life time or design life. The reservoir design case is purely hypothetical, although input data is based on an existing reservoir. The reservoir is subjected to several types of constraints, minimum and maximum reservoir storage, release, and water supply, as well as water balance and continuity of inflow. A target storage level profile is used to relate the deviation of storage from a target within a time interval. Two conflicting objectives are used to provide a manageable yet representative situation. The objectives include minimization of the required active storage, and the minimization of a sum of storage deviations from target levels. These objectives were considered to represent typical performance evaluation criteria of a reservoir and created the desired conflict.

1.3 Scope

The layout of the following six chapters reflects the main objectives as described in section 1.1. Chapter 2.0 provides a literature review covering background on the use of operations research in reservoir design, a brief introduction to sustainable reservoir design, and a thorough review of work done with de novo programming. Chapter 3.0 is devoted to the introduction of the reader to de novo programming. The basic concept of de novo programming is covered in detail in this chapter. Chapter 4.0 develops the reservoir design model formulation and presents the application of de novo programming. Here, the generation of results, which will be discussed in chapter 5.0, is the primary goal. Chapter 6.0 provides a final discussion on de novo programming from which conclusions, and recommendations are made in Chapter 7.0.

The focus of this work is the application of de novo programming, its practicality in a water resources context, benefits, and obstacles. The issue of sustainability is broad and open to interpretation, and therefore its definition will not be addressed. However, it is believed that the direction led by the main concept of de novo programming, optimal system design, will result in a more sustainable reservoir design.

2. LITERATURE REVIEW

This chapter is divided into three main sections, Operations Research for Reservoir Design, Sustainable Reservoir Development, and De Novo Programming. Due to the large research areas of the first two sections, the corresponding literature reviews are limited. In contrast, the literature review of de novo programming is considered complete, even though only several papers are reviewed. The objective of this chapter is to provide the background of operations research techniques, and sustainable issues, which will form the foundation for evaluating de novo programming as an operations research method and sustainable reservoir design tool. Specific terminology to multicriteria decision making is summarized in section 2.1.1 and will be used extensively from that point on.

2.1 Operations Research for Reservoir Design

Operations research refers to a large set of mathematical techniques which focus on optimal or best compromise system operation. These techniques require the optimization of a system with respect to a predefined set of objectives, and constraints. Loucks *et. al.*

(1981) described a basic reservoir design model which contained one objective function and two types of constraints. The objective was the minimization of the required active storage of the reservoir, subject to the continuity equation, and the maximum capacity constraint. The continuity equation related the inflow into the reservoir, losses from the reservoir, including reservoir yield, with the storage in the reservoir in a given time period. This model provided the basic reservoir design issue: what is the minimum required size of the reservoir, i.e. the required active storage, such that the demand, represented by the minimum required yield, is satisfied within each time period of the planning horizon. For a given inflow sequence, it was then possible to relate the minimum reservoir yield with an associated reservoir active storage.

The reservoir design problem becomes a complex mathematical system as different types of constraints are introduced. In general, constraints regarding the minimum and maximum reservoir release, and storage are imposed which represent environmental, social, and physical limits on the reservoir system. Large reservoir systems are further complicated when conflicting objectives are considered. Seldom are all objectives involved in the optimization problem due to two main reasons, increasing the number of objectives increases the difficulty in selecting a final compromise solution, and the qualitative nature of some objectives may not allow their direct mathematical representation in the reservoir system. Reservoir constraints are, in comparison, much more freely identified. The correct formulation of relevant objectives and the reservoir system is a crucial step in obtaining realistic model results.

In general, reservoirs are built for multipurpose use, Simonovic (1992). Reservoirs must provide benefits from water supply (municipal, industrial, irrigation), hydropower, flood protection, recreation, navigation, and low flow augmentation. The required active storage must be sufficient to satisfy each constraint with an acceptable measure of performance. Operations research techniques have evolved as practitioners needed to solve reservoir design problems of varying scales (multiple reservoir systems, multiple users) and purposes (multiple objectives).

A state of the art review of the types of operations research tools in water resources development has been performed by Yeh (1985). Yeh summarized the general principles of 4 main types of reservoir management and operations models: linear programming (LP), dynamic programming (DP), nonlinear programming, and simulation models. He summarized the evolution of each, commented on the relative advantages and disadvantages, and recommended research areas within each category. Yeh also described the historic use of linear decision rules in reservoir design and operation, as well as the use of mathematical models in real time reservoir operation. Three main reservoir system characteristics addressed were: the hydrologic stochasticity, which is directly linked to the risk of system failure, the multiple reservoir purposes which conflict in corresponding reservoir release policies, and the multiple facility nature of reservoir systems. These characteristics exist simultaneously, resulting in a range of mathematical techniques which vary in the complexity of the formulation, and solution method.

Yeh did not find any application of de novo programming. One example given in his literature review which contained some similarity to de novo programming was the application of nonlinear programming to the optimization of operations for the Pacific Northwest hydroelectric system of the Bonneville Power Administration, done by Hicks *et al.* (1974). Hicks' model contained nonlinearity in the objective function as well as some constraints. To simplify the solution procedure of finding an optimal decision, Hicks classified some constraints as "hard" and some as "soft". The hard constraints were defined as those that could not be violated in any time interval due to physical limitations. In contrast, soft constraints were allowed to be violated with a penalty, and subsequently moved from the constraint set, into the objective function. Although the resulting optimal solution was not a global optimum, the result did provide an improvement over initial estimates. The inclusion of soft and hard constraints is the main objective of de novo programming. The use of this terminology (defined in Chapter 3.0) is however a coincidence.

Inherent uncertainty in the reservoir design problem is an aspect of equal importance to the derivation of the reservoir active storage capacity. Uncertainty in the hydrology or inflow into the reservoir will have great impact on the optimal size, and decisions regarding the reservoir releases. An application of a simulation-optimization model by Barlishen *et al.* (1989) showed that reservoir capacity requirements were highly dependent on streamflow record lengths. Synthetic streamflows were generated and each sequence was then used in a simulation-optimization model to generate an optimal reservoir active storage. By comparing the resulting capacities with a 5 % probability of exceedence, it was found that relying on short periods of inflow record could lead to substantial overestimation or underestimation of the required reservoir active storage.

2.1.1 Multi-Criteria Decision Making, (MCDM)

The multiobjective character of water resources systems has led to a vast number of techniques designed to produce best compromise solutions when an ideal performance of a system is not feasible. Three categories of MCDM techniques exist, generating techniques, techniques which rely on prior articulation of preferences, and techniques which rely on progressive articulation of preferences, Cohon (1978). Generating techniques refer to those responsible for the establishment of the set of nondominated points of a feasible region. The generation of the set of nondominated points, and subsequent search for best compromise solutions has been the conventional approach to MCDM in water resources. Next, some terminology common to MCDM is summarized.

The frontier of the decision variable space, (or objective space in 2 dimensions) is known as the set of nondominated points or the pareto optimal curve, and contains solution alternatives from which a best compromise solution must be selected. To provide a definition of the set of nondominated points, it is sufficient to state that for each point outside the set, there is a nondominated solution for which all objective functions are unchanged or improved and at least one which is strictly improved. Multiobjective analysis focuses on the generation of this set in order to identify a single or several best compromise solution(s), Goicoechea *et al.* (1982).

Often the set of nondominated points will be further divided into smaller groups. Major alternative groups can be derived as those favoring either objective while being separated by a compromise group. The purpose of grouping nondominated points is to facilitate discussions about which solution to select. The techniques available for generating the pareto optimal curve involve the reformulation of the multiobjective problem and iterative optimization. A large number of methods for generating the set of nondominated points exists. They include: the weighting method, ε-constraint method, Phillip's linear multiobjective method, and Zeleny's linear multiobjective method.

The mathematical procedures available for identification of a best compromise solution can be divided into two main categories: methods with prior articulation of preferences (continuous or discrete), and methods with progressive articulation of preferences. The use of each type will depend on the nature of the problem, the availability of time, decision maker's level of understanding of the selected technique, robustness of the technique to produce a solution, and the decision maker's level of confidence in the final solution, Hobbs *et al.* (1992).

The former refers to methods where the decision maker is asked to articulate his/her worth or preference structure. In particular, the decision maker is required to articulate a preference for allocation of each objective. These preferences are then built into the formulation of the mathematical model for the multiobjective problem. By doing so the set of nondominated solutions is further divided into smaller groups with associated desirability levels. Examples of methods with prior articulation of preferences and continuous mathematical structures are: Goal programming, Utility function assessment, and The surrogate worth tradeoff method. Methods of this type which are used in discrete decision alternative models are: ELECTRE I and II, Indifference tradeoff method, Direct-rating method, and Conjunctive Ranking, Cohon (1978).

The latter type of method includes those which progressively identify an acceptable solution. This type of method is often more appropriate in situations where the decision maker is not capable of stating the preference of one objective over another, and is forced to evaluate each possible solution on a trial and error basis. The algorithm for methods with progressive articulation of preferences is summarized as follows: a nondominated solution is identified, the decision maker provides his/her response to the performance of all objectives, and finally the problem is modified according to the information generated from the previous step. For example, the decision maker may provide information which identifies the preference for tradeoff between objectives. This procedure is therefore more time consuming compared to that of the previous category but does provide the advantage of allowing the decision maker to gain understanding for the modeled system. Examples of methods which fall into this class are: Compromise Programming, Step Method (stem), Method of Geoffrion, and SEMOPS method.

An early review of available MCDM techniques is given by Cohon and Marks (1975). Cohon and Marks reviewed several techniques within each MCDM category and used the following criteria for evaluation: efficiency, explicitness of trade offs among objectives, and the amount of information generated for decision making. At the time of this review, the complexity of water resources planning problems greatly exceeded the means of solving typical problems. The criteria used by Cohon and Marks therefore stemmed from a functionality aspect of available techniques. It was found that the weighting method, and estimation of optimal weights method, ranked favorably within respective classes of techniques due to high computational efficiency and the explicit consideration of objective trade offs. The class of techniques which rely on progressive articulation of preferences was not highly recommended due to the lack of trade off definition.

A more rigorous review of MCDM methods was completed by Hobbs *et al.* (1992). Techniques which were evaluated consisted of: goal programming, ELECTRE, additive value functions applied with three different methods, and multiattribute utility functions. The criteria used to evaluate each method addressed the appropriateness and ease of use, validity, and differences in results. For each criteria, several hypotheses were made regarding the techniques in question. A thorough experiment by the U. S. Army Corps of Engineers was designed and carried out to complete the study. The authors concluded that: (1) experienced planners preferred simpler methods like additive value functions, (2) rating, the most common weight selection method, was likely to mislead the true value structure of the decision maker, and (3) decisions were highly sensitive to the implicit value structure of the decision maker.

2.2 Sustainable Reservoir Design

Dorcey, 1992 enforced the new ethic of sustainable development as the extension of existing water resources management tactics with the emphasis being the design of reservoirs. Doing so will require decision makers to change decision making tactics to involve a higher degree of knowledge regarding the interaction of a reservoir system with the environment (Simonovic, 1992). Furthermore, such knowledge will have to be extrapolated into the future, in order to incorporate possible future system outcomes. With respect to operations research methodology, new objectives will have to be introduced. The broadest goals that should be incorporated in the decision making process of reservoir design are (i) environmental integrity, (ii) economic efficiency, and (iii) equity, Young (1992).

A summary of the three main challenges to obtaining sustainable reservoir design was provided by Simonovic (1992) as: (1) the identification of relationships between the reservoir system and the environment as a whole, (2) the simulation of possible future changes in the reservoir system and it's link with the environment, and (3) the development of tools which will allow decision makers and planners to adequately address (1) and (2).

It is not expected that a precise methodology for sustainable reservoir design will evolve due to the varying objectives and constraints which may exist for a proposed reservoir design problem. The exact nature of the relationship between the reservoir and the environment as a whole is rarely known within a high confidence level, and cannot be assumed constant as the reservoir purposes, operation and management, and the environment capacities change from location to location. Schumann (1995) stated that flexibility in reservoir operation, once the facilities are designed and built, is a key issue in attaining sustainable reservoir operation. Schumann proposed that use of time series analyses, optimization and simulation models, as well as decision support systems, be made in order to close the gap between reservoir management planning and operation. The conclusion made was that if it is not possible to foresee future changes in hydrology or reservoir demand, a feasible alternative to adapting changing reservoir objectives, is to change reservoir operating rules accordingly.

Flexibility as applied to planning was proposed by Schultz and Hornbogen (1995). The objective in this paper was to develop a quantitative approach for planning sustainable water resources systems. The approach involved the definition of future scenarios, the definition of many alternative potential future development paths, and the definition of the possibility function for water resources design parameters. The use of hydrological, water balance, and water quality models was suggested for the transformation of functions reflecting the likelihood of environmental and socio-economic variables, into a possibility function or region which reflected a hydrological parameter, for example the mean monthly runoff. Water resources development alternatives were then analyzed in view of all likely hydrological design parameters. The main definition of sustainable development provided by Schultz and Hornbogen was that sustainable project alternatives are those which are viable for hydrologic variables of high likelihood, as well as of low likelihood. This definition stressed flexibility from the planning perspective, as opposed to Schumann's proposal of flexible reservoir operations.

2.3 De Novo Programming

De Novo programming is not a new methodology. Milan Zeleny first proposed the topic in 1976, for single objective linear programming problems and published an article, describing the methodology and its superiority, entitled "On The Squandering of Resources and Profits via Linear Programming" in 1981. The article used an example in which the objective was maximizing profits from the sale of two products, given a budget which limited the amount of purchased resources. Via the reshuffling of resources, it was found that profits improved while the cost of the resources stayed the same, or was less than a given resource portfolio. This outcome was the result of what Zeleny terms de novo programming, that is the optimization and design of optimal systems as opposed to the optimization of given suboptimal systems.

De novo programming begins with the formulation of soft and hard constraints. Soft constraints refer to the resources which may be designed by the optimization model itself.

Within Zeleny's context of production scheduling, soft resources can be purchased or designed. A governing budget must however be identified which limits the performance level of a system objective measured by the profit function.

Zeleny's de novo programming was extended to the multi-objective environment in "Optimal System Design with Multiple Criteria: De Novo Programming Approach", (1986). Here Zeleny showed that once again the design of system resources was a powerful and beneficial approach. An example was given which considered three conflicting objectives in a problem of production scheduling. With respect to a given system, conflict between the stated objectives existed, i.e. the ideal set of objective function values was not feasible. The ideal performance was termed the metaoptimum with respect to the given system. Zeleny went on to show that application of de novo programming resulted in the metaoptimum becoming feasible. An ideal system performance was reached, diminishing all objective conflict, while satisfying a given budget level.

It became evident that the metaoptimum was a relative ideal performance with respect to every system in the multi-objective environment, and the attainment of a metaoptimal system performance was governed by the budget level. In other words, even the de novo system existed with its own metaoptimum. The only limitation to attaining the de novo metaoptimum was the budget level which limited the purchase of soft resources. In conclusion, Zeleny stated that:

> **"Only when we cannot (all constraints are fixed or mandated), or do not wish to (the "given" system has a nostalgic value), design a new, optimal system, will traditional LP methodology remain useful and unchallenged. Most intermediate cases (partially given systems) can be handled effectively via De Novo programming."**

The number of cases where de novo programming has been applied is scarce. Two examples were identified in the field of forest land management. Bare and Mendoza (1988) applied de novo programming to single and multi objective forestry land management problems. Their objective was to demonstrate the benefit of de novo programming in a field where the application of LP was predominantly used. In the single objective problem, a de novo linear program was formed by assuming that constraints on labor, picnic sites, and hiking trails were soft resources. It was found that for the same system cost, the de novo model provided an improvement in the objective function.

This problem was modified to include two conflicting objectives. With respect to the given system the ideal combination of objectives was not feasible. Minimization of the system cost with respect to the soft and hard constraints, as well as an additional constraint on system performance, proved that the system could be designed to perform in an ideal fashion within a constant budget level. Bare and Mendoza concluded that although additional testing was needed, the use of de novo programming was technically feasible. They felt that the soft optimization approach of de novo programming was analogous to long run resource allocation problems where all resource levels were variable, as opposed to being fixed in the short run.

Following their first application of de novo programming, Bare and Mendoza (1989) provided yet another application in the field of forest land management. In this instance however, they considered a case where the formulation of a de novo program did not result in ideal system performance. Although some resources were designed via soft constraints, conflict between four objectives was not dissipated completely. In conclusion, Bare and Bendoza generated several compromise solutions of the de novo model, proving that de novo programming did improve compromise performance levels, and that the decision maker was ultimately responsible for accepting or rejecting a decision alternative.

Since de novo programming relies on the design of optimal systems via soft constraints, system flexibility is a key factor in determining whether the problem of optimal system design exists. Li and Lee (1990) extended the de novo programming methodology with fuzzy decision theory. A mathematical example was shown which considered all de novo model parameters as fuzzy, i.e. the coefficients found in the objective function, constraints, and constraint resources. They concluded that the decision maker may design an optimal system with an associated risk which reflects the level to which the solution satisfies the problem. The application of fuzzy theory was found to allow the decision maker to realistically design a system in an uncertain environment.

3. INTRODUCTION TO DE NOVO PROGRAMMING

This chapter is intended to familiarize the reader with de novo programming methodology, and its terminology. The de novo programming concept and history is reviewed briefly prior to the detailed presentation of its methodology in a single and multiobjective environment.

3.1 Basic Concept of De Novo Programming

The de novo programming approach was initially proposed by Milan Zeleny, in the early 1980's, who provided illustrative examples of the technique in the field of management. De novo programming refers to an optimization problem in which resource capacities become decision variables of the problem itself. This process is the main difference between the conventional approach to finding an optimal solution to a problem, and de novo programming. Essentially, the right hand side constants of some constraints, are allowed to be decision variables, and are referred to as soft resources. In the single objective environment, the de novo optimization formulation introduces one additional constraint, the "budget", which is to be spent on the purchase of the unknown, or to be designed resource portfolio. Multiobjective de novo model formulation includes the ideal performance being explicitly identified and included as a system constraint.

The resulting de novo solution includes the value of the optimal objective function, as well as the values of the optimal capacities of system resources. This resource portfolio will produce an optimal objective function value while producing no slack or surplus variables in the soft constraints. Since the de novo problem is essentially limited by the budget level, the higher the budget the higher the achievement level of an objective function. In this manner the de novo formulation ***designs the optimal system*** as opposed to ***optimizing a given system***, providing the decision maker with the confidence of knowing that the optimal solution is the best that can be achieved, Zeleny (1981).

3.2 De Novo Programming in a Single Objective Framework

The following paragraphs demonstrate the mathematical process of transforming a linear single objective optimization problem into a de novo system. Given a single objective to be maximized, Z, a set of m + n constraints, and a set of m resources capacities, b_i , the mathematical representation of the given system is written as:

$$\text{Maximize} \quad Z = \sum_{j=1}^{j=n} c_j x_j \tag{3-1}$$

subject to:

$$\sum a_{ij} x_j \le b_i \quad i = 1,2,\ldots,m \tag{3-2}$$

$$x_j \ge 0 \quad j = 1,2,\ldots,n$$

<u>where:</u>

x_j are decision variables;

c_j are objective coefficients;

a_{ij} are constraint matrix coefficients;

b_i are right hand sides of constraints, assumed as given constants;

m is the number of constraints; and

n is the number of decision variables.

The de novo formulation begins with the following statement. Suppose that k of the m constraints are "soft", i.e. can be relaxed, while the remaining l (l = m-k) constraints remain "hard" (those which absolutely can not be relaxed). This statement is equivalent to a problem where some system resources may be designed. Zeleny's de novo programs are referenced to the purchase of resources such as machinery, and labor. At the time of the de novo analysis, the manager will assume that system resources may be purchased in any quantity, being limited by only a predetermined budget level. The de novo model approaches the problem as follows, the objective function must be optimized with respect to a system of constraints which ensure the optimal design of the system with a limited budget. Mathematically, the de novo model is written as:

$$\text{Maximize} \quad Z = \sum_{j=1}^{j=n} c_j x_j \qquad (3 - 3)$$

subject to:

$$\sum_{j=1}^{j=n} a_{ij} x_j \leq b_i \qquad \mathrm{i = k{+}1, \ldots, m} \qquad (3 - 4)$$

$$\sum_{j=1}^{j=n} a_{ij} x_j - b_i \leq 0 \qquad \mathrm{i = 1, 2, \ldots, k} \qquad (3 - 5)$$

$$\sum p_i b_i \leq B \qquad \mathrm{i = 1, 2, \ldots, k} \qquad (3 - 6)$$

$$x_j \geq 0 \qquad \mathrm{j = 1, 2, \ldots, n}$$

where:

p_i is the per unit cost of resource b_i ; and

B is the total budget to be spent on the purchase of the soft resource portfolio.

This system can be optimized to provide an optimal set of decision variables, objective function value, and a set of resources for a given budget level. Comparison of these results to those of the given system must provide an equivalent, or improved objective function value since the resources will be designed to maximize the same objective function. At worst, nothing is gained from the de novo model, meaning the given system of resources is optimally designed. Zeleny's examples of de novo programming focus on the increase in production profit for a given budget via the design of an efficient resource portfolio.

Zeleny considered production scheduling problems in which he formulated the de novo models with all resources as decision variables. The above de novo model (3 -3) to (3 - 6) does not contain maximum system flexibility but does describe the exact de novo method. Several observations, regarding Zeleny's examples of de novo programming were made by Tabucanon (1988). Tabucanon stated the following points regarding the optimal assignment of de novo decision variables.

(1) In case of unlimited demand for the end products x_j with price p_j constant, de novo leads to a system designed to produce one single most profitable product. The most profitable product is defined as that with the highest per unit profit to per unit variable cost ratio.

(2) If (1), increasing the budget simply increases the production of the most profitable product.

(3) In case of limited demand for the end products x_j, the variety of production evolves according to profitability rank. i.e. produce as much as demanded of the most profitable product, if budget allows, produce as much as demanded of the second most profitable product, etc.

The following statements summarize Tabucanon's conclusions regarding the de novo methodology.

(1) The assumption of unlimited resources in de novo does not mean that any amount of resources can be purchased. Resources are limited by the single integrating constraint of the budget.

(2) De novo assumes the analysis is made before resources are purchased, still controllable and are not yet fixed. Furthermore, resources are assumed to be divisible, and can be purchased at any desired amount.

(3) De novo explicitly considers resource cost. This fact therefore diminishes the need for postoptimal duality analysis. Because de novo designs the resource portfolio, no unintentional surplus of resources will be achieved. All shadow prices will therefore be positive.

(4) The budget is used to explicitly value the entire resource portfolio. It serves as the common denominator or measure of committed or required resources.

This concludes the presentation of de novo programming in a single objective decision framework. Zeleny extended the application of de novo programming to a more complex situation, multiple conflicting objectives. The next section addresses this issue, and defines an important concept: the metaoptimum.

3.3 De Novo Programming in a Multiobjective Framework

In a multiobjective framework, several conflicting objectives must be optimized simultaneously with respect to a system of constraints. Expanding the single objective problem to address P objectives, all of which are to be maximized, results in the following model.

$$Maximize \quad \left\{Z_1, \quad Z_2,\ldots,Z_p,\ldots, \quad Z_P\right\} \tag{3 - 7}$$

subject to:

$$\sum_{i=1}^{i=n} a_{ij}x_j \le b_i \qquad \text{i=1,2,...,m} \tag{3 - 8}$$

$$x_j >= 0 \qquad \text{j=1,2,...,n}$$

<u>where:</u>

Z_p is the p^{th} objective function, affecting the decision process;

P is the total number of objectives under consideration; and

all other variables defined in section 3.2.

The conventional approach to solving this model, focuses on the generation of compromise solutions within the feasible set of alternatives. Individual optimization of each objective with respect to the given system of constraints, will yield an individual optimum (Z_p^*) and determine the nature of existing tradeoff between any two of the P objectives. These individual optima, defined by Zeleny as the metaoptimum, are used in the de novo model to define the desired performance of the de novo system. Again, system flexibility via soft resources is identified, together with a governing budget. Essentially, the multiobjective problem is transformed into a single objective problem with additional constraints representing the desired performance of the de novo model. Mathematically, the de novo formulation of a given multiobjective is written as:

$$\text{Minimize} \quad \sum p_i b_i = B \qquad i = 1, 2, \ldots, k \qquad (3-9)$$

subject to:

$$\sum a_{ij} x_j \leq b_i \qquad i = k+1, \ldots, m \qquad (3-10)$$

$$\sum a_{ij} x_j - b_i \leq 0 \qquad i = 1, 2, \ldots, k \qquad (3-11)$$

$$Z_1 \geq Z_1^*, \quad Z_2 \geq Z_2^*, \ldots, \quad Z_P \geq Z_P^* \qquad p = 1, 2, \ldots, P \qquad (3-12)$$

$$x_j \geq 0 \qquad j = 1, 2, \ldots, n$$

If a feasible solution exists, the de novo model results in an optimal set of decision variables, and an optimal budget to be spent on achieving the metaoptimum. As with the single objective problem, the de novo model uses system flexibility to design an optimal soft resource portfolio. It is not guaranteed that a feasible optimal solution to the de novo model exists. The deciding factor is the feasibility of the metaoptimum with respect to the hard system resources. The corresponding minimum budget level necessary to achieve the de novo solution may then be used to judge if the achievement of the metaoptimum is practical. If the price for achieving the metaoptimum is not feasible, the process of finding an acceptable solution can continue with the application of a best compromise decision techniques. The effect of de novo programming on the feasible region of decision alternatives is better illustrated through the following example which is described in detail by Tabucanon (1988).

Suppose that a given system contains two objective functions Z_1 and Z_2 which are to be maximized, four linear constraints on available resources, and two decision variables X_1 and X_2 which are constrained to be nonnegative. The given system is represented schematically in Figure 3 - 1. In addition to the feasible region formed by the six constraints (four resource, and two nonnegativity constraints), the individual optima of each objective function are also depicted. It is seen that the ideal combination of objective function values, does not fall within the feasible region of alternatives. With the fixed set of system resources, the remaining decision to be made is the selection of the best compromise solution.

De novo designs the resource portfolio which effectively modifies the slope and intercept of each soft constraint. When all four resource constraints are allowed to become decision variables, the new feasible region will be optimally modified to satisfy the metaoptimum constraint. This effect on the feasible region of alternatives is the essence of de novo programming and is shown in Figure 3 - 2. The optimal de novo solution will determine the minimum budget necessary to achieve the metaoptimum. If the metaoptimum constraints are of inequality type, such that the de novo model aspires to at least achieve the metoptimum, then it is possible to over achieve the metaoptimum.

For other examples of the de novo programming in a multiobjective environment, refer to Zeleny (1986). This source applies de novo programming to a production scheduling problem with three objectives and a system of six constraints.

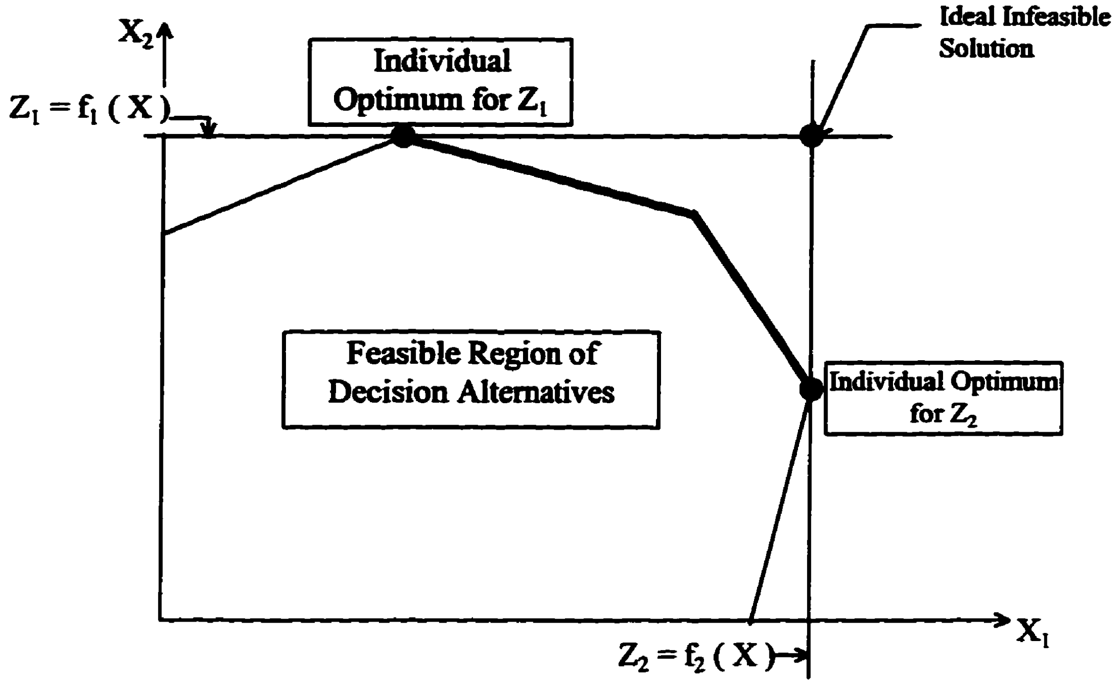

Figure 3-1 Feasible region and ideal system performance of a given system.

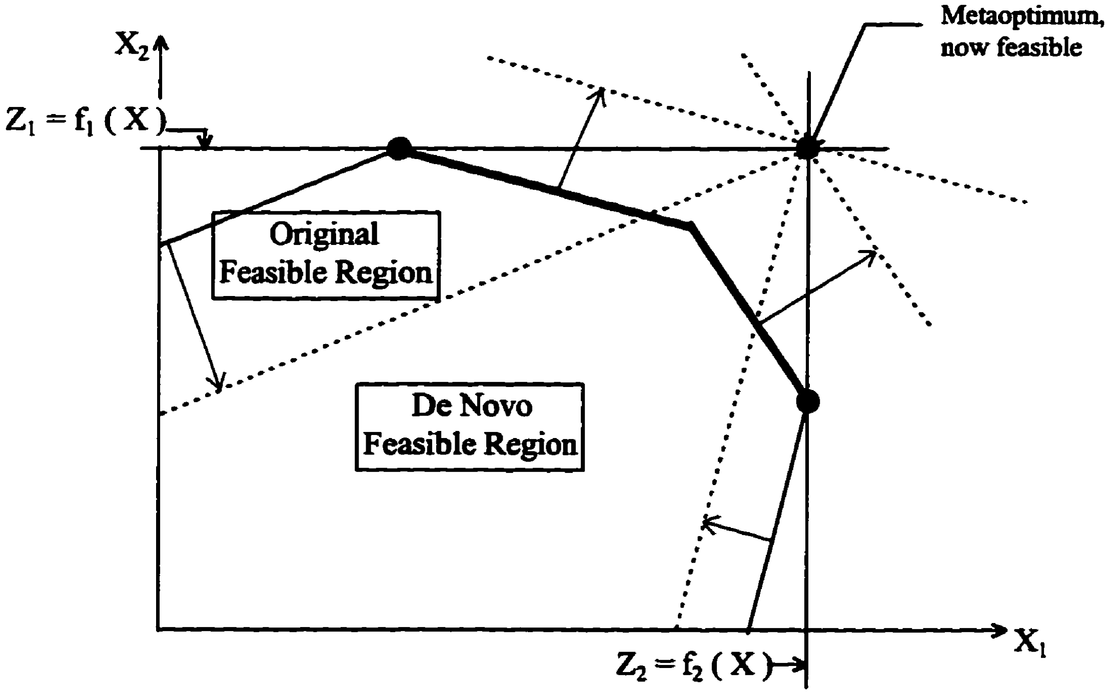

Figure 3-2 Effect of de novo programming on the feasible region of decision alternatives.

3.4 Summary of the De Novo Programming Concept

Having presented the basic formulation of a de novo program in a single, or multiobjective framework, the following conclusions can be made. First, the de novo model relies on system flexibility, or relaxation of some constraints to either improve an optimal objective function value, or to attain a metaoptimum. The amount of system flexibility introduced will be directly related to the improvement in an objective function value, and the feasibility of the metaoptimum. Second, a governing function over the flexibility is introduced. Zeleny's objective is that of the economic interpretation of flexibility, i.e. the minimization of the cost of purchasing resources. If a per unit cost of using a resource is available, then the budget is easily interpreted. However, depending on the nature of the resources, other types of governing functions may be necessary, and may not have a practical interpretation. Third, the de novo model designs the optimal system as opposed to optimizing a given system. If an improvement in the single objective problem is attained via the de novo model, one can conclude that the given system was not optimal with respect to the objective. Similarly, in the multiobjective framework, a feasibility of the metaoptimum in the de novo model would imply that the given system was not optimal with respect to the metaoptimum. Finally, the design of a resource portfolio, and thus the system itself, results in no slack variables associated with soft inequality constraints, and therefore no surplus or wasted resources.

4. APPLICATION OF DE NOVO PROGRAMMING TO RESERVOIR DESIGN

This chapter considers a hypothetical reservoir design model which will be used to compare the solutions of two optimization methods, the conventional optimization approach, and de novo programming. A multiple objective framework is selected by the introduction of two conflicting reservoir objectives. The reservoir model is made to uphold a manageable scale via the limitation of system constraints. Although these two aspects greatly simplify the problem, and therefore deviate from an expected real-time reservoir design model, the problem is adequate for the purpose of this work.

4.1 General

Reservoir construction for the purpose of temporal and physical control of water is one of the most common water resources projects used to satisfy a demand for water with a specified reliability. Damming of rivers may result in significant economic, environmental, and social impacts on a given region and therefore requires comprehensive planning and development techniques. Reservoir design problems are one category of examples which involve the participation of professionals from various fields who must use analytical models to predict the physical and operational behavior of the reservoir throughout its life time. In the planning stage of design, a required active storage, or "size" of the reservoir which will satisfy a predicted demand has to be decided upon.

The determination of size facilitates further decisions concerning the physical requirements of reservoir location, and physical attributes of the dam itself. Since the number of alternate solutions which will achieve system requirements is great, it is necessary to employ the use of *a systems approach* in order to efficiently solve the problem. This is accomplished by mathematically developing evaluation criteria which will be used to discriminate among various feasible solution alternatives.

An optimization model was developed in order to demonstrate the use of de novo programming on a hypothetical reservoir sizing problem. For the purpose of minimizing problem complexity while attaining a representative and practical reservoir sizing problem, a number of assumptions were developed. These are explained in the following section.

4.2 Reservoir Model Development

In the most general reservoir design formulation, it is necessary to minimize the required active storage of the reservoir, subject to continuity of reservoir inflow and outflow, as well as storage capacity constraints (Loucks, 1981). Mathematically, this optimization model can be expressed as follows:

$$\text{Minimize} \quad K \tag{4 - 1}$$

subject to:

$$S_t = S_{t-1} + I_t - WS_t - R_t - EVAP_t - INF_t \tag{4 - 2}$$

$$S_t \le K \tag{4 - 3}$$

$$S_o = S_T \tag{4 - 4}$$

$\{t=1,2,\ldots,T\}$

where:

K is the required active storage;

S_t is the reservoir storage at the end of time period t (S_0 and S_T are the initial and final reservoir storage, respectively);

I_t is the cumulative inflow into the reservoir for the t^th^ period, measured at the end of time period t;

WS_t is the total water supply provided by the reservoir for the t^th^ period, measured at the end of time period t;

R_t is the total downstream release from the reservoir for the t^th^ period, measured at the end of time period t;

$EVAP_t$ and INF_t are the total evaporation and infiltration losses from the reservoir measured at the end of time period t; and

T is the length of the planning horizon for the reservoir design project.

The objective is the minimization of all impacts related to the active storage of the reservoir system; the system being defined explicitly via constraints and decision variables. The first system constraint is referred to as the continuity equation since it relates the reservoir storage within each time period, to the inflow, water supply, downstream release, and reservoir losses. Water supply represents the reservoir yield within each time increment. The second equation stipulates that the required active reservoir storage must be sufficient to hold all stored water within each time period. Finally, the last constraint represents the assumption of continuity of the entire inflow sequence. This prevents the reservoir from emptying while attempting to satisfy the specified water demand and minimize the maximum storage. Precipitation directly on the reservoir, evaporation, and infiltration from the reservoir are assumed to be accounted for in the reservoir inflow sequence. Optimization of this linear program yields the required active storage which is directly related to the input into and the total demand on the system.

Other objectives may also be pertinent to the design, implementation, and management of the reservoir. Such objectives may represent environmental, economic, or social effects not implicitly defined by minimization of the required active storage. To reflect a multiobjective decision environment, it is assumed that the reservoir design process must be evaluated on the basis of two criteria: the minimization of the required active storage, and the minimization of the sum of absolute deviations of reservoir storage from predetermined target storage levels. The former objective ensures the minimization of cost related to the physical size of the required dam, evacuation of upstream residents, negative environmental effects, and other. The latter objective reflects the importance of the reservoir to provide benefits related to the regulation of the resulting lake level. For example, the reservoir may be required to satisfy multiple user demands, such as maintaining the lake level constant during the summer months. Doing so would benefit those using the lake for recreational or navigational purposes. Aesthetic appeal of the lake may also be linked to a high reservoir level.

Other demands include flood protection for downstream locations, maintenance of fish spawning conditions, or increase in hydropower generation reliability. Without particular identification of any single reservoir purpose, it was assumed that deviations from a target storage profile were to be minimized.

Additional constraints on the system bind the water supply, storage and downstream release within each time period to upper and lower limits. These constraints reflect the assumed minimum allowable river flow downstream of the reservoir, and the maximum flow of water that can be passed through various control structures, respectively. Mathematically, the complete reservoir model can be summarized as follows.

$$Minimize\quad K \qquad \& \qquad Minimize\ \sum_{t=1}^{t=T}\left|S_t - S_m^*\right| \tag{4 - 5}$$

subject to:

$$S_t = S_{t-1} + I_t - WS_t - R_t - EVAP_t - INF_t \tag{4 - 6}$$

$$S_t \le K \tag{4 - 7}$$

$$S_o = S_T \tag{4 - 8}$$

$$S_{\min} \le S_t \le S_{\max} \tag{4 - 9}$$

$$LB_m \le \left(DTAR_m\right)^{-1} WS_t \le UB_m \tag{4 - 10}$$

$$RMIN_m \le R_t \le RMAX_m \tag{4 - 11}$$

$$S_t + U_t - V_t = S_m^* \tag{4 - 12}$$

$\{t=1,2,\ldots,T\} \quad \{m=1,2,\ldots,12\}$

where:

$EVAP_t$ and INF_t are considered negligible reservoir losses;

S_{min} and S_{max} are the lower and upper bounds on the reservoir storage within time period t respectively (assumed constant for all time periods);

LB_t and UB_t are the lower and upper bounds on the fraction of water supply provided, relative to a demand target for that time period $DTAR_t$, respectively (assumed constant for all simulated years);

$DTAR_t$ are monthly demand target levels;

S^*_m are monthly target reservoir storage levels;

$RMIN_m$ and $RMAX_m$ are the minimum and maximum allowable reservoir release bounds on month m, for the satisfaction of downstream needs (assumed constant for all simulated years);

U_t, and V_t are positive variables one of which will equal zero in a given time period, t

t is the monthly time index;

m is the monthly time index for variables which are allowed to vary only throughout the year, as opposed to over the entire planning horizon; and

T is the length of the planning horizon in months.

The reservoir sizing model is a system of seven sets of constraints which is to be optimized with respect to two criteria. Optimization of either of the objectives will yield respective optimal values of each criterion as well as a set of optimal decision variables. Limiting resources and other system parameters which complete the given reservoir model, are described next.

4.3 Reservoir Model Input Data

The data used in the definition of the given reservoir model is based to a large extent on the characteristics of the Shellmouth Reservoir, better known as Lake of the Prairies. Shellmouth Reservoir was constructed near Russell, Manitoba, Canada, in 1971 and in full operation from 1972 to the present day. Since this date, a reliable inflow record has been maintained with a calibrated hydrological gauge. Although the entire available inflow record for a reservoir site should be used to ensure that all hydrological periods are captured in the design process, only 15 years of the available hydrology were selected in order to minimize the number of constraints, and therefore the difficulty in obtaining solutions from the optimization solver.

Minimum and maximum reservoir releases are based on those corresponding to the minimum release required for survival of downstream aquatic life, and maximum operational capabilities with two release gates open, respectively.

Available data representing the demand for water withdrawn from the reservoir for municipal purposes at the location of, or downstream from, the reservoir are based on the projected total demand for the year 2040. This number is based on the extrapolation of the cumulative demand for water licenses between Shellmouth Reservoir and Winnipeg, Manitoba between the present and the year 2040. A cumulative downstream release was obtained by summing water demand for: low flow augmentation, irrigation demand, demand for thermal generation cooling, and dilution of treated sewage discharge.

The multipurpose nature of Shellmouth Reservoir is reflected in its operational rule curve. The reservoir is operated in a manner which ensures available storage of the spring freshet and high lake elevation levels during the summer months. Although the reservoir does not always attain its target storage within each month, it is operated in a manner that incorporates reservoir inflow forecasts, and a series of operational rules which minimize the amount of target storage deviation. The rule curve for the Shellmouth Reservoir is used as the set of monthly target storage levels in the given reservoir model. It is assumed that the rule curve, and monthly target demand levels remain constant for every year during the planning horizon.

The use of Shellmouth Reservoir data is made to illustrate the type of information that may be taken as given by an analyst in a hypothetical case. The results in this work, have no reflection on the operation of Shellmouth Reservoir. All input data used in the development of the given and de novo reservoir models is tabulated in Appendix A. Next, the given reservoir model is analyzed prior to the application of de novo programming.

4.4 Conventional Reservoir Design Optimization Model

The conventional optimization approach requires the acceptance of all system constraints as given, and the optimization of the given system with respect to individual objectives. In a multiobjective framework, the conventional approach immediately focuses on the generation of feasible compromise solutions, since by definition, compromising objectives can not be optimal simultaneously. Optimization of the given system with respect to individual objectives provides insight into the level of compromise needed to be made. This process also identifies the metaoptimum of the given system.

GAMS (General Algebraic Modeling System) software was selected as the optimization tool and used to generate all optimization solutions discussed hereafter. Appendices B and C provide the GAMS input and output data files, respectively, for the given reservoir model.

Optimization of the given reservoir model while minimizing the required active storage yielded an optimal reservoir active storage of 319.5 $*(10^6\ m^3)$, and an associated value of the second objective of 32,317.1 $*(10^6\ m^3)$. The storage, water supply, and downstream release profiles for the planning horizon are shown in Figures 4-1, 4-2, and 4-3 respectively. In this case, optimal reservoir operation provides the required amount of release to satisfy current demand, store a minimum required volume of water for future demand which could not be satisfied by the provision of future inflow, and release all additional inflow which is not vital to the provision for current or future demand. In this manner the storage in the reservoir is minimized within each time period.

The optimal storage profile reaches a maximum at approximately the halfway point in the planning horizon indicating an accumulation of reservoir storage followed by a progressive decrease in order to attain a feasible solution (the beginning and ending storage levels must be equal). Comparison of the optimal storage profile with the target storage profile for the planning horizon indicated the model did not address the importance of storage deviation. The optimal water supply revealed that the majority of the allocations for this purpose coincided with the minimum bound of the water supply

target. Only when the reservoir storage reached its maximum, did the model allow an upper bound of water supply to be reached. As the reservoir storage decreased, however, the lower bound on water supply was maintained. The optimal downstream release profile followed a similar pattern to that of the water supply. A minimum bound for downstream release was attained for the majority of the planning horizon, being exceeded only around the time of the maximum storage in the reservoir. This type of optimal reservoir operation is expected since the prevailing objective drives the model to satisfy the minimum total demand, providing an amount above the minimum only when unnecessary reservoir storage would result.

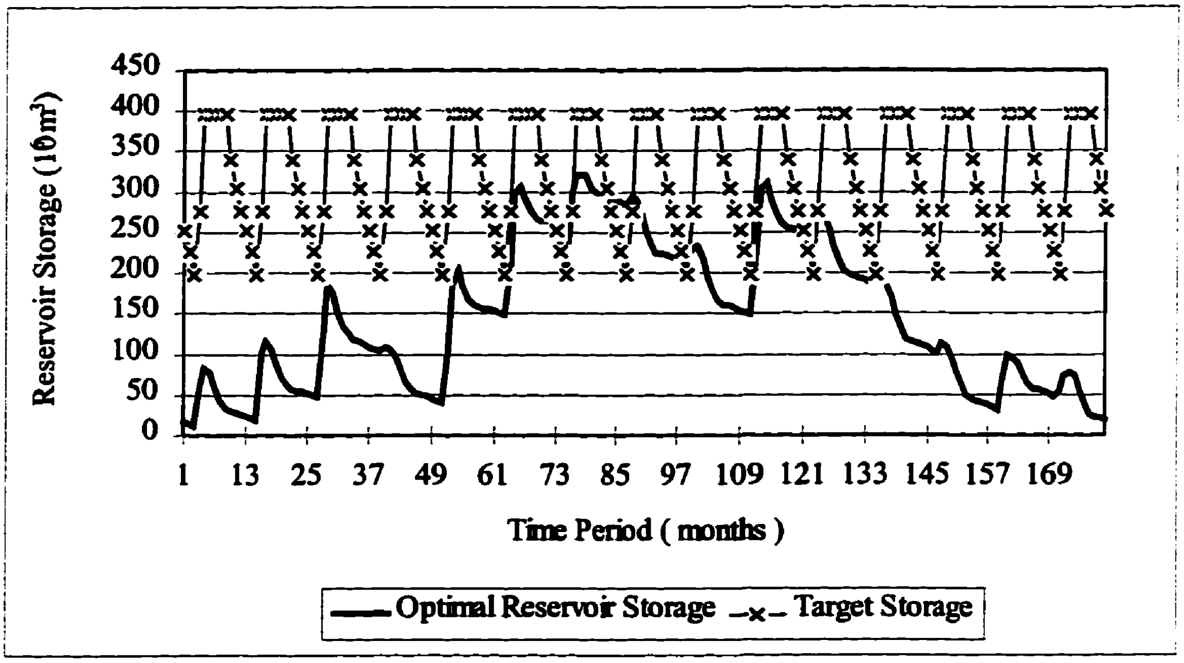

Figure 4-1 Optimal Reservoir Storage Profile, Minimization of the Required Active Storage for the Given Reservoir System

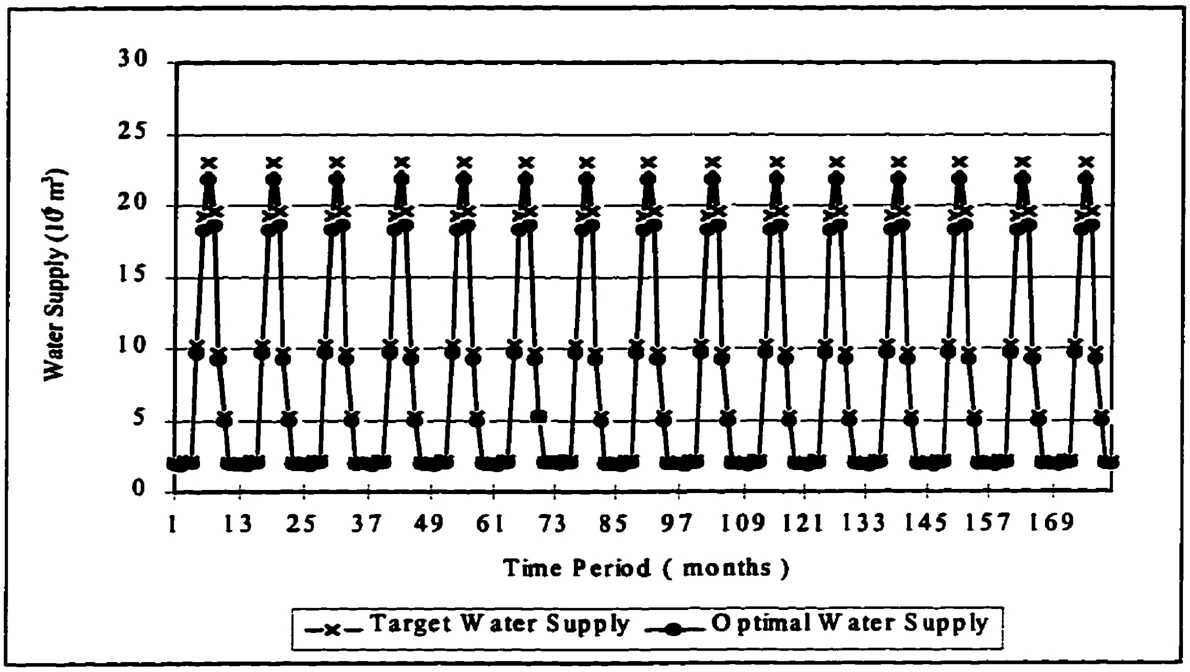

Figure 4-2 Optimal Water Supply Profile, Minimization of the Required Active Storage for the Given Reservoir System

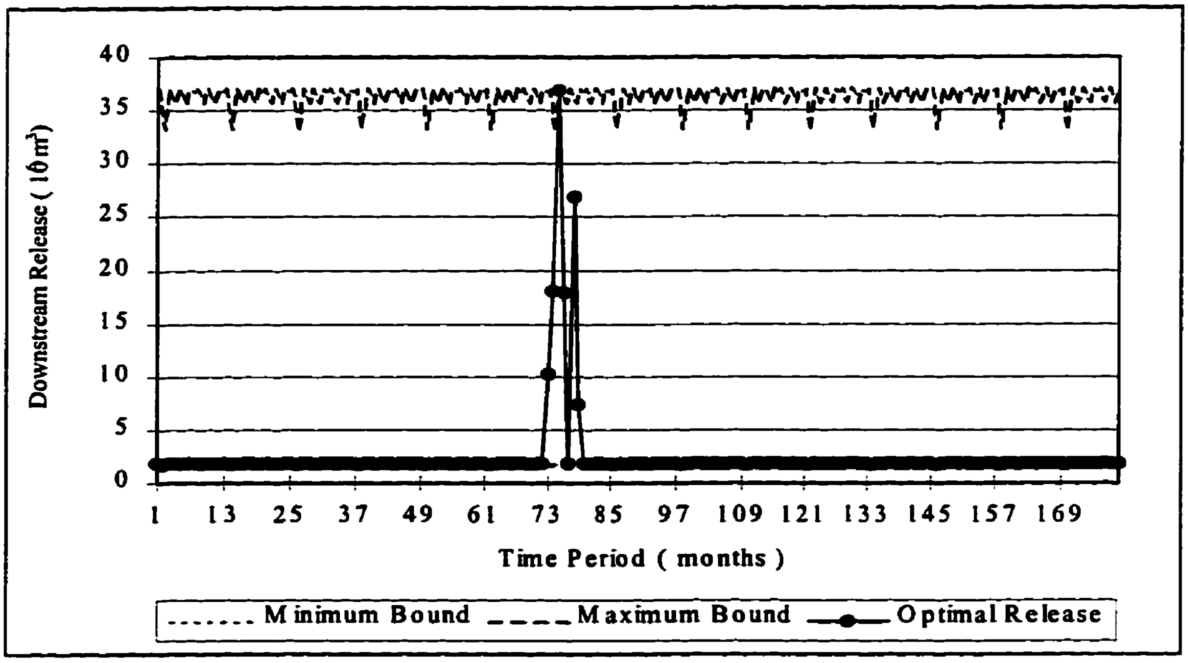

Figure 4-3 Optimal Reservoir Release Profile, Minimization of the Required Active Storage for the Given Reservoir System

Optimization of the reservoir model while minimizing the sum of the deviations of storage from target storage yielded an optimal sum of deviations of 14,945.8 *(10^6 m^3), and an associated value of the first objective of 477.4 *(10^6 m^3). The storage, water supply, and downstream release profiles for the planning horizon are shown in figures 4-4, 4-5, and 4-6 respectively. In this case, the model is driven by the goal of minimization of the total sum of reservoir storage deviations. Implicitly, this objective does not address penalties pertaining to the sign of deviation (i.e. positive or negative), nor does it define a preference for deviations to occur within any time period during the planning horizon.

The optimal storage profile shows a dramatic change in reservoir operation compared to that in the previous solution and mimics the reservoir rule curve. This is an outcome of the objective and demand requirements. In general, the maximum reservoir storage exceeded that of the previous case (minimization of the required active storage), and the maximum reservoir downstream releases were relatively less. The inflow hydrology does however ensure that similar reservoir operation exists between these two scenarios. In general, the effect of the second objective results in an upward shift of the optimal reservoir storage profile, and the decrease of the peak downstream release.

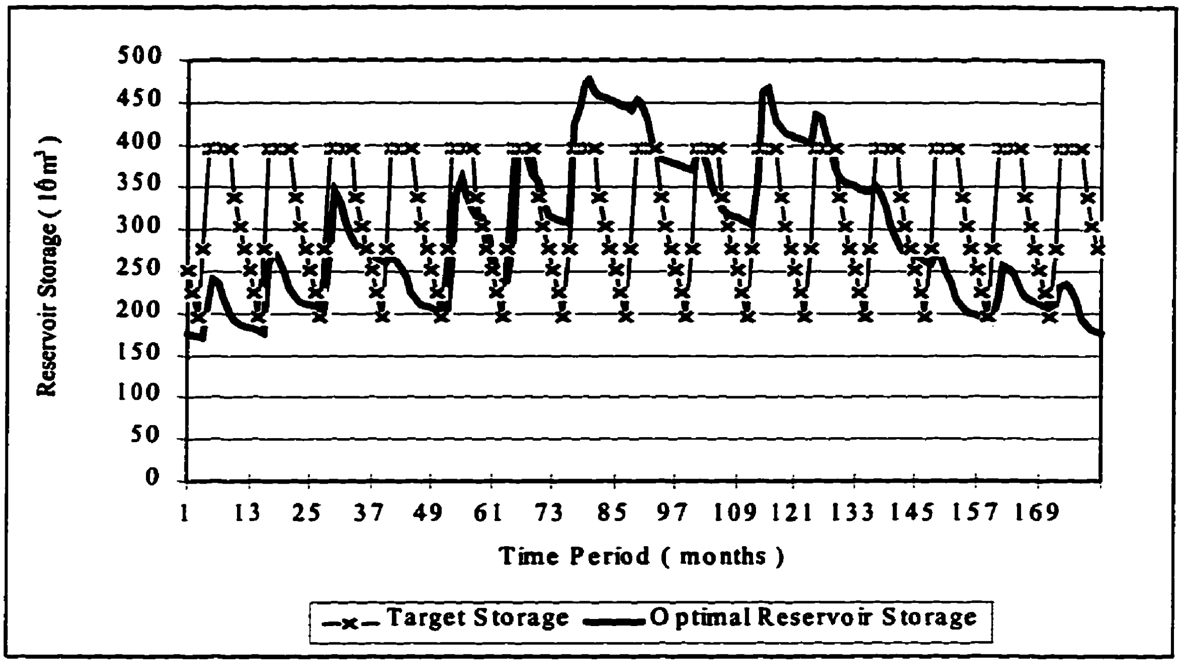

Figure 4-4 Optimal Reservoir Storage Profile, Minimization of the Sum of Storage Deviations for the Given Reservoir System

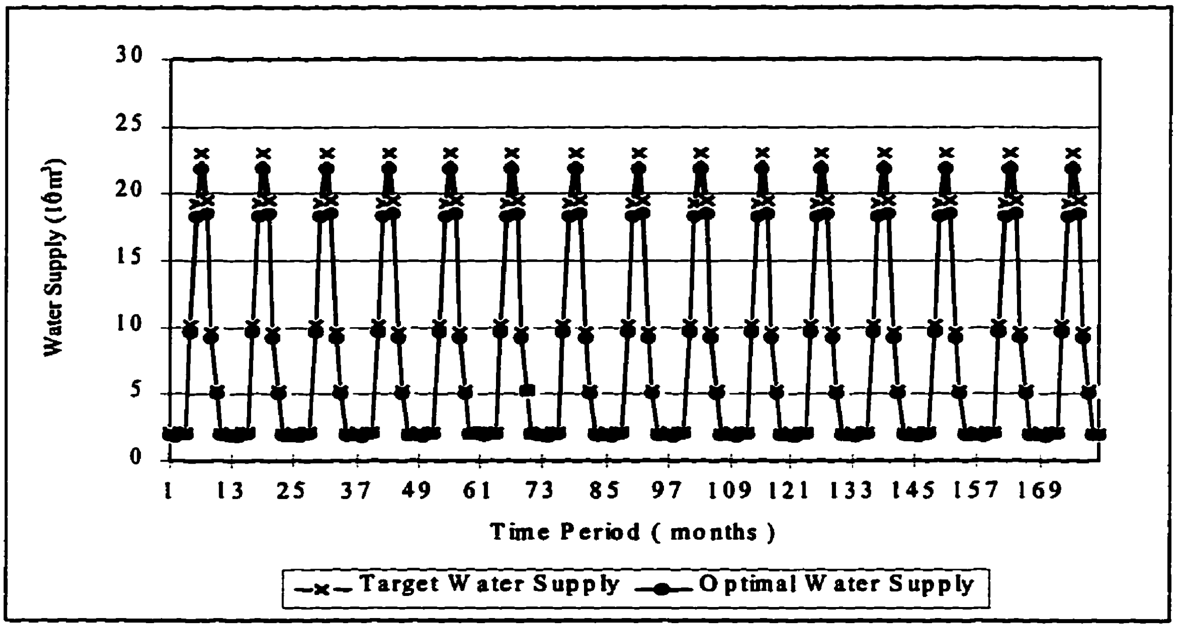

Figure 4-5 Optimal Water Supply Profile, Minimization of the Sum of Storage Deviations for the Given Reservoir System

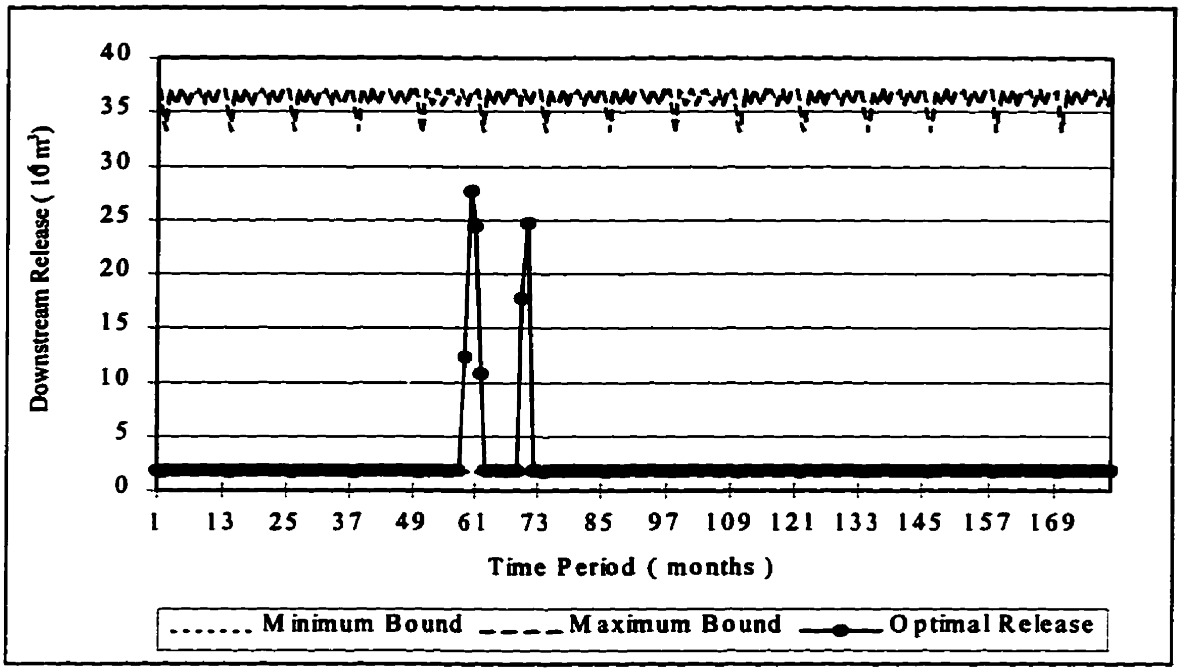

Figure 4-6 Optimal Reservoir Release Profile, Minimization of the Sum of Storage Deviations for the Given Reservoir System

It is clear that an *ideal solution* which would include the optimal required active storage, as well as the optimal sum of storage deviations for the given reservoir model is *not feasible*. Based on the discussion of de novo programming, Chapter 3.0, this combination of optimal individual optima may be defined as the metaoptimum referenced to the given system. The next step in conventional reservoir design calls for the identification of the set of nondominated points which is defined as: the frontier of decision space including all compromise solutions worthy of consideration. The generation of the set of nondominated points for the given reservoir model will be continued in section 4.6.1 . Next a de novo formulation of the given reservoir model is developed.

4.5 De Novo Reservoir Design Optimization Model

Reformulation of the given system into a de novo model requires the introduction of system flexibility. Introduction of system flexibility to the reservoir design problem was subjected to one principle goal, to reasonably justify constraint relaxation. Although many possibilities were available, the final selection of the de novo model structure was also required to produce unique solutions linked to realistic reservoir characteristics. The selection of soft resources was based on the premise of maximum flexibility in reservoir location, maximum and minimum storage capabilities, and downstream reservoir release.

The formulation of the budget could not be formed in a monetary sense. Assumptions regarding the interpretation of the budget coefficients were therefore necessary. This issue will be revisited in section 6.2. The de novo formulation of the reservoir design problem comprises of the following assumptions: all resources except for the storage targets and the lower bound on the water supply are allowed to become soft resources to be designed by the de novo formulation, the ideal performance or the given metaoptimum is defined as the combination of the optimal objective values found in the individual optimization of each objective with respect to the given system, and cost coefficients used in the expression of the budget are assumed to be unity.

Relaxation of maximum and minimum storage and release restrictions is indicative of the preliminary nature of the reservoir design stage. Often preceding a prefeasibility stage of reservoir design, an inception phase will be carried out during which information regarding the geology, hydrology, climate, sediment transport, and other pertinent aspects of a watershed (where construction of the dam is proposed) will be collected. The following prefeasibility stage of the project often focuses on the watershed yield and flood characteristics of the dam itself, intake and outflow control structures, as well as spillway design. Therefore relaxation of the above variables may be interpreted as the inability of the system analyst to determine the exact values of the specified system parameters.

For example, the maximum storage which is a function of reservoir location and dam height may not be known with certainty, may not be a restriction on the system, or may be known without complete certainty. Minimum storage is related to the expected life of the reservoir, reservoir purpose, sediment transport capabilities of the river, and perhaps environmental reasons. Minimum reservoir release may be needed for natural channels where aquatic life conditions are sensitive to low flow levels, but this may not be the case for man made channels. Maximum reservoir release may be constrained by the design of outlets. For example, pipe diameter or gate height. This parameter may also be limited by structural stability limitations and downstream channel capacities. However, prior to the selection of dam location, and the design of physical dam components, the maximum reservoir release may be uncertain.

The upper bound on the fraction of water to be supplied for consumptive purposes may reflect the nature of the demand type. Municipal demand often requires a target level during a time period for which a negative deviation coincides with a steep penalty. A positive deviation, in general, does not result in a penalty, i.e. the water simply will not be consumed. Industrial demand has similar characteristics, however penalties associated with deviations from target levels are not as severe. Demand for irrigation water supply focuses on a minimum water supply, and often accepts water available above this level. Timing of water supply is as important as the quantity available. The large number of parameters associated with development of crop types is directly responsible for the uncertainty of irrigation water demand.

Certainly the relaxation of a system resources involves a thorough thought process. The nature of the resource and its part in the overall system must be addressed before a decision can be made. An issue that has not been mentioned thus far involves associated economic impacts. Projects involving dam construction are always under strict financial constraints. The relaxation of a system resource may involve an unrealistic economic outcome, or doing so may be done deliberately in order to measure the effect of system flexibility on the cost of a project component. The analyst should consider all aspects of de novo model formulation. Constraint types can be grouped into broad categories, involving economic, physical, institutional or operational, social, and ecological types of resources. Experts in each field can then tackle each category individually, with final recommendations for soft resources being conglomerated and discussed with respect to the reservoir system as a whole.

The de novo model is forced to supply the minimum level of the water supply target, and must obey a given operating rule curve for target storage levels. These characteristics were not allowed to be relaxed to preserve the multipurpose nature of the reservoir, i.e. the provision of water supply, recreation (high summer reservoir elevation), and flood protection during spring months. The metaoptimum is defined as the set of optimal objective function values of the given reservoir system and is stipulated via additional constraints. The de novo reservoir design model is written as follows.

$$Minimize \quad Budget = \left\{ S_{\min} + S_{\max} + \sum_{m=1}^{m=12} UB_m + \sum_{m=1}^{m=12} RMIN_m + \sum_{m=1}^{m=12} RMAX_m \right\} \qquad (4\text{-}13)$$

Subject to:

$$S_t = S_{t-1} + I_t - WS_t - R_t \qquad (4\text{-}14)$$

$$S_t \le K \qquad (4\text{-}15)$$

$$S_0 = S_T \qquad (4\text{-}16)$$

$$0 \le S_{\min} - S_t - S_{\max} \le 0 \qquad (4\text{-}17)$$

$$LB_m \le \left(DTAR_m\right)^{-1} WS_t - UB_m \le 0 \qquad (4\text{-}18)$$

$$0 \le RMIN_m - R_t - RMAX_m \le 0 \qquad (4\text{-}19)$$

$$S_t + U_t - V_t = S_m^{*} \qquad (4\text{-}20)$$

$$K \equiv 319.55 \quad \left(10^6 m^3\right) \qquad (4\text{-}21)$$

$$\sum_{t=1}^{t=T} \left| S_t - S_m^* \right| = 14945.83 \quad \left(10^6 m^3\right) \qquad (4 - 22)$$

$$t = 1,2,\ldots,(T = 180) \qquad m = 1,2,\ldots,12$$

Minimization of the objective with respect to the de novo model provides the optimal budget which will ensure the achievement of the metaoptimum, i.e. constraints (4 - 21) and (4 - 22) must be satisfied, via the design of an optimal soft resource portfolio, provided such a solution exists. It was found that an optimal solution to the de novo model was not feasible (GAMS input and output data files for the de novo reservoir model, are provided in Appendices D and E respectively). Comparison of the de novo with the given reservoir model revealed that an insufficient amount of system flexibility has been provided to achieve the demanding task of satisfying the metaoptimum constraints.

At this time, the following options exist: the system can be reformulated to provide more system flexibility and the analysis repeated, the metaoptimum can be relaxed and the analysis repeated, a combination of both, or the de novo model accepted and further analyzed. The last option falls into an expected category, unfeasibility of an ideal system performance, and therefore to fully evaluate de novo programming, this option will become the focus of the remaining work. Comparison of either system's performance will require the generation of nondominated points for each reservoir system, and the selection of compromise solutions which is done in the next two sections.

4.5.1 Nondominated Sets of Conventional and De Novo Reservoir Models

Considering the efficiency, and the precision of results, the weighting method was selected for generation of the pareto optimal curves for the given and de novo reservoir models.

The weighting method uses numerical weights to combine conflicting model objectives into a single weighted system objective. Optimization of a system with a selected pair of weights yields a single feasible solution which is mathematically guaranteed to lie within the set of nondominated points. Iterative variation of objective weights and subsequent optimization of a system, results in a series of nondominated points which together represent the pareto optimal curve. The advantage of the weighting method is its simplicity in application and understanding, and explicit consideration of objective trade offs. Negative aspects include the high time consumption related to the fact that successive system performance levels guide the choice of an appropriate pair of weights for the next iteration, and the possibility of a large number of different weights yielding the same nondominated solution.

Mathematical programs used in the development of the given and de novo nondominated sets of points are listed below. The objective in each comprises of a sum of weighted required active storage, and weighted sum of storage deviations. The model for the generation of the set of nondominated points of the given reservoir system is summarized as:

$$\textit{Minimize} \quad \left\{ W1 * K + W2 * \left[\sum_{t=1}^{t=T} \left| S_{t} - S_{m}^{*} \right| \right] \right\} \tag{4 - 23}$$

subject to:

equation (4 - 5) to (4 - 12)

The model for the generation of the de novo set of nondominated points is similar to that of the given reservoir system. The main difference being the inclusion of soft resources.

Minimize (4 - 23)

subject to:

equation (4 - 13) to (4 - 22)

where:

W1 and W2 are arbitrary constants.

Note that neither system includes the given metaoptimum constraints. These constraints are excluded in the de novo system to avoid an unnecessary bias with respect to the given system. Since it was established that the given metaoptimum can not be attained, the de novo set of nondominated points cannot possibly include this point.

Approximately 150 iterations involving the selection of arbitrary constants were required to develop the representative pareto optimal curves for the given and de novo reservoir systems, respectively. A graphical comparison between the respective sets is presented in Figure 4-7.

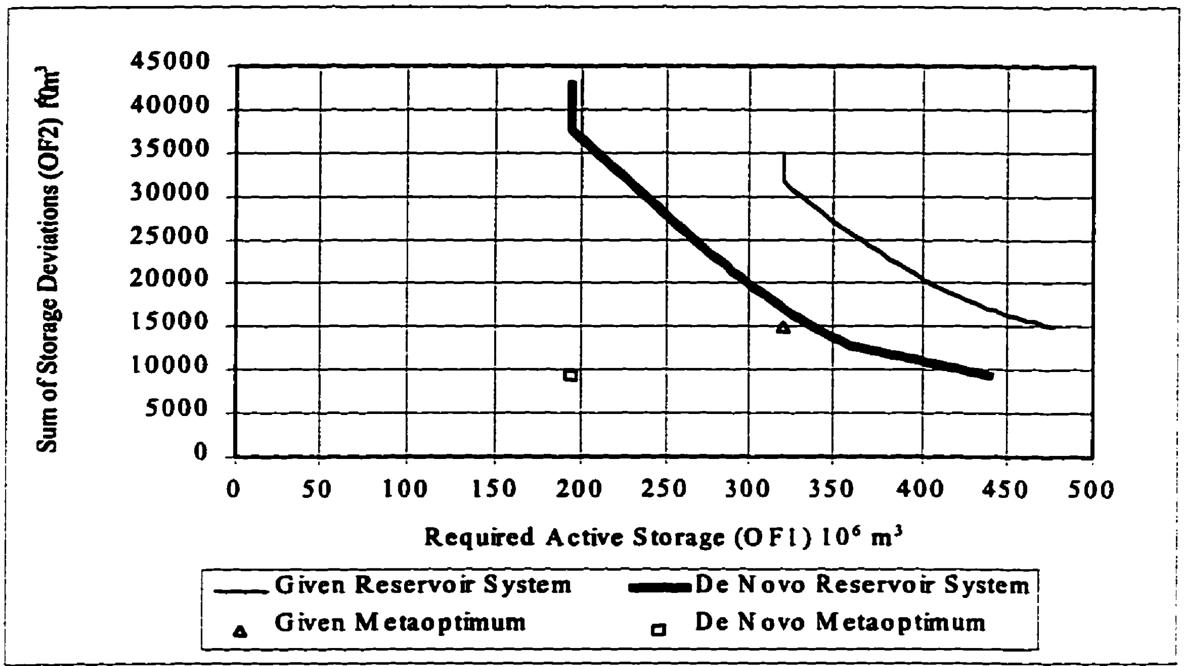

Figure 4-7 Comparison of the given and de novo nondominated sets of points, with respective metaoptima

The frontier of the de novo set of nondominated points is redesigned in accordance with the inclusion of soft resources. All points on the de novo pareto optimal curve exhibit an improvement in one or both objectives when compared to various points in the given set. Drawing vertical and horizontal lines through any point on the given pareto optimal curve results in the precise isolation of these points in the de novo set, which exhibit an improvement in one or both objectives. In this manner an exact level of improvement may be measured between a compromise de novo solution, and a given compromise solution.

As expected it is seen that the de novo pareto optimal curve does not pass through the location of the given metaoptimum. The location of the de novo metaoptimum is also seen to be excluded from the de novo set in conjunction with the level of objective conflict which exists in the de novo system.

Chapter 3.0 demonstrated the effect of de novo programming on a decision space, the same presentation can not be made with either reservoir system due to the large number of decision variables. However, the effect of de novo reservoir system is demonstrated in objective space as seen in Figure 4-7. The relationship between decision variables and objective space is unique, and therefore guarantees that an effect on the shape of the frontier of nondominated points is reflected in an effect on the shape of decision variable space, and vice versa. This notion can therefore be used to state that in the case of de novo model infeasibility, de novo programming redesigns the shape of the feasible region in decision variable space, and therefore redesigns the pareto optimal curve in objective function space.

The generation of nondominated sets is necessary to ultimately select a best compromise solution. There is no single method of identifying a best compromise solution, rather, the decision maker's preference for a solution is incorporated into the decision making process. Prior to the selection of a formal solution technique, it may be possible for the decision maker to possess strong feelings toward a particular solution or group of solutions. In this case, and especially when a time constraint on the decision process is imposed, a decision maker may prefer to select a solution, based on his/her experience. Otherwise a multitude of formal search techniques exist. Some of these were briefly described in the literature review. The next section employs one technique, compromise programming, to identify best compromise solutions for the given and de novo reservoir models.

4.5.2 Compromise Solutions of Conventional and De Novo Reservoir Models

Compromise programming identifies the solution which is guaranteed to lie in a set of nondominated points, by minimizing the weighted "distance" between nondominated points and an ideal or the metaoptimum. In practice, three best compromise solutions are typically generated in order to provide a sensitivity distribution of the best compromise solution to the decision makers preference for objective importance, and its deviation from the ideal. The distance metric written for *minimization* of a multiobjective problem obtains the following general form:

$$\left[L_s(x) = \sum_{i=1}^{p} \alpha_i^s \left[\frac{Z_i(x) - Z_i^*}{Z_i^{**} - Z_i^*}\right]^s\right] \qquad (4-24)$$

<u>where:</u>

$L_s(x)$ is the weighted distance of a point in the set of nondominated points and a point representing the ideal solution or metaoptimum;

Z_i is the ith objective function level;

Z^{*}_{i} is the ideal level of the i^{th} objective function;

Z^{**}_{i} is the maximum level of the i^{th} objective function;

s is a constant used to express the decision makers concern with the maximal deviation, typically the problem is solved for three levels of s (s = 1, s = 2, s = 100) which yield three best compromise decision alternatives;

α_i is a weight used to represent the decision makers relative importance of the i^{th} objective function;

p is the number of objectives (p = 2); and

x is a vector of decision variables.

The complete compromise set is determined by solving a compromise model for a set of weights, $\{\alpha_i\}$ and for all $1 \leq s \leq \infty$. Since the generation of an infinite number of compromise solutions is not possible, three points of the set are usually calculated, mainly those corresponding to s = 1, s = 2, and s = 100. Each of these cases corresponds to a specific interpretation of the double weighting method. Variation and substitution of the “s” parameter in the distance metric reveals that a different meaning in the objective is achieved.

The linear case (s = 1) results in the distance being defined as the sum of weighted deviations of each objective relative to a predefined ideal. The objective weights are described by the parameter α_i which signifies the relative importance of each objective. In this case the deviations from the metaoptimum are weighted equally with a unit weight. If the deviation is raised to the second power ($s = 2$), all deviations will be weighted in proportion to their magnitude. Continuing to increase the power to which the deviation is raised to, results in higher deviations being increasingly weighted. An infinitely large power results in the largest deviation receiving all weight. Combination of this effect and the α_i parameter produces the double weighting scheme with the s parameter being interpreted as the importance of the maximal deviation, and the α_i parameter as the importance of the i^{th} objective.

The denominator of the distance metric may not be self evident. If the objective functions are not expressed in commensurable terms, then it is necessary to introduce a scaling function (the denominator) to ensure a common range for each objective (0 to 1). The advantage of doing so ensures mathematical scaling of the distance metric which in turn prevents problems encountered in the search procedure of the nonlinear optimization process. Typical problems include numerical instability, and inaccuracy which pose problems in finding an optimal solution to the compromise model. Another advantage to scaling deviations is the fact that all terms in the compromise objective become dimensionless, simplifying the interpretation of the objective. For the given and de novo reservoir models, the maximum values of each objective were obtained through observation of bounds on corresponding sets of nondominated points.

The distance metric for the given reservoir system was related to the given metaoptimum, and obtained the following form.

$$\text{Distance (given system)} = \left[\frac{(OF1-319.55)}{(477.36-319.55)}\right]^{S} + \left[\frac{(OF2-14945.83)}{31694.80-14945.83)}\right]^{S} \qquad (4-25)$$

where:

OF1 represents the first objective function, minimization of the required active storage;

OF2 represents the second objective function, minimization of the sum of storage deviations;

S = 1, 2, 100; and

(319.555, 14 945.83) is the location of the given metaoptimum in objective space

477.36 and 31694.80 are the maximum bounds on each objective functions OF1 and OF2, respectively, units are 10^6 m^3.

Similarly, the distance metric for the de novo reservoir system was defined as:

$$\text{Distance (de novo system)} = \left[\frac{(OF1-194.40)}{(439.10-194.40)}\right]^{S} + \left[\frac{(OF2-9378.50)}{(37684.90-9378.50)}\right]^{S} \qquad (4-26)$$

where:

OF1 represents the first objective function, minimization of the required active storage;

OF2 represents the second objective function, minimization of the sum of storage deviations;

S = 1, 2, 100; and

(194.40, 9378.50) is the location of the given metaoptimum in objective space

439.10 and 37684.90 are the maximum bounds on each objective functions OF1 and OF2, respectively, units are 10^6 m^3.

A total of six optimization problems are created from the above distance metrics. For each compromise model, it was assumed that the objectives were equally important ($\alpha = 1.0$). Summaries of the solutions are provided in Table 4-1, and Table 4-2.

Table 4-1 Best compromise solutions for s = 1, 2, 100, and $\alpha = 1.0$ of the given reservoir system, distance measured with respect to the given metaoptimum.

S	**Optimal OF1** 10^6 m^3	**Optimal OF2** 10^6 m^3
p = 1	403.19	20202.45
p = 2	392.12	21485.53
p = 100	456.69	15949.35

Table 4-2 Best compromise solutions for s = 1, 2, 100, and $\alpha = 1.0$ of the de novo reservoir system, distance measured with respect to the de novo metaoptimum.

S	**Optimal OF1** 10^6 m^3	**Optimal OF2** 10^6 m^3
p = 1	335.67	15158.66
p = 2	301.65	19556.83
p = 100	408.56	9782.45

It can be seen that all compromise performance levels are improved on by the de novo reservoir design. This is not a surprising conclusion since the generation of given and de novo sets of nondominated points implied this result. The exercise of generating compromise solutions does however provide exact measures of improvement for different objective deviation preferences. The relative location of each generated compromise solution is shown graphically in Figure 4-8.

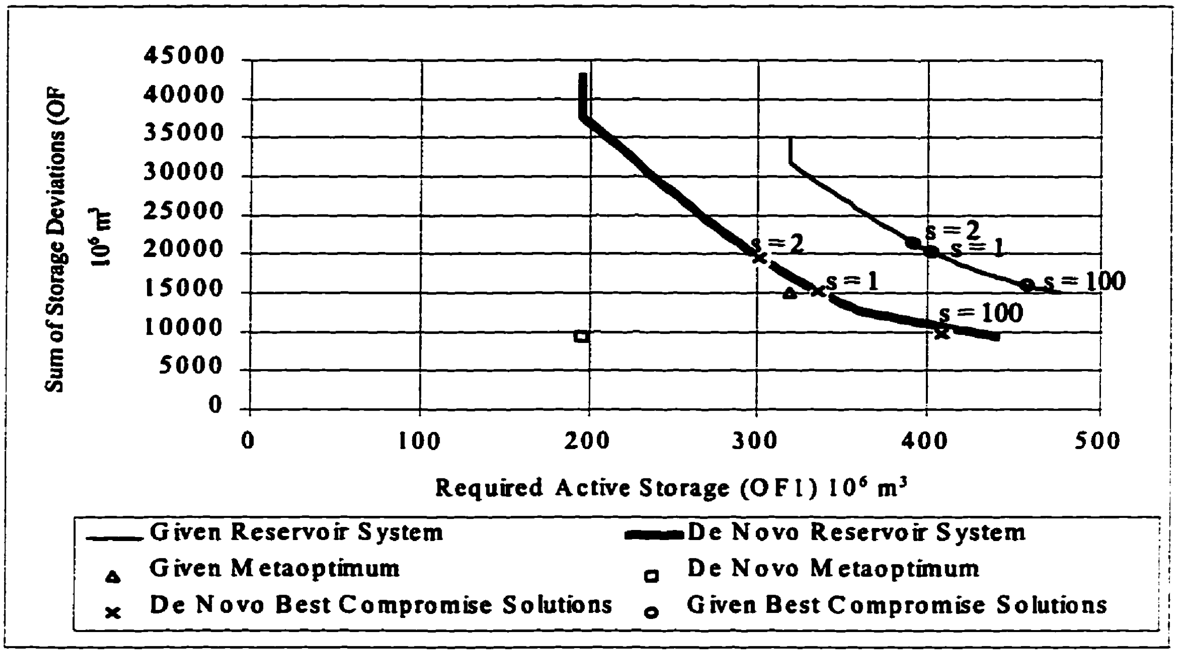

Figure 4-8 Location of optimal compromise solutions for given and de novo reservoir systems

The de novo reservoir model designed the soft resource portfolio in a manner that dissipated some objective conflict. At best, the de novo system could have attained the given metaoptimum (metaoptimum included in the de novo model as equality constraints with respect to the given system), and at worst no benefit could have been gained. An intermediate state where the performance of compromise solutions is improved, is also possible. It is evident that de novo programming may improve system performance via the optimal design of a reservoir system. It is not possible to improve upon an optimal system design once all soft resources have been identified. The next chapter provides a detailed presentation of the reservoir performance in each generated compromise solution.

5. COMPARISON OF GIVEN AND DE NOVO RESERVOIR SYSTEMS

Compromise solutions for two uniquely designed reservoir systems have been generated. This chapter concentrates on comparing the configuration of given and de novo reservoir systems. Each type of compromise solution ($s = 1$, $s = 2$, $s = 100$) reflects the decision maker's preference for objective deviation and is discussed individually. System configuration refers to physical as well as operational reservoir characteristics which are depicted in reservoir storage, water supply, and downstream release profiles. A final discussion regarding the de novo programming concept is provided in chapter 6.0.

5.1 Equal Preference for Objective Deviation, s = 1

The given reservoir model assumed fixed resources for all constraints. Within the given feasible region, the performance of this compromise solution requires a minimum required active storage of 403.19 $*(10^6 \text{ m}^3)$ and a minimum sum of storage deviations of 20202.45 $*(10^6 \text{ m}^3)$.

The de novo model designed a soft resource portfolio which included a maximum required active storage of 335.67 *(10^6 m^3), a minimum storage of zero, minimum monthly release policy of zero (for every month), maximum monthly release equaling zero in every month except for March in which it is 0.75 *(10^6 m^3), and an upper bound policy for water supply varying from 0.95 to 15.08. The performance of the de novo model is measured by the objective function values. The minimum required active storage was equal to the maximum reservoir storage attained during the planning horizon, 335.67 *(10^6 m^3), with a corresponding total minimum sum of storage deviations of 15158.66 *(10^6 m^3).

Reservoir operating strategies for each compromise solution are depicted in Figures 5-1, 5-2, and 5-3 where a direct comparison of reservoir storage, water supply, and downstream release can be made.

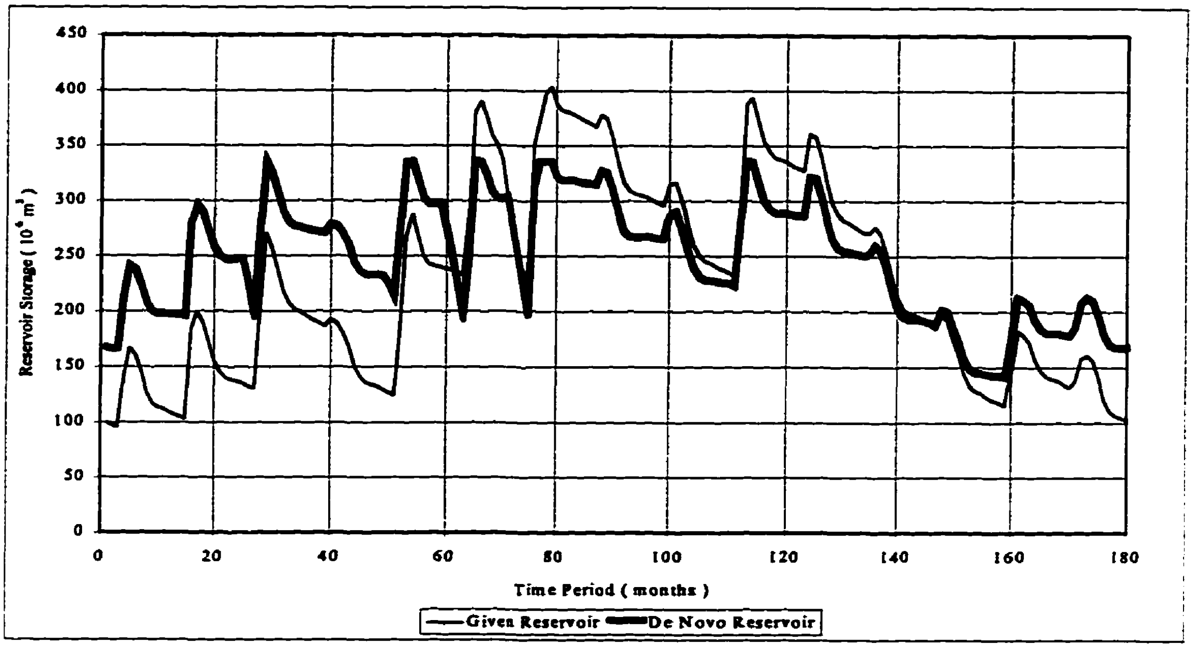

Figure 5-1 Comparison of reservoir storage profiles of the given and de novo reservoir models, compromise solution with s = 1

The given model results in a higher range of reservoir storage than does the de novo model. This is due to a higher cumulative demand placed on the given model (no relaxation of the minimum downstream release). Due to the selected double weighting method, the de novo model is therefore capable of maintaining a higher average reservoir storage, while achieving a relatively smaller active storage. Reservoir storage is a function of the inflow and total reservoir release within a time period. The water supply and total release profiles are shown next.

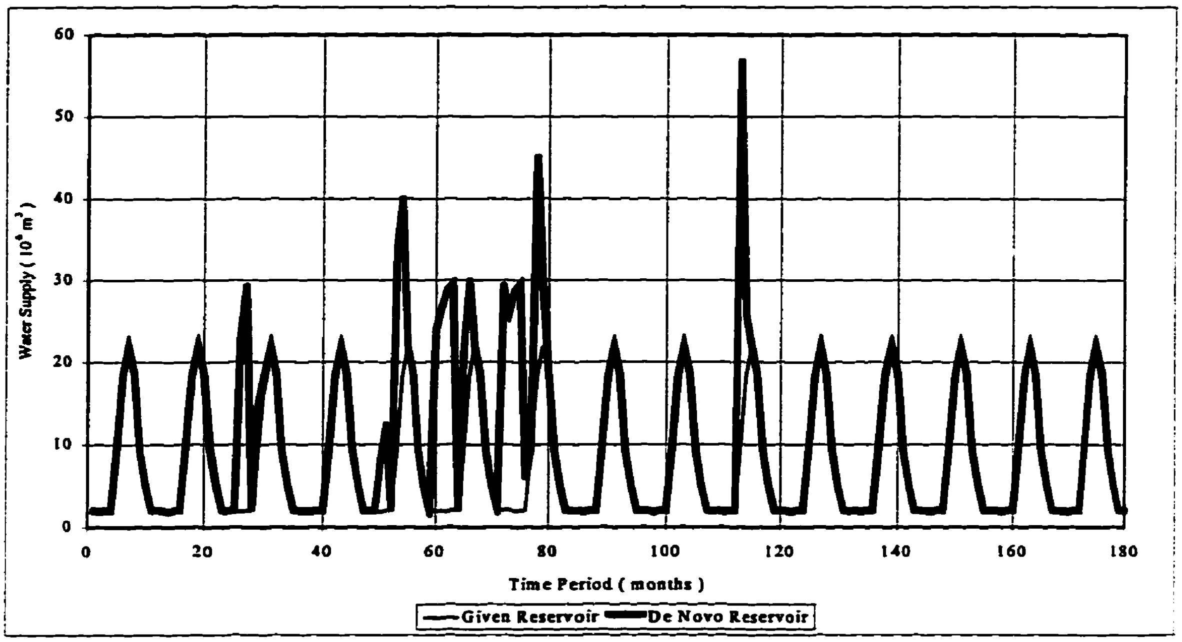

Figure 5-2 Comparison of reservoir water supply profiles of the given and de novo reservoir models, compromise solution with s = 1

The given model requires that the water supply provision be within 95% to 100% of the specified target demand. The de novo model allows water supply provision above monthly minimum levels. To reflect the selected objective preference structure, the de novo model releases water as necessary to minimize the required active storage and sum of storage deviations. The relaxation of the upper bound on water supply implies the acceptance of variability in maximum water supply levels. In this example, the maximum water supply as designed by the de novo model, was approximately 160% greater than that in the given reservoir system.

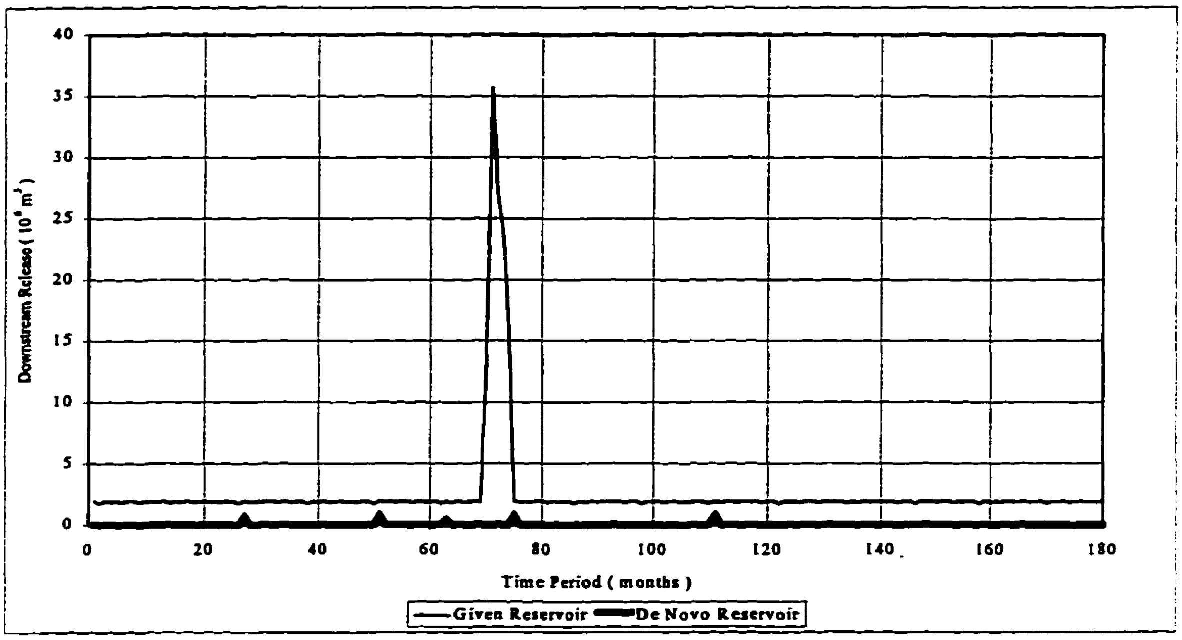

Figure 5-3 Comparison of reservoir downstream release profiles of the given and de novo reservoir models, compromise solution with s = 1

The given model does not result in many time periods, in which downstream reservoir release exceeds the assumed minimum requirement. Months 76 to 80 are the only time periods in which the maximum release is achieved. The de novo model does not provide any downstream release in the majority of the planning horizon. Five time periods, corresponding to the month of March, obtain a nonzero allocation of downstream release. These time periods correspond to high reservoir inflows, high provision of water supply, and high reservoir storage levels. In order to minimize both objectives, the de novo model must provide an allocation of water to downstream release during these time periods.

5.2 Proportional Weighting of Objective Deviations, s = 2

The given reservoir model assumed fixed resources for all constraints. Within the given feasible region, the performance of this compromise solution requires a minimum required active storage of 392.12 $*(10^6\ m^3)$ and a minimum sum of storage deviations of 21485.53 $*(10^6\ m^3)$.

The de novo model designed a soft resource portfolio which included a maximum required active storage of 301.65 $*(10^6\ m^3)$, a minimum storage of zero, minimum monthly release policy of zero (for every month), maximum monthly release equaling zero in every month, and an upper bound policy for water supply varying from 18.95 to 0.95. The minimum required active storage was equal to the maximum reservoir storage attained during the planning horizon, 301.65 $*(10^6\ m^3)$, with a corresponding total minimum sum of storage deviations of 19556.83 $*(10^6\ m^3)$.

Reservoir operating strategies for each compromise solution are depicted in Figures 5-4, 5-5, and 5-6 where a direct comparison of reservoir storage, water supply, and downstream release can be made.

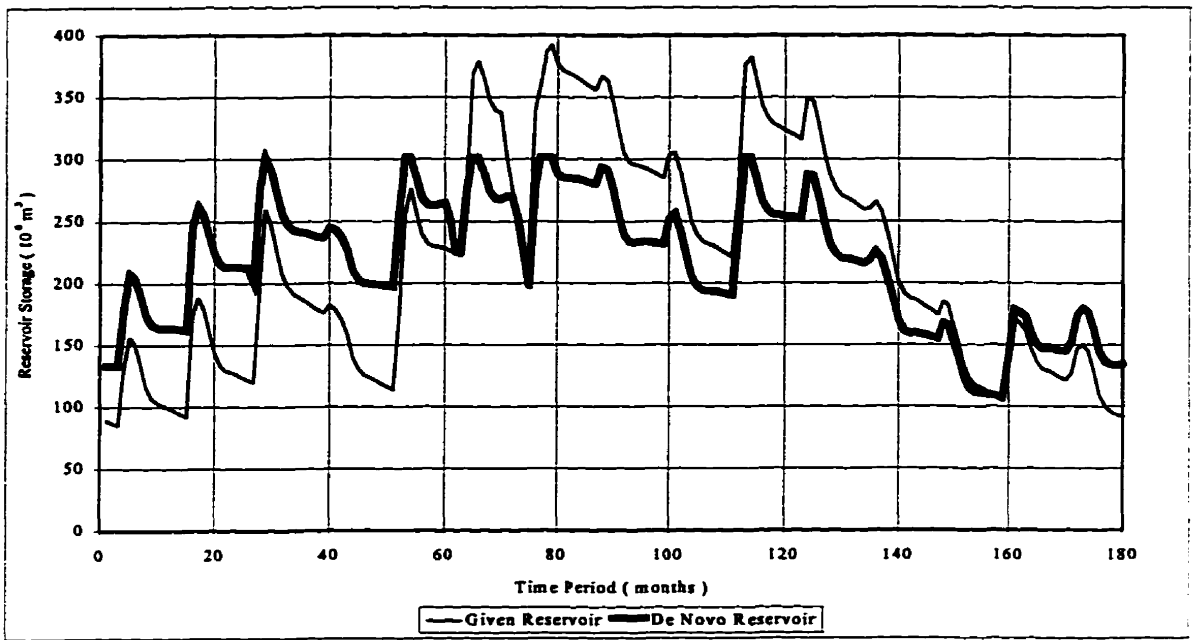

Figure 5-4 Comparison of reservoir storage profiles of the given and de novo reservoir models, compromise solution with s = 2

The double weighting structure for this compromise solution results in the minimization of the required active storage receiving more weight relative to the second objective. The de novo model is capable of maintaining a higher average reservoir storage during the first 60 months of the planning horizon, sufficient to provide the minimum water supply demand during the remainder of the planning horizon. Reservoir active storage is decreased by approximately 10% with a corresponding increase in the sum of storage deviations of approximately 29%. The water supply and downstream release profiles, shown next, prove that a higher total reservoir release (sum of water supply and downstream release) is necessary to achieve the performance of this reservoir system.

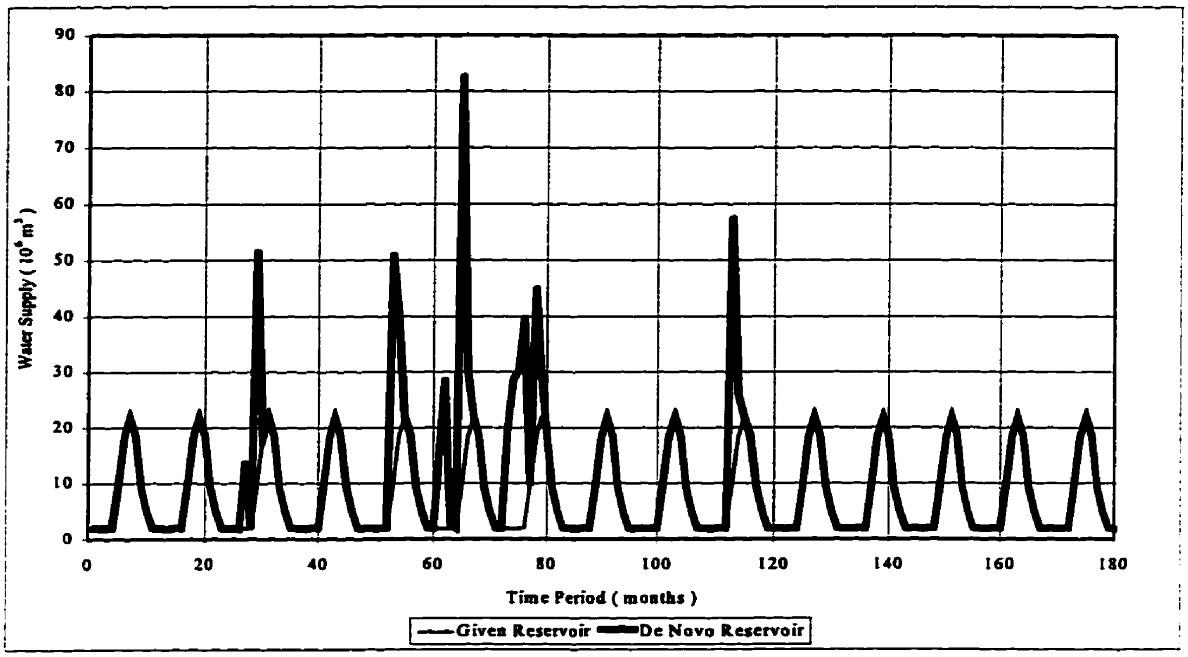

Figure 5-5 Comparison of reservoir water supply profiles of the given and de novo reservoir models, compromise solution with s = 2

The strict restriction on the water supply provision in the given model can not change the water supply profile drastically. The de novo model however shows a considerably higher peak water supply (in month 65). Although the total water supply provision did not change significantly, this water supply profile is responsible for the tradeoff in objective function values observed in the s = 1 and s = 2 compromise solutions.

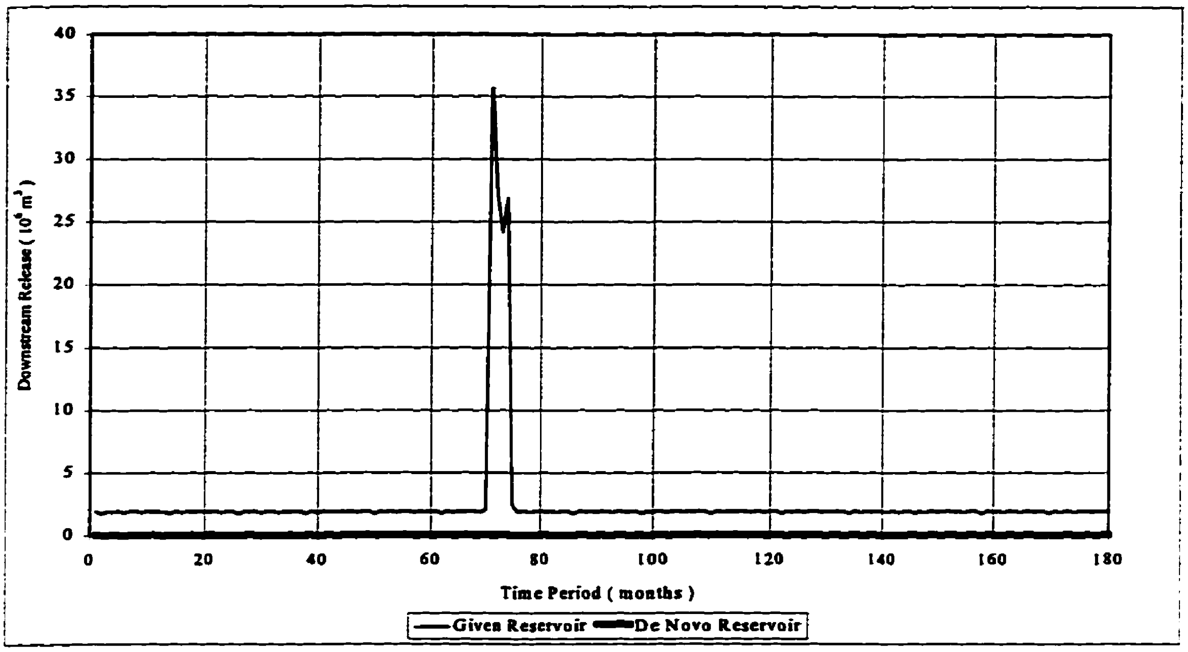

Figure 5-6 Comparison of reservoir downstream release profiles of the given and de novo reservoir models, compromise solution with s = 2

The total reservoir release does not increase for the given model significantly, compared to the s = 1 compromise solution. The de novo model shows that no release for downstream purposes should be made. This outcome is again an indication that the de novo model does not address a preference for reservoir releases to be allocated to water supply or downstream needs.

5.3 Minimization of the HIGHEST Objective Deviation, s = 100

Within the given feasible region, the performance of this compromise solution requires a minimum required active storage of 456.69 $*(10^6\ m^3)$ and a minimum sum of storage deviations of 15949.35 $*(10^6\ m^3)$.

The de novo model designed a soft resource portfolio which included a maximum required active storage of 408.56 *(10^6 m^3), a minimum storage of zero, minimum monthly release policy of zero (for every month), maximum monthly release equaling zero in every month, and an upper bound policy for water supply varying from 18.77 to 0.95. The performance of the de novo model is measured by the objective function values. The minimum required active storage was equal to the maximum reservoir storage attained during the planning horizon, 408.56 *(10^6 m^3), with a corresponding total minimum sum of storage deviations of 9782.45 *(10^6 m^3).

Reservoir operating strategies for each compromise solution are depicted in Figures 5-7, 5-8, and 5-9 where a direct comparison of reservoir storage, water supply, and downstream release can be made.

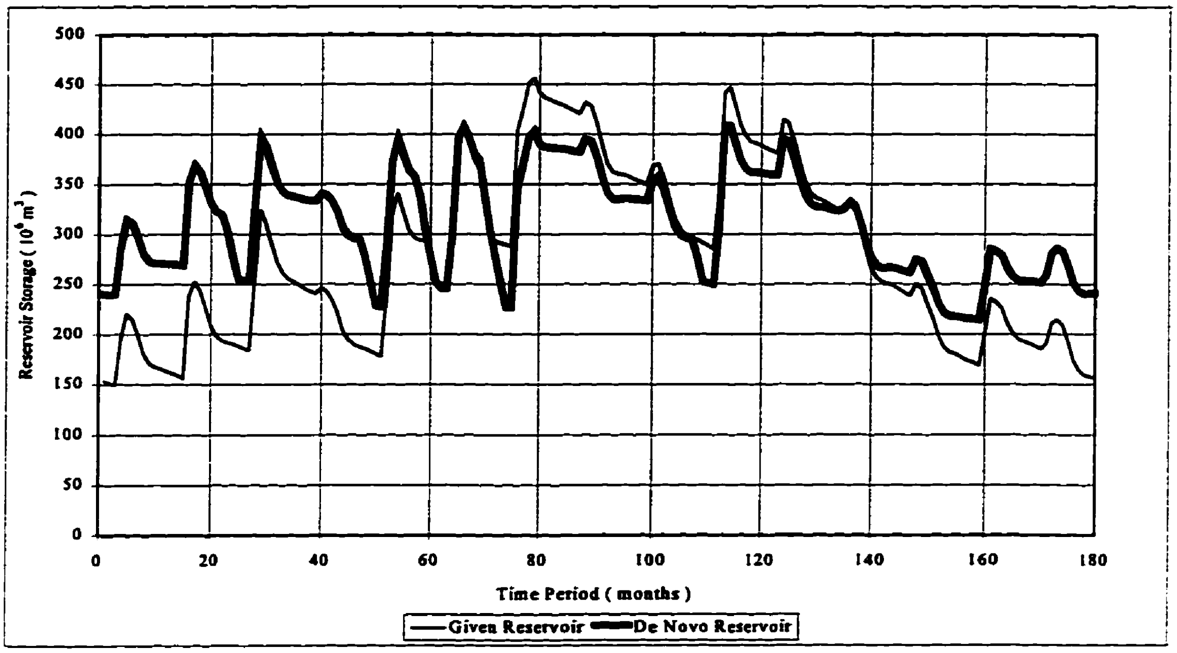

Figure 5-7 Comparison of reservoir storage profiles of the given and de novo reservoir models, compromise solution with s = 100

This compromise solution reveals a higher preference for the minimization of the sum of storage deviations. The required active storage for the given and de novo models increases by approximately 13% and 22% respectively, when compared to the s = 1 compromise solution. Accordingly the sum of storage deviations decreases by approximately 21% and 35%. The range of reservoir storage for both models decreased compared to the s = 1 and s = 2 cases reflecting the regulation of storage with respect to the specified target levels.

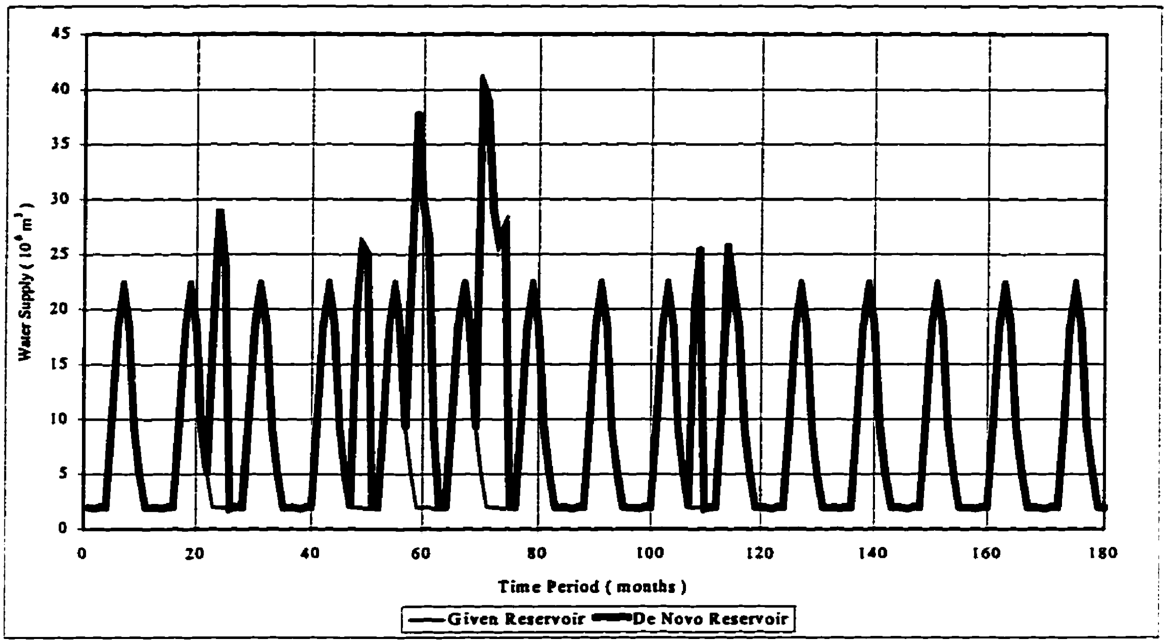

Figure 5-8 Comparison of reservoir water supply profiles of the given and de novo reservoir models, compromise solution with s = 100

The peak water supply for the de novo model reached 40.38 $*(10^6\ m^3)$, significantly less than that achieved in the s = 1, and s = 2 solutions (50.96 $*(10^6\ m^3)$, and 82.87 $*(10^6\ m^3)$ respectively). This an indication that comparatively, more water must be stored in the reservoir as demanded by monthly storage target levels.

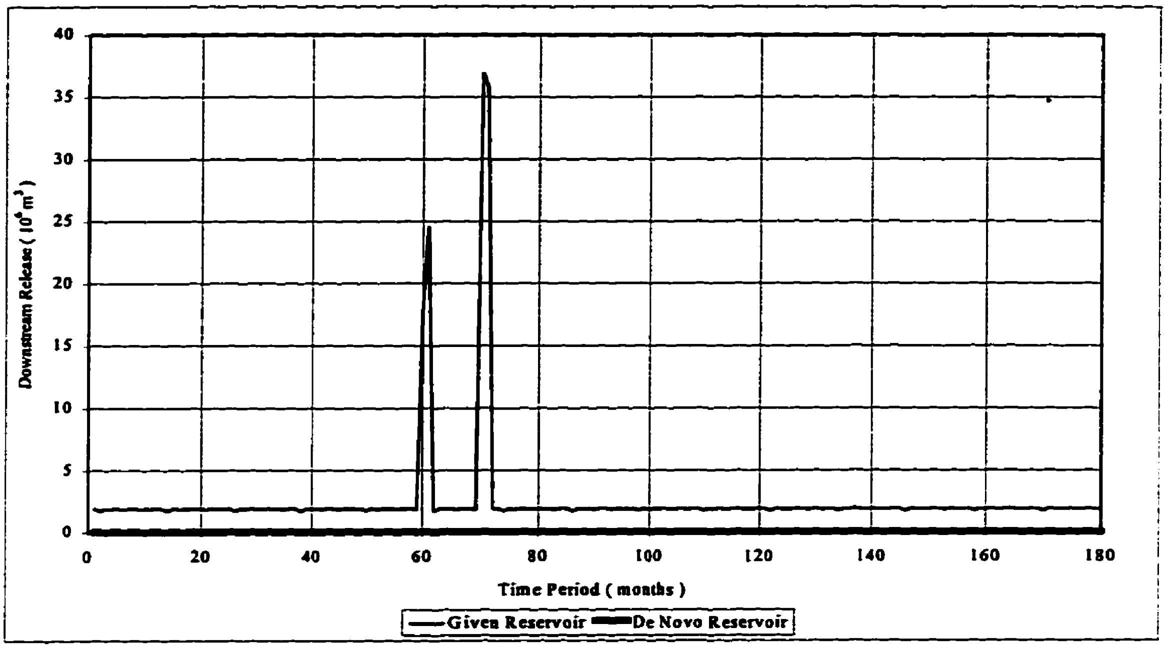

Figure 5-9 Comparison of reservoir downstream release profiles of the given and de novo reservoir models, compromise solution with s = 100

The total downstream reservoir release for the given model did not vary significantly among all compromise solutions (442.20 *(10^6 m^3), 442.78 *(10^6 m^3), and 442.88 *(10^6 m^3) for s = 1, s = 2, and s = 100 respectively). Once again the de novo model does not provide any downstream release as release from the reservoir would hinder the storage needed to reflect the importance of minimizing storage deviations.

6. DISCUSSION

This chapter considers two main aspects of de novo programming, (1) the identification of soft resources which creates system flexibility and allows system efficiency to be maximized, and (2) the formulation of the budget objective. The goal of this chapter is to discuss the main characteristics of de novo programming which will be used to make final conclusions and recommendations in Chapter 7.0.

6.1 System Flexibility

The process of soft resource identification has been demonstrated in the development of the de novo reservoir model formulation. Several comments can be made based on this experience and the familiarity with water resources problems.

Constraints may be separated into groups, such as physical, environmental, social, or economic constraints. This division will allow experts in particular fields to identify the acceptable deviation from target resource levels. Doing so will result in the generation of resources which must be fixed, and soft resources. This process alone, may generate new insight into the interaction of the reservoir system with its surrounding environment. Soft resources or constraints will, in any case, be accepted under the pretense that the decision maker and analyst have the authority of designing the system. It is obvious that the selection of soft resources must be done on a case by case basis. Certainly, as the reservoir environment, and purpose changes, the system resources may change.

Intuitively, the potential for identifying soft resources exists at the design stage of water resources systems. Since the physical components are not fixed, some physical limitations may be considered soft. Similarly, more flexibility may exist in other constraints within the social, and environmental categories. However, the design stage of water resources systems is not exclusive to the application of de novo programming. Existing systems which involve multiple reservoirs, users, and objectives may also posses soft constraints. Due to the high complexity of such a system, optimization of reservoir operation may result in infeasibility of a solution. Some constraints may therefore be relaxed in order to identify a feasible solution. For example, constraints limiting the maximum or minimum channel flow capacities may be allowed to be relaxed a percentage of the planning time. Alternatively, however, the de novo programming approach may be used to design the optimal set of system resources.

6.2 De Novo Objective Function

Zeleny's application of de novo programming focuses on the minimization of a financial budget used to purchase a soft resource portfolio. In the reservoir design context this may not be directly applicable due to difficulty of obtaining the per unit cost values of intangible quantities. If possible, the de novo objective may take the form of total cost. The benefit of de novo programming may be equally as powerful if the budget is allowed to be interpreted as necessary for a particular problem. This implies that the budget should be considered a *governing objective function.*

The governing objective may be thought of as a conglomeration of several independent objectives. As with Zeleny's case each term in the budget represent the total cost of a particular resource. The budget then sums each individual resource cost to form the overall goal, to minimize the total cost of all soft resources. Extending this idea to the reservoir design problem is not as simple since the relaxation of one constraint, may have a very different effect, or purpose, than another soft resource. The de novo reservoir objective developed in Chapter 4.0, may be interpreted in this manner.

With respect to the reservoir design problem, soft resources were assumed to be equally important, or contain unit cost coefficients. Therefore the *cumulative impact* of the reservoir was minimized. Each term in the de novo reservoir objective can be analyzed individually, and related to specific impacts. Minimization of the reservoir dead storage, resulted in the decrease of environmental impacts (i.e.disruption of fish habitat in upstream rivers). Minimization of the maximum reservoir storage decreased impacts such as the economic value of the height of the dam and related operational structures, flooding of upstream land, resettlement of upstream villages, environmental and social impacts on the surrounding region due to the reservoir lake. Relaxation of the minimum bounds on the reservoir downstream releases minimized downstream river flow. Although this would not be desirable in the case of natural channels where vegetation and aquatic life are of concern, for man made channels a minimum bound may be more flexible. The design of the maximum limit on the reservoir release, minimized downstream flooding. Finally, minimizing the upper bound on the water supply, minimized the maximum demand, which may reflect a degree of demand side management.

The use of unit coefficients in the de novo reservoir model, resulted in all terms being weighed equally. Assignment of non unit coefficients would have resulted in increased importance of the corresponding term. In this manner it is possible to implicitly assign preference to reservoir impacts. The nature of the relationship between the water resources system, people as well as the environment will affect the choice coefficients which will be used to define the governing objective function. Zeleny's budget may therefore be referred to as a governing function comprised of either: (1) benefits, costs, or net benefit coefficients representing value related to resources designed by the de novo system, or (2) weighted terms used to define a structure of relative importance between soft resources, and their impacts.

The next section briefly considers an alternative de novo reservoir model which demonstrates that the interpretation of the de novo objective is dependent on the selection of a soft resource portfolio.

6.2.1 Rule Curve Designed De Novo

A common problem in existing reservoir operation, and therefore reservoir design problems, is the derivation of an optimal operating rule curve. Reservoir operators rely on rule curves to make appropriate reservoir releases, which reflect a desired system performance and can be measured by objectives such as flood protection, hydropower production, and recreation. The case when only the rule curve is considered a soft resource, is considered in this section.

The derivation of cost coefficients in the budget may be done by strategic weighting, or by relating the target reservoir storage to the resulting damages. Since the storage of water forfeits the use of water at other locations in direct proportion to the amount stored, the cost coefficient may be derived as a function of reservoir storage. The purpose(s) of the reservoir will determine the exact nature of the cost function and the time period it is valid in. For example losses due to inadequate reservoir elevation levels, and therefore recreation on the lake, may only be important during the summer months. Flood storage on the other hand may be required for the storage of the spring freshet.

A de novo model which considered storage targets as soft, was formulated to demonstrate an alternative de novo objective. This de novo objective function is summarized in equation 6-1. The system of constraints used in this de novo model was identical to that developed in section 4.3 with storage targets treated as soft resources, and metaoptimum constraints identifying the desired system performance.

$$\textit{Minimize} \quad \textit{Budget} \quad B = \sum_{m=1}^{m=12} c_m S_m^* \tag{6 - 1}$$

<u>where:</u>

m represents a month index

c_m is a monthly cost function of the corresponding target reservoir storage, assumed equal to 1.0

S^*_m is the target reservoir storage for month m

The cost coefficients were assumed to be unity, and therefore the de novo model did not define a monthly preference structure for reservoir storage. Essentially, the budget represents the minimum sum of storage target levels that will satisfy the water supply, downstream release, and metaoptimum constraints. A feasible optimal solution to the de novo model was found (GAMS input and output data files are provided in Appendices F and G, respectively). The de novo reservoir system achieved the metaoptimum, (

Required Active Storage = $319.55*10^6$ m^3, Sum of Deviations = $14945.83*10^6$ m^3). Figure 6-1 compares the given and optimal rule curves. Since the proper definition of monthly target storage levels, depicted by the de novo rule curve, achieved the system performance not feasible in the given reservoir system, no compromise between the two major objectives was needed. Furthermore, monthly variation of the de novo rule curve has a similar trend as the given rule curve. This is due to the natural seasonality of inflow into, and total water, which are identical in both models.

To summarize, the construction of the de novo objective via reservoir target levels may provide a practical interpretation and is one type of objective which may be linked to per unit cost or benefit. Although the de novo model used in this section did not consider varying cost coefficients, it did show the effect a rule curve has on the system performance.

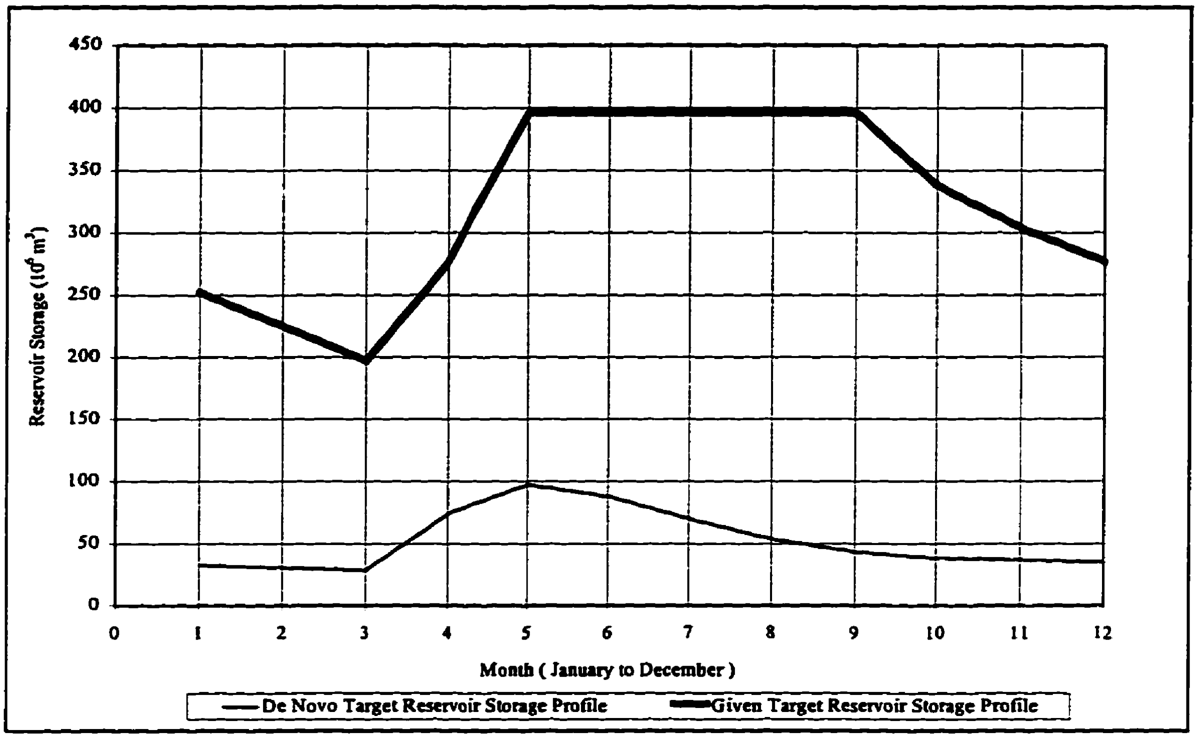

Figure 6-1 Comparison of Given and De Novo designed Target Storage Profiles when the rule curve is used as the soft resource portfolio.

7. CONCLUSIONS AND RECOMMENDATIONS

A reservoir design model was created and two methods of optimization were applied, the conventional, and de novo programming. An increase in system flexibility through the introduction of soft constraints was seen not to achieve a metaoptimal performance, instead best compromise solutions were generated for each solution method . Resulting reservoir characteristics, and operational strategies, were then compared. A final discussion on the selection of a soft resource portfolio, and formation of the de novo reservoir objective function provided insight into the suitability of de novo programming for reservoir design and water resources planning problems. In particular, a rule curve was used to demonstrate one possible interpretation of the budget and means of attaining metaoptimal performance.

This chapter concludes the investigation of de novo programming. Conclusions regarding potential benefit of this technique and limitations are made. Based on the observed potential of de novo programming recommendations are made regarding its future use in water resources planning and management.

7.1 Conclusions

Based on the experience in applying de novo programming to a reservoir design problem (Chapter 4.0), the analysis of its solution (Chapter 5.0), and its discussion in a broader context (Chapter 6.0), the following conclusions are made.

(i) The de novo optimization technique provides an improved reservoir system design on the condition that some flexibility in the system characteristics is allowed.

(ii) System flexibility is best judged on a case by case basis. It may be created via relaxation of constraints. Since each constraint is related to a system of environmental, economic, and social impacts, a thorough examination of each constraint must be performed in order to fully understand the de novo system. This requirement leads to the involvement of experts in the design of the reservoir system.

(iii) The de novo system objective may or may not be easily interpreted, and may be thought of as: a total cost to be minimized, a total benefit to be maximized, or a net benefit to be maximized.

(iv) The de novo objective coefficients can be arbitrary constants used to apply specific weighting to each term of the budget objective.

(v) If a strict environment exists, where system flexibility can not be considered in a realistic manner, the de novo technique does not provide additional information, as compared to the traditional approach of optimizing a given system. However, it may be used to generate and investigate hypothetical scenarios.

(vi) De novo results can lead to undesirable or unrealistic system design or operation, if constraint relaxation is not carried out in a comprehensive manner.

(vii) Implementation of the de novo technique is best suited for study levels where the system is ill defined, or not defined at all. For example, the prefeasibility, feasibility, and design stages of reservoir development. The de novo technique is also applicable for existing reservoir systems. If the physical system is fixed, other types of optimization problems suitable for the implementation of the de novo techniques may still exist. For example, the optimal system operating strategy, the optimal system expansion, or other types of problems where it may be required to simulate a system's behavior under various constraint assumptions.

(viii) The de novo programming technique changes the focus from the optimization of given reservoir systems to the design of optimal reservoir systems.

(viv) A de novo reservoir system may lead to improvement in the best compromise solution, when a metaoptimal system performance is not feasible.

(x) The decision maker and analyst must ultimately have the authority to design the reservoir system.

(xi) De novo programming provides a methodology for optimal system design, therefore with the identification of sustainable objectives and/or constraints, de novo programming provides the methodology for sustainable reservoir system design.

7.2 Recommendations

Several recommendations are made which are meant to provide a direction for future work in applying the de novo optimization approach to reservoir design and other problems in the water resources field. All recommendations are based on two factors. (1) The need to complete further studies . Since many simplifying factors were made for the purpose of introducing the de novo programming theory, the conclusions made in this work are limited. (2) The need to provide direction for the development of mathematical techniques which will be regarded as sustainable decision making tools.

(i) Application of the de novo technique to single and multiple reservoir systems where a multitude of conflicting objectives govern the decision making process. Examples may range from single reservoir design for the satisfaction of multiple needs, to the development of master plans for entire river basins.

(ii) Application of the de novo technique to systems which utilize stochastic variables, constraints, and objectives.

(iii) Investigation of de novo objective coefficients. The creation of de novo objectives may lead to the introduction of new resource "costs" which may be required for adequate objective representation.

(iv) The introduction of system flexibility via objective and/or constraint function coefficients. Thus far de novo programming has concentrated on the right hand sides of constraints, due to its origin of production scheduling. However, there is no reason why system flexibility can not be derived from other sources such as term coefficients in left hand sides of constraints, or within the objective function.

(v) Incorporation of objectives and constraints which correctly represent the relationship between the reservoir system and the environment as a whole.

The last recommendation touches upon an important task for water resources engineers, that is to fully consider the reservoir system and its surroundings. According to the accepted definition of sustainable development, we must consider water resources development impacts on today's society and environment as well as that in the future. However, complete system knowledge and methodology capable of achieving this task is only beginning to be researched. The de novo programming approach offers one of these two requirements, the mathematical methodology. What remains is the integration of knowledge from many scientific fields of expertise, which will allow present and future reservoir impacts to be defined mathematically, at the design stage.

Recommendation (v) has inspired the following presentation of a sustainable de novo reservoir design model. Assuming that adequate mathematical representation of the system and its environment is possible, the given and de novo reservoir design problems can be related as follows.

<u>Given Reservoir Design Model</u>

Minimize Required Active Storage (and other) (7 - 1)

subject to:

physical requirements ≤ physical capacity* (7 - 2)

economic requirements ≤ economic capacity* (7 - 3)

environmental concern ≤ environmental carrying capacity* (7 - 4)

social concern ≤ social capacity* (7 - 5)

* These constraint groups include both soft and hard resource capacities, which in the given reservoir model are treated as fixed.

<u>De Novo Reservoir Design Model</u>

Optimize

a* ***soft physical capacity*** +

b* ***soft economic capacity*** +

c* ***soft environmental carrying capacity*** +

d* ***soft social capacity*** (7 - 6)

<u>Subject to</u>:

physical requirements - ***soft physical capacity***≤ 0 (7 - 7)

physical requirements ≤ fixed physical capacity (7 - 8)

economic requirements - ***soft economic capacity*** ≤ 0 (7 - 9)

economic requirements ≤ fixed economic capacity (7 - 10)

environmental concern - ***soft environmental carrying capacity*** ≤ 0 (7 - 11)

environmental concern ≤ fixed environmental carrying capacity (7 - 12)

social concern - ***soft social capacity*** ≤ 0 (7 - 13)

social concern ≤ fixed social capacity (7 - 14)

required active storage (and other) = metaoptimum (7 - 15) where a, b, c, and d are per unit "cost" coefficients .

The de novo model makes three major assumptions, first the existence of sufficient knowledge such that the reservoir design variables can be linked to different capacities, or resource limits, the possibility of designing some resources which are limited only with respect to the given system, and the establishment of per unit cost coefficients of soft resources. These assumptions are an indication that further work will be necessary to obtain sufficient information to fully utilize the de novo approach. It is certain however that it is ignorant to assume perfect knowledge of complex water resources systems when we have the power to design optimal water resources systems.

REFERENCES

Bare B. B., Mendoza G. A., (1988). " A soft optimization approach to forest land management planning. ", *Canadian Journal of Forestry Resources*, Vol. 18, pp. 545-552.

Bare B. B., Mendoza G. A., (1990). " Designing Forest Plans with Conflicting Objectives using De Novo Programming. ", *Journal of Environmental Management*, Vol. 31, pp. 237-246.

Barlishen Kim D., Simonovic Slobodan P., Burn Donald H., (1989). " A simulation-optimization algorithm for reservoir capacity calculation: the effect of inflow data set length.", *Canadian Journal of Civil Engineering*, Vol. 16, pp. 477-482.

Bazarraa Mokhtar S., Jarvis John J., (1977). Linear Programming and Network Flows, John Wiley and Sons, New York.

Cohon Jared L., (1978). Multiobjective Programming and Planning, Academic Press Inc., New York.

Cohon Jared L., Marks David H., (1975). " A Review and Evaluation of Multiobjective Programming Techniques. ", *Water Resources Research*, Vol. 11, No. 2, pp. 208-220.

Dorcey T., (1992). " Sustainable Development Principles for Water Resources Management in Canada: Towards a New Consensus. ", *Water News, Canadian Water Resources Association Newsletter*, technical bureau supplement, January.

Dovers S. and Handmer J., (1993). "Contradictions in Sustainability.", *Environmental Conservation*, Vol. 20, No. 3, pp. 217-222.

Goicoechea A., Hansen D. R., Duckstein L., (1982). Multiobjective Decision Analysis with Engineering and Business Applications, John Wiley and Sons, New York.

Hobbs Benjamin F., Chankong Vira, Hamadeh Wael, Stakhiv Eugene Z., (1992). " Does Choice of Multicriteria Method Matter? An Experiment in Water Resources Planning. ", Water Resources Research, Vol. 28, No. 7, pp. 1767-1779.

Lele S., (1991). " Sustainable Development: A Critical Review. ", *World Development*, Vol. 19, No. 6, pp. 607-621.

Li R. J., Lee E. S., (1990). " Multi-Criteria De Novo Programming with Fuzzy Parameters. ", *Computer Math. Applic.*, Vol. 19, pp. 13-20.

Loucks Daniel P., Stedinger Jery R., Haith Douglas A., (1981). Water Resource Systems Planning and Analysis. Prentice-Hall Inc., Englewood Cliffs, New Jersey.

Schultz Gert A., Hornbogen Martin, (1995). " Sustainable development of water resources systems with regard to long-term changes of design variables. ", *Modeling and Management of Sustainable Basin-scale Water Resources Systems, Proceedings of a Boulder Symposium, IAHS* Publ. No. 231.

Schumann Andreas H., (1995). "Flexibility and adjustability of reservoir operation as an aid for sustainable water management. ", *Modeling and Management of Sustainable Basin-scale Water Resources Systems, Proceedings of a Boulder Symposium, IAHS* Publ. No. 231.

Simonovic S. P., (1989). " Application of Water Resources Systems Concept to the Formulation of a Water Master Plan. ", *Water International*, 14(1), pp. 37-51.

Simonovic S. P. (1992). " Reservoir Systems Analysis: Closing Gap Between Theory and Practice. ", *ASCE Journal of Water Resources Planning and Management*, 118(3), pp. 262-280.

Tabucanon Mario T. (1988). Multiple Criteria Decision Making in Industry, Amsterdam [The Netherlands], New York.

World Commission on Environment and Development (WCED), (1987). " Our Common Future.", Oxford University Press, London, UK.

Yeh W. W-G., (1984). " A state-of-the-art Review of Systems Analysis in Reservoir Management and Operation. ", *Water Resources Research*, 20(7), pp. 959-972.

Young M. D., (1992). " Sustainable Investment and Resource Use. ", *UNESCO, Man and the Biosphere Series*, Vol. 9, The Parthenon Publishing Group, Casternton Hall, Carnforth, UK.

Zeleny M., (1973). " Compromise Programming. ", *Multiple Criteria Decision Making*, Cochrane J. L. and Zeleny M. (eds.), University of South Carolina Press, Columbia.

Zeleny M., (1981). " On the squandering of resources and profits via linear programming. ", *Interfaces*, Vol. 11, No. 5, pp. 101-107.

Zeleny M., (1982). Multiple Criteria Decision Making. McGraw-Hill, New York, pp. 563.

Appendix A Reservoir Model Characteristics

Table A-1 Reservoir Inflow Values, (10^6 m^3).

YEAR	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	1.20	1.10	2.30	49.37	37.08	14.19	7.55	2.45	1.88	2.65	2.31	1.60
2	1.57	1.40	1.23	85.78	26.03	11.06	5.96	3.71	0.75	1.90	2.37	2.00
3	1.77	1.39	1.87	78.60	76.70	7.29	3.49	1.23	0.66	0.96	1.18	0.72
4	0.38	0.37	1.56	9.93	7.91	11.87	11.32	2.09	1.92	1.92	1.88	1.75
5	1.23	1.15	1.24	65.33	92.84	40.24	4.85	2.57	3.45	4.65	3.45	2.62
6	1.91	1.76	1.68	54.64	107.77	30.11	10.13	2.89	3.16	4.34	4.49	1.95
7	1.50	1.67	1.98	120.87	33.44	45.26	29.24	5.05	5.77	5.03	1.52	1.15
8	0.77	0.88	1.02	15.08	7.60	2.37	2.23	1.61	3.54	4.59	2.76	1.74
9	1.35	0.93	1.63	22.51	13.83	4.35	2.82	0.73	0.89	1.59	2.11	1.32
10	0.94	0.81	0.80	55.64	115.88	25.88	3.94	1.24	1.41	1.17	1.96	1.25
11	1.20	1.13	1.25	37.81	8.42	1.65	1.27	1.08	0.96	1.44	1.73	0.84
12	0.52	0.60	4.81	9.10	4.43	3.47	2.72	1.52	0.71	2.69	2.96	1.12
13	0.43	0.53	0.73	14.90	8.17	3.33	9.60	2.98	0.55	1.47	1.69	0.90
14	1.06	1.12	1.05	35.42	47.29	16.03	17.95	4.72	0.97	1.46	2.15	1.56
15	0.96	0.97	9.71	23.81	14.93	14.99	8.04	0.87	0.83	2.44	1.99	2.61

Table A-2 Constraint Limitations, (10^6 m^3).

MONTH	Minimum Required Release	Maximum Allowable Release	Target Water Supply	Target Reservoir Storage
Jan	1.90	36.88	2.09	252.15
Feb	1.72	33.31	1.91	225.09
Mar	1.90	36.88	2.14	196.80
Apr	1.84	35.69	2.10	276.75
May	1.90	36.88	10.18	396.00
Jun	1.84	35.69	19.26	396.00
Jul	1.90	36.88	23.03	396.00
Aug	1.90	36.88	19.53	396.00
Sep	1.84	35.69	9.69	396.00
Oct	1.90	36.88	5.25	338.25
Nov	1.84	35.69	2.07	303.81
Dec	1.90	36.88	2.04	276.75

Table A-3 Constraint Limitations.

Model Variable	Value
Minimum Reservoir Storage	12.34 (10^6 m^3)
Maximum Reservoir Storage	477.36 (10^6 m^3)
Lower Bound on Water Supply	0.95
Upper Bound on Water Supply	1.00

Appendix B GAMS Input File Code for the Given Reservoir Model

```
**********************************************************************
*  This file provides the basic input data file into GAMS for the    *
*  Given Reservoir System.  The Given Reservoir System is defined    *
*  by the system constraints.  Five objectives were used to          *
*  create five solutions, that which provides the minimum required   *
*  active storage, minimum sum of storage deviations, a compromise   *
*  between these two primary objectives with the s = 1 case, a       *
*  compromise between the primary objectives with the s = 2 case,    *
*  and finally, a compromise between the primary objectives with    *
*  the s = 100 case.                                                 *
*                                                                    *
*  The objective functions for each solution were substituted into   *
*  the constraint called OF..                                        *
*  The following equations provide a summary of each objective       *
*  function used with respect to the GIVEN RESERVOIR SYSTEM.         *
*                                                                    *
*  1.  Minimization of the Required Active Storage                   *
*      OF..  OF1 = E = K;                                            *
*                                                                    *
*  2.  Minimization of the Sum of Storage Deviations                 *
*      OF..  OF2 = E = SUM(T,V(T)+U(T));                             *
*                                                                    *
*  3.  Compromise between 1. and 2., s = 1                           *
*      OF..  DISTANCE=E= POWER(((K-319.545)/(477.36-319.545)),1)     *
*              +POWER(((OF2-14945.83)/(31694.80-14945.83)),1);       *
*      ( as given in this data input )                               *
*                                                                    *
*  4.  Compromise between 1. and 2., s = 2                           *
*      OF..  DISTANCE=E= POWER(((K-319.545)/(477.36-319.545)),2)     *
*            +POWER(((OF2-14945.83)/(31694.80-14945.83)),2);         *
*                                                                    *
*  5.  Compromise between 2. and 2., s = 100                         *
*      OF..  DISTANCE=E= POWER(((K-319.545)/(477.36-319.545)),100)   *
*            +POWER(((OF2-14945.83)/(31694.80-14945.83)),100);       *
**********************************************************************


**********************************************************************
*  This routine is supplied the following input:                     *
*                                                                    *
*  15 years of monthly inflow in to the Shellmouth Reservoir         *
*  12 Monthly minimum and maximum Shellmouth Reservoir releases      *
*  12 Monthly water supply targets                                   *
*  12 Monthly lower and upper bounds on the water supply             *
*  12 Storage targets based on the Shellmouth operating rule curve   *
*  Minimum and Maximum storage for Shellmouth Reservoir              *
*                                                                    *
**********************************************************************

OPTION ITERLIM = 50000;
OPTION RESLIM = 50000;
OPTION LIMROW = 0;
OPTION LIMCOL = 0;

SETS
  T time period in years /1*180/
DISPLAY T;

SCALARS STOMIN min reservoir storage
        STOMAX max reservoir storage
```

```
         LOWB lower bound on water supply
         UPB upper bound on water supply;

STOMIN=12.34 ;
STOMAX=477.3645;
LOWB=0.95;
UPB=1.0;

FILE F0 /G1.OUT/;

PARAMETERS  INFLOW(T)   monthly inflow in to shellmouth reservoir
/       1      1.2                51     1.24                 101    13.83
        2      1.1                52    65.33                 102     4.35
        3      2.3                53    92.84                 103     2.82
        4    49.37                54    40.24                 104     0.73
        5    37.08                55     4.85                 105     0.89
        6    14.19                56     2.57                 106     1.59
        7     7.55                57     3.45                 107     2.11
        8     2.45                58     4.65                 108     1.32
        9     1.88                59     3.45                 109     0.94
       10     2.65                60     2.62                 110     0.81
       11     2.31                61     1.91                 111      0.8
       12      1.6                62     1.76                 112    55.64
       13     1.57                63     1.68                 113   115.88
       14      1.4                64    54.64                 114    25.88
       15     1.23                65   107.77                 115     3.94
       16    85.78                66    30.11                 116     1.24
       17    26.03                67    10.13                 117     1.41
       18    11.06                68     2.89                 118     1.17
       19     5.96                69     3.16                 119     1.96
       20     3.71                70     4.34                 120     1.25
       21     0.75                71     4.49                 121      1.2
       22      1.9                72     1.95                 122     1.13
       23     2.37                73      1.5                 123     1.25
       24        2                74     1.67                 124    37.81
       25     1.77                75     1.98                 125     8.42
       26     1.39                76   120.87                 126     1.65
       27     1.87                77    33.44                 127     1.27
       28     78.6                78    45.26                 128     1.08
       29     76.7                79    29.24                 129     0.96
       30     7.29                80     5.05                 130     1.44
       31     3.49                81     5.77                 131     1.73
       32     1.23                82     5.03                 132     0.84
       33     0.66                83     1.52                 133     0.52
       34     0.96                84     1.15                 134      0.6
       35     1.18                85     0.77                 135     4.81
       36     0.72                86     0.88                 136      9.1
       37     0.38                87     1.02                 137     4.43
       38     0.37                88    15.08                 138     3.47
       39     1.56                89      7.6                 139     2.72
       40     9.93                90     2.37                 140     1.52
       41     7.91                91     2.23                 141     0.71
       42    11.87                92     1.61                 142     2.69
       43    11.32                93     3.54                 143     2.96
       44     2.09                94     4.59                 144     1.12
       45     1.92                95     2.76                 145     0.43
       46     1.92                96     1.74                 146     0.53
       47     1.88                97     1.35                 147     0.73
       48     1.75                98     0.93                 148     14.9
       49     1.23                99     1.63                 149     8.17
       50     1.15               100    22.51                 150     3.33
```

```
        151     9.6                   161   47.29                  171     9.71
        152    2.98                   162   16.03                  172    23.81
        153    0.55                   163   17.95                  173    14.93
        154    1.47                   164    4.72                  174    14.99
        155    1.69                   165    0.97                  175     8.04
        156     0.9                   166    1.46                  176     0.87
        157    1.06                   167    2.15                  177     0.83
        158    1.12                   168    1.56                  178     2.44
        159    1.05                   169    0.96                  179     1.99
        160   35.42                   170    0.97                  180     2.61/
RMIN(T)  minimum allowable monthly release
/         1  1.9017                    51  1.9017                  101  1.9017
          2  1.7176                    52  1.8403                  102  1.8403
          3  1.9017                    53  1.9017                  103  1.9017
          4  1.8403                    54  1.8403                  104  1.9017
          5  1.9017                    55  1.9017                  105  1.8403
          6  1.8403                    56  1.9017                  106  1.9017
          7  1.9017                    57  1.8403                  107  1.8403
          8  1.9017                    58  1.9017                  108  1.9017
          9  1.8403                    59  1.8403                  109  1.9017
         10  1.9017                    60  1.9017                  110  1.7176
         11  1.8403                    61  1.9017                  111  1.9017
         12  1.9017                    62  1.7176                  112  1.8403
         13  1.9017                    63  1.9017                  113  1.9017
         14  1.7176                    64  1.8403                  114  1.8403
         15  1.9017                    65  1.9017                  115  1.9017
         16  1.8403                    66  1.8403                  116  1.9017
         17  1.9017                    67  1.9017                  117  1.8403
         18  1.8403                    68  1.9017                  118  1.9017
         19  1.9017                    69  1.8403                  119  1.8403
         20  1.9017                    70  1.9017                  120  1.9017
         21  1.8403                    71  1.8403                  121  1.9017
         22  1.9017                    72  1.9017                  122  1.7176
         23  1.8403                    73  1.9017                  123  1.9017
         24  1.9017                    74  1.7176                  124  1.8403
         25  1.9017                    75  1.9017                  125  1.9017
         26  1.7176                    76  1.8403                  126  1.8403
         27  1.9017                    77  1.9017                  127  1.9017
         28  1.8403                    78  1.8403                  128  1.9017
         29  1.9017                    79  1.9017                  129  1.8403
         30  1.8403                    80  1.9017                  130  1.9017
         31  1.9017                    81  1.8403                  131  1.8403
         32  1.9017                    82  1.9017                  132  1.9017
         33  1.8403                    83  1.8403                  133  1.9017
         34  1.9017                    84  1.9017                  134  1.7176
         35  1.8403                    85  1.9017                  135  1.9017
         36  1.9017                    86  1.7176                  136  1.8403
         37  1.9017                    87  1.9017                  137  1.9017
         38  1.7176                    88  1.8403                  138  1.8403
         39  1.9017                    89  1.9017                  139  1.9017
         40  1.8403                    90  1.8403                  140  1.9017
         41  1.9017                    91  1.9017                  141  1.8403
         42  1.8403                    92  1.9017                  142  1.9017
         43  1.9017                    93  1.8403                  143  1.8403
         44  1.9017                    94  1.9017                  144  1.9017
         45  1.8403                    95  1.8403                  145  1.9017
         46  1.9017                    96  1.9017                  146  1.7176
         47  1.8403                    97  1.9017                  147  1.9017
         48  1.9017                    98  1.7176                  148  1.8403
         49  1.9017                    99  1.9017                  149  1.9017
         50  1.7176                   100  1.8403                  150  1.8403
```

```
        151  1.9017          161  1.9017          171  1.9017
        152  1.9017          162  1.8403          172  1.8403
        153  1.8403          163  1.9017          173  1.9017
        154  1.9017          164  1.9017          174  1.8403
        155  1.8403          165  1.8403          175  1.9017
        156  1.9017          166  1.9017          176  1.9017
        157  1.9017          167  1.8403          177  1.8403
        158  1.7176          168  1.9017          178  1.9017
        159  1.9017          169  1.9017          179  1.8403
        160  1.8403          170  1.7176          180  1.9017/
RMAX(T) maximum monthly release
/         1   36.88           51   36.88         101   36.88
          2   33.31           52   35.69         102   35.69
          3   36.88           53   36.88         103   36.88
          4   35.69           54   35.69         104   36.88
          5   36.88           55   36.88         105   35.69
          6   35.69           56   36.88         106   36.88
          7   36.88           57   35.69         107   35.69
          8   36.88           58   36.88         108   36.88
          9   35.69           59   35.69         109   36.88
         10   36.88           60   36.88         110   33.31
         11   35.69           61   36.88         111   36.88
         12   36.88           62   33.31         112   35.69
         13   36.88           63   36.88         113   36.88
         14   33.31           64   35.69         114   35.69
         15   36.88           65   36.88         115   36.88
         16   35.69           66   35.69         116   36.88
         17   36.88           67   36.88         117   35.69
         18   35.69           68   36.88         118   36.88
         19   36.88           69   35.69         119   35.69
         20   36.88           70   36.88         120   36.88
         21   35.69           71   35.69         121   36.88
         22   36.88           72   36.88         122   33.31
         23   35.69           73   36.88         123   36.88
         24   36.88           74   33.31         124   35.69
         25   36.88           75   36.88         125   36.88
         26   33.31           76   35.69         126   35.69
         27   36.88           77   36.88         127   36.88
         28   35.69           78   35.69         128   36.88
         29   36.88           79   36.88         129   35.69
         30   35.69           80   36.88         130   36.88
         31   36.88           81   35.69         131   35.69
         32   36.88           82   36.88         132   36.88
         33   35.69           83   35.69         133   36.88
         34   36.88           84   36.88         134   33.31
         35   35.69           85   36.88         135   36.88
         36   36.88           86   33.31         136   35.69
         37   36.88           87   36.88         137   36.88
         38   33.31           88   35.69         138   35.69
         39   36.88           89   36.88         139   36.88
         40   35.69           90   35.69         140   36.88
         41   36.88           91   36.88         141   35.69
         42   35.69           92   36.88         142   36.88
         43   36.88           93   35.69         143   35.69
         44   36.88           94   36.88         144   36.88
         45   35.69           95   35.69         145   36.88
         46   36.88           96   36.88         146   33.31
         47   35.69           97   36.88         147   36.88
         48   36.88           98   33.31         148   35.69
         49   36.88           99   36.88         149   36.88
         50   33.31          100   35.69         150   35.69
```

```
      151   36.88               161   36.88               171   36.88
      152   36.88               162   35.69               172   35.69
      153   35.69               163   36.88               173   36.88
      154   36.88               164   36.88               174   35.69
      155   35.69               165   35.69               175   36.88
      156   36.88               166   36.88               176   36.88
      157   36.88               167   35.69               177   35.69
      158   33.31               168   36.88               178   36.88
      159   36.88               169   36.88               179   35.69
      160   35.69               170   33.31               180   36.88/
STAR(T)  monthly reservoir target storage
/       1  252.15                51   196.8               101     396
        2  225.09                52  276.75               102     396
        3   196.8                53     396               103     396
        4  276.75                54     396               104     396
        5     396                55     396               105     396
        6     396                56     396               106  338.25
        7     396                57     396               107  303.81
        8     396                58  338.25               108  276.75
        9     396                59  303.81               109  252.15
       10  338.25                60  276.75               110  225.09
       11  303.81                61  252.15               111   196.8
       12  276.75                62  225.09               112  276.75
       13  252.15                63   196.8               113     396
       14  225.09                64  276.75               114     396
       15   196.8                65     396               115     396
       16  276.75                66     396               116     396
       17     396                67     396               117     396
       18     396                68     396               118  338.25
       19     396                69     396               119  303.81
       20     396                70  338.25               120  276.75
       21     396                71  303.81               121  252.15
       22  338.25                72  276.75               122  225.09
       23  303.81                73  252.15               123   196.8
       24  276.75                74  225.09               124  276.75
       25  252.15                75   196.8               125     396
       26  225.09                76  276.75               126     396
       27   196.8                77     396               127     396
       28  276.75                78     396               128     396
       29     396                79     396               129     396
       30     396                80     396               130  338.25
       31     396                81     396               131  303.81
       32     396                82  338.25               132  276.75
       33     396                83  303.81               133  252.15
       34  338.25                84  276.75               134  225.09
       35  303.81                85  252.15               135   196.8
       36  276.75                86  225.09               136  276.75
       37  252.15                87   196.8               137     396
       38  225.09                88  276.75               138     396
       39   196.8                89     396               139     396
       40  276.75                90     396               140     396
       41     396                91     396               141     396
       42     396                92     396               142  338.25
       43     396                93     396               143  303.81
       44     396                94  338.25               144  276.75
       45     396                95  303.81               145  252.15
       46  338.25                96  276.75               146  225.09
       47  303.81                97  252.15               147   196.8
       48  276.75                98  225.09               148  276.75
       49  252.15                99   196.8               149     396
       50  225.09               100  276.75               150     396
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      151     396              161     396              171   196.8
      152     396              162     396              172  276.75
      153     396              163     396              173     396
      154  338.25              164     396              174     396
      155  303.81              165     396              175     396
      156  276.75              166  338.25              176     396
      157  252.15              167  303.81              177     396
      158  225.09              168  276.75              178  338.25
      159   196.8              169  252.15              179  303.81
      160  276.75              170  225.09              180  276.75/
DTAR(T)  monthly demand target level
/       1 2.089152             51   2.14272             101  10.17792
        2 1.911168             52   2.09952             102  19.25856
        3  2.14272             53  10.17792             103  23.03424
        4  2.09952             54  19.25856             104  19.52554
        5 10.17792             55  23.03424             105  9.69408
        6 19.25856             56  19.52554             106  5.249664
        7 23.03424             57   9.69408             107   2.0736
        8 19.52554             58  5.249664             108  2.035584
        9  9.69408             59    2.0736             109  2.089152
       10  5.249664            60 2.035584              110  1.911168
       11    2.0736            61 2.089152              111  2.14272
       12  2.035584            62 1.911168              112  2.09952
       13  2.089152            63  2.14272              113 10.17792
       14  1.911168            64  2.09952              114 19.25856
       15   2.14272            65 10.17792              115 23.03424
       16    2.09952           66 19.25856              116 19.52554
       17   10.17792           67 23.03424              117 9.69408
       18   19.25856           68 19.52554              118 5.249664
       19   23.03424           69   9.69408             119  2.0736
       20   19.52554           70   5.249664            120 2.035584
       21   9.69408            71    2.0736             121 2.089152
       22  5.249664            72 2.035584              122 1.911168
       23    2.0736            73 2.089152              123 2.14272
       24  2.035584            74 1.911168              124 2.09952
       25  2.089152            75  2.14272              125 10.17792
       26  1.911168            76  2.09952              126 19.25856
       27   2.14272            77 10.17792              127 23.03424
       28   2.09952            78 19.25856              128 19.52554
       29  10.17792            79  23.03424             129 9.69408
       30   19.25856           80  19.52554             130 5.249664
       31  23.03424            81    9.69408            131  2.0736
       32  19.52554            82   5.249664            132 2.035584
       33   9.69408            83     2.0736            133 2.089152
       34  5.249664            84   2.035584            134 1.911168
       35    2.0736            85   2.089152            135 2.14272
       36  2.035584            86   1.911168            136 2.09952
       37 2.089152             87     2.14272           137 10.17792
       38 1.911168             88     2.09952           138 19.25856
       39   2.14272            89   10.17792            139 23.03424
       40   2.09952            90 19.25856              140 19.52554
       41  10.17792            91 23.03424              141 9.69408
       42  19.25856            92  19.52554             142 5.249664
       43  23.03424            93    9.69408            143  2.0736
       44  19.52554            94  5.249664             144 2.035584
       45    9.69408           95     2.0736            145 2.089152
       46  5.249664            96  2.035584             146 1.911168
       47    2.0736            97  2.089152             147 2.14272
       48  2.035584            98  1.911168             148 2.09952
       49  2.089152            99    2.14272            149 10.17792
       50    1.911168         100  2.09952              150 19.25856
```

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     151 23.03424             161 10.17792             171 2.14272
     152 19.52554             162 19.25856             172 2.09952
     153 9.69408              163 23.03424             173 10.17792
     154 5.249664             164 19.52554             174 19.25856
     155  2.0736              165 9.69408              175 23.03424
     156 2.035584             166 5.249664             176 19.52554
     157 2.089152             167  2.0736              177 9.69408
     158 1.911168             168 2.035584             178 5.249664
     159 2.14272              169 2.089152             179  2.0736
     160 2.09952              170 1.911168             180  2.035584/;

VARIABLES
OF2  objective function two
START  starting storage of the reservoir
S(T) monthly reservoir storage
R(T) monthly reservoir downstream release
WS(T) monthly reservoir water supply level
K the required active storage of the reservoir
V(T) positive storage deviation
U(T) negative storage deviation
DISTANCE

POSITIVE VARIABLES OF1,OF2,START,S(T),R(T),WS(T),K,V(T),U(T);
K.UP= 477.36;
OF2.UP= 31694.8;

K.LO= 319.55;
OF2.LO= 14945.83;

S.UP(T)=1000;
START.UP=1000;
R.UP(T)=1000;
WS.UP(T)=1000;
V.UP(T)=1000;
U.UP(T)=1000;

EQUATIONS
CONTIN(T)        continuity equation
CONTINF(T)       continuity of inflow
RAS(T)           required active storage must exceed monthly storage
MINREL(T)        minimum release bounds
MAXREL(T)        maximum release bounds
MINSTO(T)        minimum storage bound
MINWS(T)         minimum water supply bounds
MAXWS(T)         maximum water supply bounds
MAXSTO(T)        maximum storage bound
STOTAR(T)        storage target deviation constraints
SECOND           the sum of storage deviations
MAXDIST          the maximum distance to the metaoptimum is one
OF               distance to the metaoptimum;

CONTIN(T)..  S(T)=E=[START+INFLOW(T)-R(T)-WS(T)]$(ORD(T) EQ 1)
                   + [S(T-1)+INFLOW(T)-R(T)-WS(T)]$(ORD(T) GT 1);
CONTINF(T)$(ORD(T) EQ 180)..  START=E=S(T);
RAS(T)..  S(T)=L=K;
MINREL(T)..  RMIN(T)=L=R(T);
MAXREL(T)..  R(T)=L=RMAX(T);
MINSTO(T)..  S(T)=G=STOMIN;
MAXSTO(T)..  S(T)=L=STOMAX;
MINWS(T)..  LOWB=L=((1/DTAR(T))*WS(T));
MAXWS(T)..  ((1/DTAR(T))*WS(T))=L=UPB;
```

```
STOTAR(T)..  S(T)-V(T)+U(T)=E=STAR(T);
SECOND..  OF2=E=SUM(T,V(T)+U(T));
MAXDIST..  DISTANCE=L=1.0;

**********************************************************************
OF..  DISTANCE=E= POWER(((K-319.545)/(477.36-319.545)),1)
                 +POWER(((OF2-14945.83)/(31694.80-14945.83)),1);
**********************************************************************

MODEL GIVBC1 /ALL/;
GIVBC1.OPTFILE =1;
SOLVE GIVBC1 USING NLP MINIMIZING DISTANCE;

*  Post Processing
PUT FO;
PUT  '*******************************************'
PUT /'*    SUMMARY OF THE OPTIMAL CONDITIONS    *'
PUT /'*******************************************'
PUT /
PUT /'OF1':>15,'OF2':>15;
PUT / K.L :>15;PUT OF2.L:>15;
PUT /
PUT /'*****************************************************':>53;
PUT /'MAX STORAGE':>11,'MIN STORAGE':>14,'LOW WS BOUND':>14,
'UP WS BOUND':>14;
PUT /'*****************************************************':>53;
PUT /STOMAX:>11; PUT STOMIN:>14; PUT LOWB:>14; PUT UPB:>14;
PUT /
PUT /
PUT
/'********************************************************************':
>68,'**':>2;
PUT /'TIME':>4,'RMIN':>10,'RMAX':>7,'DTAR':>7,
'STORAGE':>14,'D/S RELEASE':>14,'WATER SUPPLY':>14;
PUT
/'********************************************************************':
>68,'**':>2;
PUT /
LOOP(T, PUT / T.TL:>4;
PUT RMIN(T):>10; PUT RMAX(T):>7; PUT DTAR(T):>7;
PUT S.L(T):>14; PUT R.L(T):>14; PUT WS.L(T):>14;);
```

□

Appendix C GAMS Output for the Given Reservoir System

Table C-1 Optimal Objective Function Values

Required Active Storage (10^6 m^3)	Sum of Storage Deviations (10^6 m^3)
319.55	31703.28

Table C-2 Minimum and Maximum Constraint Bounds

Maximum Storage (10^6 m^3)	Minimum Storage (10^6 m^3)	Minimum Fraction of Target Water Supply	Maximum Fration of Target Water Supply
477.36	12.34	0.95	1.00

Table C-3 Optimal Decision Variables, Minimum and Maximum Downstream Reservoir Releases, and Monthly Target Water Supply Levels, (10^6 m^3)

Time (months)	Minimum Release	Maximum Release	Target Water Supply	Optimal Reservoir Storage	Optimal Reservoir Release	Optimal Reservoir Water Supply
1	1.90	36.88	2.09	16.41	1.90	1.98
2	1.72	33.31	1.91	13.98	1.72	1.82
3	1.90	36.88	2.14	12.34	1.90	2.04
4	1.84	35.69	2.10	57.88	1.84	1.99
5	1.90	36.88	10.18	83.38	1.90	9.67
6	1.84	35.69	19.26	77.44	1.84	18.30
7	1.90	36.88	23.03	61.20	1.90	21.88
8	1.90	36.88	19.53	43.20	1.90	18.55
9	1.84	35.69	9.69	34.03	1.84	9.21
10	1.90	36.88	5.25	29.79	1.90	4.99
11	1.84	35.69	2.07	28.29	1.84	1.97
12	1.90	36.88	2.04	26.06	1.90	1.93
13	1.90	36.88	2.09	23.74	1.90	1.98
14	1.72	33.31	1.91	21.61	1.72	1.82
15	1.90	36.88	2.14	18.90	1.90	2.04
16	1.84	35.69	2.10	100.85	1.84	1.99
17	1.90	36.88	10.18	115.31	1.90	9.67
18	1.84	35.69	19.26	106.23	1.84	18.30
19	1.90	36.88	23.03	88.41	1.90	21.88
20	1.90	36.88	19.53	71.67	1.90	18.55
21	1.84	35.69	9.69	61.37	1.84	9.21
22	1.90	36.88	5.25	56.38	1.90	4.99
23	1.84	35.69	2.07	54.94	1.84	1.97
24	1.90	36.88	2.04	53.10	1.90	1.93
25	1.90	36.88	2.09	50.98	1.90	1.98
26	1.72	33.31	1.91	48.84	1.72	1.82
27	1.90	36.88	2.14	46.77	1.90	2.04
28	1.84	35.69	2.10	121.54	1.84	1.99
29	1.90	36.88	10.18	186.67	1.90	9.67
30	1.84	35.69	19.26	173.82	1.84	18.30
31	1.90	36.88	23.03	153.53	1.90	21.88
32	1.90	36.88	19.53	134.31	1.90	18.55
33	1.84	35.69	9.69	123.92	1.84	9.21
34	1.90	36.88	5.25	117.99	1.90	4.99
35	1.84	35.69	2.07	115.36	1.84	1.97

36	1.90	36.88	2.04	112.24	1.90	1.93
37	1.90	36.88	2.09	108.74	1.90	1.98
38	1.72	33.31	1.91	105.57	1.72	1.82
39	1.90	36.88	2.14	103.20	1.90	2.04
40	1.84	35.69	2.10	109.29	1.84	1.99
41	1.90	36.88	10.18	105.63	1.90	9.67
42	1.84	35.69	19.26	97.36	1.84	18.30
43	1.90	36.88	23.03	84.90	1.90	21.88
44	1.90	36.88	19.53	66.54	1.90	18.55
45	1.84	35.69	9.69	57.41	1.84	9.21
46	1.90	36.88	5.25	52.44	1.90	4.99
47	1.84	35.69	2.07	50.51	1.84	1.97
48	1.90	36.88	2.04	48.43	1.90	1.93
49	1.90	36.88	2.09	45.77	1.90	1.98
50	1.72	33.31	1.91	43.39	1.72	1.82
51	1.90	36.88	2.14	40.69	1.90	2.04
52	1.84	35.69	2.10	102.18	1.84	1.99
53	1.90	36.88	10.18	183.45	1.90	9.67
54	1.84	35.69	19.26	203.56	1.84	18.30
55	1.90	36.88	23.03	184.62	1.90	21.88
56	1.90	36.88	19.53	166.74	1.90	18.55
57	1.84	35.69	9.69	159.14	1.84	9.21
58	1.90	36.88	5.25	156.90	1.90	4.99
59	1.84	35.69	2.07	156.54	1.84	1.97
60	1.90	36.88	2.04	155.33	1.90	1.93
61	1.90	36.88	2.09	153.35	1.90	1.98
62	1.72	33.31	1.91	151.58	1.72	1.82
63	1.90	36.88	2.14	149.32	1.90	2.04
64	1.84	35.69	2.10	200.13	1.84	1.99
65	1.90	36.88	10.18	296.33	1.90	9.67
66	1.84	35.69	19.26	306.30	1.84	18.30
67	1.90	36.88	23.03	292.64	1.90	21.88
68	1.90	36.88	19.53	275.08	1.90	18.55
69	1.84	35.69	9.69	267.19	1.84	9.21
70	1.90	36.88	5.25	264.38	1.90	5.25
71	1.84	35.69	2.07	264.96	1.84	2.07
72	1.90	36.88	2.04	262.97	1.90	2.04
73	1.90	36.88	2.09	252.15	10.23	2.09
74	1.72	33.31	1.91	233.84	18.07	1.91
75	1.90	36.88	2.14	196.80	36.88	2.14
76	1.84	35.69	2.10	297.68	18.00	1.99
77	1.90	36.88	10.18	319.55	1.90	9.67
78	1.84	35.69	19.26	319.55	26.96	18.30
79	1.90	36.88	23.03	319.55	7.36	21.88
80	1.90	36.88	19.53	304.14	1.90	18.55
81	1.84	35.69	9.69	298.86	1.84	9.21
82	1.90	36.88	5.25	297.01	1.90	4.99
83	1.84	35.69	2.07	294.72	1.84	1.97
84	1.90	36.88	2.04	292.03	1.90	1.93
85	1.90	36.88	2.09	288.91	1.90	1.98
86	1.72	33.31	1.91	286.26	1.72	1.82
87	1.90	36.88	2.14	283.34	1.90	2.04
88	1.84	35.69	2.10	294.59	1.84	1.99
89	1.90	36.88	10.18	290.62	1.90	9.67
90	1.84	35.69	19.26	272.85	1.84	18.30
91	1.90	36.88	23.03	251.30	1.90	21.88
92	1.90	36.88	19.53	232.46	1.90	18.55
93	1.84	35.69	9.69	224.95	1.84	9.21
94	1.90	36.88	5.25	222.65	1.90	4.99
95	1.84	35.69	2.07	221.60	1.84	1.97
96	1.90	36.88	2.04	219.50	1.90	1.93

97	1.90	36.88	2.09	216.97	1.90	1.98
98	1.72	33.31	1.91	214.36	1.72	1.82
99	1.90	36.88	2.14	212.06	1.90	2.04
100	1.84	35.69	2.10	230.73	1.84	1.99
101	1.90	36.88	10.18	232.99	1.90	9.67
102	1.84	35.69	19.26	217.20	1.84	18.30
103	1.90	36.88	23.03	196.24	1.90	21.88
104	1.90	36.88	19.53	176.52	1.90	18.55
105	1.84	35.69	9.69	166.36	1.84	9.21
106	1.90	36.88	5.25	161.06	1.90	4.99
107	1.84	35.69	2.07	159.36	1.84	1.97
108	1.90	36.88	2.04	156.84	1.90	1.93
109	1.90	36.88	2.09	153.90	1.90	1.98
110	1.72	33.31	1.91	151.17	1.72	1.82
111	1.90	36.88	2.14	148.04	1.90	2.04
112	1.84	35.69	2.10	199.84	1.84	1.99
113	1.90	36.88	10.18	304.15	1.90	9.67
114	1.84	35.69	19.26	309.90	1.84	18.30
115	1.90	36.88	23.03	290.05	1.90	21.88
116	1.90	36.88	19.53	270.84	1.90	18.55
117	1.84	35.69	9.69	261.20	1.84	9.21
118	1.90	36.88	5.25	255.48	1.90	4.99
119	1.84	35.69	2.07	253.63	1.84	1.97
120	1.90	36.88	2.04	251.05	1.90	1.93
121	1.90	36.88	2.09	248.36	1.90	1.98
122	1.72	33.31	1.91	245.96	1.72	1.82
123	1.90	36.88	2.14	243.27	1.90	2.04
124	1.84	35.69	2.10	277.24	1.84	1.99
125	1.90	36.88	10.18	274.09	1.90	9.67
126	1.84	35.69	19.26	255.61	1.84	18.30
127	1.90	36.88	23.03	233.09	1.90	21.88
128	1.90	36.88	19.53	213.72	1.90	18.55
129	1.84	35.69	9.69	203.63	1.84	9.21
130	1.90	36.88	5.25	198.18	1.90	4.99
131	1.84	35.69	2.07	196.10	1.84	1.97
132	1.90	36.88	2.04	193.11	1.90	1.93
133	1.90	36.88	2.09	189.74	1.90	1.98
134	1.72	33.31	1.91	186.81	1.72	1.82
135	1.90	36.88	2.14	187.68	1.90	2.04
136	1.84	35.69	2.10	192.95	1.84	1.99
137	1.90	36.88	10.18	185.81	1.90	9.67
138	1.84	35.69	19.26	169.14	1.84	18.30
139	1.90	36.88	23.03	148.08	1.90	21.88
140	1.90	36.88	19.53	129.14	1.90	18.55
141	1.84	35.69	9.69	118.81	1.84	9.21
142	1.90	36.88	5.25	114.61	1.90	4.99
143	1.84	35.69	2.07	113.76	1.84	1.97
144	1.90	36.88	2.04	111.04	1.90	1.93
145	1.90	36.88	2.09	107.58	1.90	1.98
146	1.72	33.31	1.91	104.58	1.72	1.82
147	1.90	36.88	2.14	101.37	1.90	2.04
148	1.84	35.69	2.10	112.44	1.84	1.99
149	1.90	36.88	10.18	109.04	1.90	9.67
150	1.84	35.69	19.26	92.23	1.84	18.30
151	1.90	36.88	23.03	78.05	1.90	21.88
152	1.90	36.88	19.53	60.58	1.90	18.55
153	1.84	35.69	9.69	50.08	1.84	9.21
154	1.90	36.88	5.25	44.66	1.90	4.99
155	1.84	35.69	2.07	42.54	1.84	1.97
156	1.90	36.88	2.04	39.60	1.90	1.93
157	1.90	36.88	2.09	36.78	1.90	1.98

158	1.72	33.31	1.91	34.36	1.72	1.82
159	1.90	36.88	2.14	31.48	1.90	2.04
160	1.84	35.69	2.10	63.06	1.84	1.99
161	1.90	36.88	10.18	98.78	1.90	9.67
162	1.84	35.69	19.26	94.67	1.84	18.30
163	1.90	36.88	23.03	88.84	1.90	21.88
164	1.90	36.88	19.53	73.11	1.90	18.55
165	1.84	35.69	9.69	63.03	1.84	9.21
166	1.90	36.88	5.25	57.60	1.90	4.99
167	1.84	35.69	2.07	55.94	1.84	1.97
168	1.90	36.88	2.04	53.66	1.90	1.93
169	1.90	36.88	2.09	50.74	1.90	1.98
170	1.72	33.31	1.91	48.18	1.72	1.82
171	1.90	36.88	2.14	53.95	1.90	2.04
172	1.84	35.69	2.10	73.92	1.84	1.99
173	1.90	36.88	10.18	77.28	1.90	9.67
174	1.84	35.69	19.26	72.14	1.84	18.30
175	1.90	36.88	23.03	56.39	1.90	21.88
176	1.90	36.88	19.53	36.81	1.90	18.55
177	1.84	35.69	9.69	26.59	1.84	9.21
178	1.90	36.88	5.25	22.14	1.90	4.99
179	1.84	35.69	2.07	20.32	1.84	1.97
180	1.90	36.88	2.04	19.10	1.90	1.93

Table C-4 Optimal Objective Function Values

Required Active Storage (10^6 m^3)	Sum of Storage Deviations (10^6 m^3)
477.36	14945.98

Table C-5 Minimum and Maximum Constraint Bounds

Maximum Storage (10^6 m^3)	Minimum Storage (10^6 m^3)	Minimum Fraction of Target Water Supply	Maximum Fration of Target Water Supply
477.36	12.34	0.95	1.00

Table C-6 Optimal Decision Variables, Minimum and Maximum Downstream Reservoir Releases, and Monthly Target Water Supply Levels, (10^6 m^3)

Time (months)	Minimum Release	Maximum Release	Target Water Supply	Optimal Reservoir Storage	Optimal Reservoir Release	Optimal Reservoir Water Supply
1	1.90	36.88	2.09	174.23	1.90	1.98
2	1.72	33.31	1.91	171.80	1.72	1.82
3	1.90	36.88	2.14	170.16	1.90	2.04
4	1.84	35.69	2.10	215.69	1.84	1.99
5	1.90	36.88	10.18	241.20	1.90	9.67
6	1.84	35.69	19.26	235.26	1.84	18.30
7	1.90	36.88	23.03	219.02	1.90	21.88
8	1.90	36.88	19.53	201.02	1.90	18.55
9	1.84	35.69	9.69	191.85	1.84	9.21
10	1.90	36.88	5.25	187.61	1.90	4.99
11	1.84	35.69	2.07	186.11	1.84	1.97
12	1.90	36.88	2.04	183.88	1.90	1.93
13	1.90	36.88	2.09	181.56	1.90	1.98
14	1.72	33.31	1.91	179.43	1.72	1.82
15	1.90	36.88	2.14	176.72	1.90	2.04
16	1.84	35.69	2.10	258.67	1.84	1.99
17	1.90	36.88	10.18	273.13	1.90	9.67
18	1.84	35.69	19.26	264.05	1.84	18.30
19	1.90	36.88	23.03	246.23	1.90	21.88
20	1.90	36.88	19.53	229.48	1.90	18.55
21	1.84	35.69	9.69	219.19	1.84	9.21
22	1.90	36.88	5.25	214.20	1.90	4.99
23	1.84	35.69	2.07	212.76	1.84	1.97
24	1.90	36.88	2.04	210.92	1.90	1.93
25	1.90	36.88	2.09	208.80	1.90	1.98
26	1.72	33.31	1.91	206.66	1.72	1.82
27	1.90	36.88	2.14	204.59	1.90	2.04
28	1.84	35.69	2.10	279.36	1.84	1.99
29	1.90	36.88	10.18	344.49	1.90	9.67
30	1.84	35.69	19.26	331.64	1.84	18.30
31	1.90	36.88	23.03	311.35	1.90	21.88
32	1.90	36.88	19.53	292.13	1.90	18.55
33	1.84	35.69	9.69	281.74	1.84	9.21

34	1.90	36.88	5.25	275.81	1.90	4.99
35	1.84	35.69	2.07	273.18	1.84	1.97
36	1.90	36.88	2.04	270.06	1.90	1.93
37	1.90	36.88	2.09	266.56	1.90	1.98
38	1.72	33.31	1.91	263.39	1.72	1.82
39	1.90	36.88	2.14	261.02	1.90	2.04
40	1.84	35.69	2.10	267.11	1.84	1.99
41	1.90	36.88	10.18	263.45	1.90	9.67
42	1.84	35.69	19.26	255.18	1.84	18.30
43	1.90	36.88	23.03	242.72	1.90	21.88
44	1.90	36.88	19.53	224.36	1.90	18.55
45	1.84	35.69	9.69	215.23	1.84	9.21
46	1.90	36.88	5.25	210.26	1.90	4.99
47	1.84	35.69	2.07	208.33	1.84	1.97
48	1.90	36.88	2.04	206.24	1.90	1.93
49	1.90	36.88	2.09	203.59	1.90	1.98
50	1.72	33.31	1.91	201.21	1.72	1.82
51	1.90	36.88	2.14	198.51	1.90	2.04
52	1.84	35.69	2.10	260.00	1.84	1.99
53	1.90	36.88	10.18	341.27	1.90	9.67
54	1.84	35.69	19.26	361.38	1.84	18.30
55	1.90	36.88	23.03	342.44	1.90	21.88
56	1.90	36.88	19.53	324.56	1.90	18.55
57	1.84	35.69	9.69	316.96	1.84	9.21
58	1.90	36.88	5.25	314.72	1.90	4.99
59	1.84	35.69	2.07	303.81	12.29	2.07
60	1.90	36.88	2.04	276.75	27.64	2.04
61	1.90	36.88	2.09	252.15	24.42	2.09
62	1.72	33.31	1.91	241.28	10.72	1.91
63	1.90	36.88	2.14	239.02	1.90	2.04
64	1.84	35.69	2.10	289.83	1.84	1.99
65	1.90	36.88	10.18	386.03	1.90	9.67
66	1.84	35.69	19.26	396.00	1.84	18.30
67	1.90	36.88	23.03	382.35	1.90	21.88
68	1.90	36.88	19.53	364.78	1.90	18.55
69	1.84	35.69	9.69	356.90	1.84	9.21
70	1.90	36.88	5.25	338.25	17.74	5.25
71	1.84	35.69	2.07	315.97	24.69	2.07
72	1.90	36.88	2.04	314.09	1.90	1.93
73	1.90	36.88	2.09	311.70	1.90	1.98
74	1.72	33.31	1.91	309.84	1.72	1.82
75	1.90	36.88	2.14	307.88	1.90	2.04
76	1.84	35.69	2.10	424.92	1.84	1.99
77	1.90	36.88	10.18	446.78	1.90	9.67
78	1.84	35.69	19.26	471.91	1.84	18.30
79	1.90	36.88	23.03	477.36	1.90	21.88
80	1.90	36.88	19.53	461.96	1.90	18.55
81	1.84	35.69	9.69	456.68	1.84	9.21
82	1.90	36.88	5.25	454.82	1.90	4.99
83	1.84	35.69	2.07	452.53	1.84	1.97
84	1.90	36.88	2.04	449.85	1.90	1.93
85	1.90	36.88	2.09	446.73	1.90	1.98
86	1.72	33.31	1.91	444.08	1.72	1.82
87	1.90	36.88	2.14	441.16	1.90	2.04
88	1.84	35.69	2.10	452.41	1.84	1.99
89	1.90	36.88	10.18	448.44	1.90	9.67
90	1.84	35.69	19.26	430.67	1.84	18.30
91	1.90	36.88	23.03	409.12	1.90	21.88
92	1.90	36.88	19.53	390.28	1.90	18.55
93	1.84	35.69	9.69	382.77	1.84	9.21
94	1.90	36.88	5.25	380.47	1.90	4.99

95	1.84	35.69	2.07	379.42	1.84	1.97
96	1.90	36.88	2.04	377.32	1.90	1.93
97	1.90	36.88	2.09	374.79	1.90	1.98
98	1.72	33.31	1.91	372.18	1.72	1.82
99	1.90	36.88	2.14	369.87	1.90	2.04
100	1.84	35.69	2.10	388.55	1.84	1.99
101	1.90	36.88	10.18	390.81	1.90	9.67
102	1.84	35.69	19.26	375.02	1.84	18.30
103	1.90	36.88	23.03	354.06	1.90	21.88
104	1.90	36.88	19.53	334.34	1.90	18.55
105	1.84	35.69	9.69	324.18	1.84	9.21
106	1.90	36.88	5.25	318.88	1.90	4.99
107	1.84	35.69	2.07	317.18	1.84	1.97
108	1.90	36.88	2.04	314.66	1.90	1.93
109	1.90	36.88	2.09	311.72	1.90	1.98
110	1.72	33.31	1.91	308.99	1.72	1.82
111	1.90	36.88	2.14	305.86	1.90	2.04
112	1.84	35.69	2.10	357.66	1.84	1.99
113	1.90	36.88	10.18	461.97	1.90	9.67
114	1.84	35.69	19.26	467.72	1.84	18.30
115	1.90	36.88	23.03	447.87	1.90	21.88
116	1.90	36.88	19.53	428.66	1.90	18.55
117	1.84	35.69	9.69	419.02	1.84	9.21
118	1.90	36.88	5.25	413.30	1.90	4.99
119	1.84	35.69	2.07	411.45	1.84	1.97
120	1.90	36.88	2.04	408.87	1.90	1.93
121	1.90	36.88	2.09	406.18	1.90	1.98
122	1.72	33.31	1.91	403.78	1.72	1.82
123	1.90	36.88	2.14	401.09	1.90	2.04
124	1.84	35.69	2.10	435.06	1.84	1.99
125	1.90	36.88	10.18	431.91	1.90	9.67
126	1.84	35.69	19.26	413.43	1.84	18.30
127	1.90	36.88	23.03	390.91	1.90	21.88
128	1.90	36.88	19.53	371.54	1.90	18.55
129	1.84	35.69	9.69	361.45	1.84	9.21
130	1.90	36.88	5.25	356.00	1.90	4.99
131	1.84	35.69	2.07	353.92	1.84	1.97
132	1.90	36.88	2.04	350.93	1.90	1.93
133	1.90	36.88	2.09	347.56	1.90	1.98
134	1.72	33.31	1.91	344.63	1.72	1.82
135	1.90	36.88	2.14	345.50	1.90	2.04
136	1.84	35.69	2.10	350.77	1.84	1.99
137	1.90	36.88	10.18	343.63	1.90	9.67
138	1.84	35.69	19.26	326.96	1.84	18.30
139	1.90	36.88	23.03	305.90	1.90	21.88
140	1.90	36.88	19.53	286.96	1.90	18.55
141	1.84	35.69	9.69	276.62	1.84	9.21
142	1.90	36.88	5.25	272.43	1.90	4.99
143	1.84	35.69	2.07	271.58	1.84	1.97
144	1.90	36.88	2.04	268.86	1.90	1.93
145	1.90	36.88	2.09	265.40	1.90	1.98
146	1.72	33.31	1.91	262.40	1.72	1.82
147	1.90	36.88	2.14	259.19	1.90	2.04
148	1.84	35.69	2.10	270.26	1.84	1.99
149	1.90	36.88	10.18	266.86	1.90	9.67
150	1.84	35.69	19.26	250.05	1.84	18.30
151	1.90	36.88	23.03	235.87	1.90	21.88
152	1.90	36.88	19.53	218.40	1.90	18.55
153	1.84	35.69	9.69	207.90	1.84	9.21
154	1.90	36.88	5.25	202.48	1.90	4.99
155	1.84	35.69	2.07	200.36	1.84	1.97

156	1.90	36.88	2.04	197.42	1.90	1.93
157	1.90	36.88	2.09	194.60	1.90	1.98
158	1.72	33.31	1.91	192.18	1.72	1.82
159	1.90	36.88	2.14	189.30	1.90	2.04
160	1.84	35.69	2.10	220.88	1.84	1.99
161	1.90	36.88	10.18	256.60	1.90	9.67
162	1.84	35.69	19.26	252.49	1.84	18.30
163	1.90	36.88	23.03	246.66	1.90	21.88
164	1.90	36.88	19.53	230.93	1.90	18.55
165	1.84	35.69	9.69	220.85	1.84	9.21
166	1.90	36.88	5.25	215.42	1.90	4.99
167	1.84	35.69	2.07	213.76	1.84	1.97
168	1.90	36.88	2.04	211.48	1.90	1.93
169	1.90	36.88	2.09	208.56	1.90	1.98
170	1.72	33.31	1.91	205.99	1.72	1.82
171	1.90	36.88	2.14	211.77	1.90	2.04
172	1.84	35.69	2.10	231.74	1.84	1.99
173	1.90	36.88	10.18	235.10	1.90	9.67
174	1.84	35.69	19.26	229.96	1.84	18.30
175	1.90	36.88	23.03	214.21	1.90	21.88
176	1.90	36.88	19.53	194.63	1.90	18.55
177	1.84	35.69	9.69	184.41	1.84	9.21
178	1.90	36.88	5.25	179.96	1.90	4.99
179	1.84	35.69	2.07	178.14	1.84	1.97
180	1.90	36.88	2.04	176.92	1.90	1.93

Appendix C: Compromise Solution (s = 1) for the Given Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

Table C-7 Optimal Objective Function Values

Required Active Storage (10^6 m^3)	Sum of Storage Deviations (10^6 m^3)
403.19	20202.45

Table C-8 Minimum and Maximum Constraint Bounds

Maximum Storage (10^6 m^3)	Minimum Storage (10^6 m^3)	Minimum Fraction of Target Water Supply	Maximum Fration of Target Water Supply
477.36	12.34	0.95	1

Table C-9 Optimal Decision Variables, Minimum and Maximum Downstream Reservoir Releases, and Monthly Target Water Supply Levels, (10^6 m^3)

Time (months)	Minimum Release	Maximum Release	Target Water Supply	Optimal Reservoir Storage	Optimal Reservoir Release	Optimal Reservoir Water Supply
1	1.90	36.88	2.09	100.05	1.90	1.98
2	1.72	33.31	1.91	97.62	1.72	1.82
3	1.90	36.88	2.14	95.98	1.90	2.04
4	1.84	35.69	2.10	141.52	1.84	1.99
5	1.90	36.88	10.18	167.03	1.90	9.67
6	1.84	35.69	19.26	161.08	1.84	18.30
7	1.90	36.88	23.03	144.85	1.90	21.88
8	1.90	36.88	19.53	126.84	1.90	18.55
9	1.84	35.69	9.69	117.68	1.84	9.21
10	1.90	36.88	5.25	113.44	1.90	4.99
11	1.84	35.69	2.07	111.94	1.84	1.97
12	1.90	36.88	2.04	109.70	1.90	1.93
13	1.90	36.88	2.09	107.38	1.90	1.98
14	1.72	33.31	1.91	105.25	1.72	1.82
15	1.90	36.88	2.14	102.54	1.90	2.04
16	1.84	35.69	2.10	184.49	1.84	1.99
17	1.90	36.88	10.18	198.95	1.90	9.67
18	1.84	35.69	19.26	189.87	1.84	18.30
19	1.90	36.88	23.03	172.05	1.90	21.88
20	1.90	36.88	19.53	155.31	1.90	18.55
21	1.84	35.69	9.69	145.01	1.84	9.21
22	1.90	36.88	5.25	140.02	1.90	4.99
23	1.84	35.69	2.07	138.58	1.84	1.97
24	1.90	36.88	2.04	136.74	1.90	1.93
25	1.90	36.88	2.09	134.63	1.90	1.98
26	1.72	33.31	1.91	132.48	1.72	1.82
27	1.90	36.88	2.14	130.42	1.90	2.04
28	1.84	35.69	2.10	205.18	1.84	1.99
29	1.90	36.88	10.18	270.31	1.90	9.67
30	1.84	35.69	19.26	257.46	1.84	18.30
31	1.90	36.88	23.03	237.17	1.90	21.88
32	1.90	36.88	19.53	217.95	1.90	18.55
33	1.84	35.69	9.69	207.56	1.84	9.21
34	1.90	36.88	5.25	201.63	1.90	4.99
35	1.84	35.69	2.07	199.00	1.84	1.97

Appendix C: Compromise Solution (s = 1) for the Given Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

36	1.90	36.88	2.04	195.88	1.90	1.93
37	1.90	36.88	2.09	192.38	1.90	1.98
38	1.72	33.31	1.91	189.22	1.72	1.82
39	1.90	36.88	2.14	186.84	1.90	2.04
40	1.84	35.69	2.10	192.93	1.84	1.99
41	1.90	36.88	10.18	189.27	1.90	9.67
42	1.84	35.69	19.26	181.01	1.84	18.30
43	1.90	36.88	23.03	168.54	1.90	21.88
44	1.90	36.88	19.53	150.18	1.90	18.55
45	1.84	35.69	9.69	141.05	1.84	9.21
46	1.90	36.88	5.25	136.08	1.90	4.99
47	1.84	35.69	2.07	134.15	1.84	1.97
48	1.90	36.88	2.04	132.07	1.90	1.93
49	1.90	36.88	2.09	129.41	1.90	1.98
50	1.72	33.31	1.91	127.03	1.72	1.82
51	1.90	36.88	2.14	124.33	1.90	2.04
52	1.84	35.69	2.10	185.83	1.84	1.99
53	1.90	36.88	10.18	267.09	1.90	9.67
54	1.84	35.69	19.26	287.20	1.84	18.30
55	1.90	36.88	23.03	268.26	1.90	21.88
56	1.90	36.88	19.53	250.38	1.90	18.55
57	1.84	35.69	9.69	242.78	1.84	9.21
58	1.90	36.88	5.25	240.54	1.90	4.99
59	1.84	35.69	2.07	240.18	1.84	1.97
60	1.90	36.88	2.04	238.97	1.90	1.93
61	1.90	36.88	2.09	236.99	1.90	1.98
62	1.72	33.31	1.91	235.22	1.72	1.82
63	1.90	36.88	2.14	232.96	1.90	2.04
64	1.84	35.69	2.10	283.77	1.84	1.99
65	1.90	36.88	10.18	379.97	1.90	9.67
66	1.84	35.69	19.26	389.94	1.84	18.30
67	1.90	36.88	23.03	376.29	1.90	21.88
68	1.90	36.88	19.53	358.73	1.90	18.55
69	1.84	35.69	9.69	350.84	1.84	9.21
70	1.90	36.88	5.25	337.08	12.84	5.25
71	1.84	35.69	2.07	303.81	35.69	2.07
72	1.90	36.88	2.04	276.75	26.97	2.04
73	1.90	36.88	2.09	252.15	24.01	2.09
74	1.72	33.31	1.91	235.66	16.25	1.91
75	1.90	36.88	2.14	233.70	1.90	2.04
76	1.84	35.69	2.10	350.74	1.84	1.99
77	1.90	36.88	10.18	372.61	1.90	9.67
78	1.84	35.69	19.26	397.73	1.84	18.30
79	1.90	36.88	23.03	403.19	1.90	21.88
80	1.90	36.88	19.53	387.79	1.90	18.55
81	1.84	35.69	9.69	382.51	1.84	9.21
82	1.90	36.88	5.25	380.65	1.90	4.99
83	1.84	35.69	2.07	378.36	1.84	1.97
84	1.90	36.88	2.04	375.67	1.90	1.93
85	1.90	36.88	2.09	372.56	1.90	1.98
86	1.72	33.31	1.91	369.90	1.72	1.82
87	1.90	36.88	2.14	366.98	1.90	2.04
88	1.84	35.69	2.10	378.23	1.84	1.99
89	1.90	36.88	10.18	374.26	1.90	9.67
90	1.84	35.69	19.26	356.49	1.84	18.30
91	1.90	36.88	23.03	334.94	1.90	21.88
92	1.90	36.88	19.53	316.10	1.90	18.55
93	1.84	35.69	9.69	308.59	1.84	9.21
94	1.90	36.88	5.25	306.29	1.90	4.99
95	1.84	35.69	2.07	305.24	1.84	1.97
96	1.90	36.88	2.04	303.14	1.90	1.93

Appendix C: Compromise Solution (s = 1) for the Given Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

97	1.90	36.88	2.09	300.61	1.90	1.98
98	1.72	33.31	1.91	298.00	1.72	1.82
99	1.90	36.88	2.14	295.70	1.90	2.04
100	1.84	35.69	2.10	314.37	1.84	1.99
101	1.90	36.88	10.18	316.63	1.90	9.67
102	1.84	35.69	19.26	300.85	1.84	18.30
103	1.90	36.88	23.03	279.88	1.90	21.88
104	1.90	36.88	19.53	260.16	1.90	18.55
105	1.84	35.69	9.69	250.00	1.84	9.21
106	1.90	36.88	5.25	244.70	1.90	4.99
107	1.84	35.69	2.07	243.00	1.84	1.97
108	1.90	36.88	2.04	240.49	1.90	1.93
109	1.90	36.88	2.09	237.54	1.90	1.98
110	1.72	33.31	1.91	234.82	1.72	1.82
111	1.90	36.88	2.14	231.68	1.90	2.04
112	1.84	35.69	2.10	283.48	1.84	1.99
113	1.90	36.88	10.18	387.79	1.90	9.67
114	1.84	35.69	19.26	393.54	1.84	18.30
115	1.90	36.88	23.03	373.69	1.90	21.88
116	1.90	36.88	19.53	354.48	1.90	18.55
117	1.84	35.69	9.69	344.84	1.84	9.21
118	1.90	36.88	5.25	339.12	1.90	4.99
119	1.84	35.69	2.07	337.27	1.84	1.97
120	1.90	36.88	2.04	334.69	1.90	1.93
121	1.90	36.88	2.09	332.00	1.90	1.98
122	1.72	33.31	1.91	329.60	1.72	1.82
123	1.90	36.88	2.14	326.91	1.90	2.04
124	1.84	35.69	2.10	360.89	1.84	1.99
125	1.90	36.88	10.18	357.74	1.90	9.67
126	1.84	35.69	19.26	339.25	1.84	18.30
127	1.90	36.88	23.03	316.74	1.90	21.88
128	1.90	36.88	19.53	297.36	1.90	18.55
129	1.84	35.69	9.69	287.27	1.84	9.21
130	1.90	36.88	5.25	281.83	1.90	4.99
131	1.84	35.69	2.07	279.75	1.84	1.97
132	1.90	36.88	2.04	276.75	1.90	1.93
133	1.90	36.88	2.09	273.38	1.90	1.98
134	1.72	33.31	1.91	270.45	1.72	1.82
135	1.90	36.88	2.14	271.32	1.90	2.04
136	1.84	35.69	2.10	276.59	1.84	1.99
137	1.90	36.88	10.18	269.45	1.90	9.67
138	1.84	35.69	19.26	252.78	1.84	18.30
139	1.90	36.88	23.03	231.72	1.90	21.88
140	1.90	36.88	19.53	212.79	1.90	18.55
141	1.84	35.69	9.69	202.45	1.84	9.21
142	1.90	36.88	5.25	198.25	1.90	4.99
143	1.84	35.69	2.07	197.40	1.84	1.97
144	1.90	36.88	2.04	194.68	1.90	1.93
145	1.90	36.88	2.09	191.23	1.90	1.98
146	1.72	33.31	1.91	188.22	1.72	1.82
147	1.90	36.88	2.14	185.02	1.90	2.04
148	1.84	35.69	2.10	196.08	1.84	1.99
149	1.90	36.88	10.18	192.68	1.90	9.67
150	1.84	35.69	19.26	175.87	1.84	18.30
151	1.90	36.88	23.03	161.69	1.90	21.88
152	1.90	36.88	19.53	144.22	1.90	18.55
153	1.84	35.69	9.69	133.72	1.84	9.21
154	1.90	36.88	5.25	128.30	1.90	4.99
155	1.84	35.69	2.07	126.18	1.84	1.97
156	1.90	36.88	2.04	123.24	1.90	1.93
157	1.90	36.88	2.09	120.42	1.90	1.98

Appendix C: Compromise Solution (s = 1) for the Given Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

158	1.72	33.31	1.91	118.00	1.72	1.82
159	1.90	36.88	2.14	115.12	1.90	2.04
160	1.84	35.69	2.10	146.70	1.84	1.99
161	1.90	36.88	10.18	182.42	1.90	9.67
162	1.84	35.69	19.26	178.32	1.84	18.30
163	1.90	36.88	23.03	172.48	1.90	21.88
164	1.90	36.88	19.53	156.75	1.90	18.55
165	1.84	35.69	9.69	146.67	1.84	9.21
166	1.90	36.88	5.25	141.24	1.90	4.99
167	1.84	35.69	2.07	139.58	1.84	1.97
168	1.90	36.88	2.04	137.31	1.90	1.93
169	1.90	36.88	2.09	134.38	1.90	1.98
170	1.72	33.31	1.91	131.82	1.72	1.82
171	1.90	36.88	2.14	137.59	1.90	2.04
172	1.84	35.69	2.10	157.56	1.84	1.99
173	1.90	36.88	10.18	160.92	1.90	9.67
174	1.84	35.69	19.26	155.78	1.84	18.30
175	1.90	36.88	23.03	140.03	1.90	21.88
176	1.90	36.88	19.53	120.45	1.90	18.55
177	1.84	35.69	9.69	110.23	1.84	9.21
178	1.90	36.88	5.25	105.78	1.90	4.99
179	1.84	35.69	2.07	103.96	1.84	1.97
180	1.90	36.88	2.04	102.74	1.90	1.93

Appendix C: Compromise Solution (s = 2) for the Given Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

Table C-10 Optimal Objective Function Values

Required Active Storage (10^6 m^3)	Sum of Storage Deviations (10^6 m^3)
392.12	21485.53

Table C-11 Minimum and Maximum Constraint Bounds

Maximum Storage (10^6 m^3)	Minimum Storage (10^6 m^3)	Minimum Fraction of Target Water Supply	Maximum Fration of Target Water Supply
477.36	12.34	0.95	1

Table C-12 Optimal Decision Variables, Minimum and Maximum Downstream Reservoir Releases, and Monthly Target Water Supply Levels, (10^6 m^3)

Time (months)	Minimum Release	Maximum Release	Target Water Supply	Optimal Reservoir Storage	Optimal Reservoir Release	Optimal Reservoir Water Supply
1	1.90	36.88	2.09	88.99	1.90	1.98
2	1.72	33.31	1.91	86.55	1.72	1.82
3	1.90	36.88	2.14	84.92	1.90	2.04
4	1.84	35.69	2.10	130.45	1.84	1.99
5	1.90	36.88	10.18	155.96	1.90	9.67
6	1.84	35.69	19.26	150.01	1.84	18.30
7	1.90	36.88	23.03	133.78	1.90	21.88
8	1.90	36.88	19.53	115.78	1.90	18.55
9	1.84	35.69	9.69	106.61	1.84	9.21
10	1.90	36.88	5.25	102.37	1.90	4.99
11	1.84	35.69	2.07	100.87	1.84	1.97
12	1.90	36.88	2.04	98.63	1.90	1.93
13	1.90	36.88	2.09	96.32	1.90	1.98
14	1.72	33.31	1.91	94.18	1.72	1.82
15	1.90	36.88	2.14	91.48	1.90	2.04
16	1.84	35.69	2.10	173.42	1.84	1.99
17	1.90	36.88	10.18	187.88	1.90	9.67
18	1.84	35.69	19.26	178.81	1.84	18.30
19	1.90	36.88	23.03	160.98	1.90	21.88
20	1.90	36.88	19.53	144.24	1.90	18.55
21	1.84	35.69	9.69	133.94	1.84	9.21
22	1.90	36.88	5.25	128.95	1.90	4.99
23	1.84	35.69	2.07	127.51	1.84	1.97
24	1.90	36.88	2.04	125.68	1.90	1.93
25	1.90	36.88	2.09	123.56	1.90	1.98
26	1.72	33.31	1.91	121.42	1.72	1.82
27	1.90	36.88	2.14	119.35	1.90	2.04
28	1.84	35.69	2.10	194.11	1.84	1.99
29	1.90	36.88	10.18	259.24	1.90	9.67
30	1.84	35.69	19.26	246.40	1.84	18.30
31	1.90	36.88	23.03	226.10	1.90	21.88
32	1.90	36.88	19.53	206.88	1.90	18.55
33	1.84	35.69	9.69	196.49	1.84	9.21
34	1.90	36.88	5.25	190.56	1.90	4.99
35	1.84	35.69	2.07	187.93	1.84	1.97

Appendix C: Compromise Solution (s = 2) for the Given Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

36	1.90	36.88	2.04	184.82	1.90	1.93
37	1.90	36.88	2.09	181.31	1.90	1.98
38	1.72	33.31	1.91	178.15	1.72	1.82
39	1.90	36.88	2.14	175.77	1.90	2.04
40	1.84	35.69	2.10	181.87	1.84	1.99
41	1.90	36.88	10.18	178.21	1.90	9.67
42	1.84	35.69	19.26	169.94	1.84	18.30
43	1.90	36.88	23.03	157.48	1.90	21.88
44	1.90	36.88	19.53	139.11	1.90	18.55
45	1.84	35.69	9.69	129.99	1.84	9.21
46	1.90	36.88	5.25	125.02	1.90	4.99
47	1.84	35.69	2.07	123.09	1.84	1.97
48	1.90	36.88	2.04	121.00	1.90	1.93
49	1.90	36.88	2.09	118.34	1.90	1.98
50	1.72	33.31	1.91	115.96	1.72	1.82
51	1.90	36.88	2.14	113.26	1.90	2.04
52	1.84	35.69	2.10	174.76	1.84	1.99
53	1.90	36.88	10.18	256.03	1.90	9.67
54	1.84	35.69	19.26	276.13	1.84	18.30
55	1.90	36.88	23.03	257.20	1.90	21.88
56	1.90	36.88	19.53	239.32	1.90	18.55
57	1.84	35.69	9.69	231.72	1.84	9.21
58	1.90	36.88	5.25	229.48	1.90	4.99
59	1.84	35.69	2.07	229.12	1.84	1.97
60	1.90	36.88	2.04	227.90	1.90	1.93
61	1.90	36.88	2.09	225.93	1.90	1.98
62	1.72	33.31	1.91	224.15	1.72	1.82
63	1.90	36.88	2.14	221.90	1.90	2.04
64	1.84	35.69	2.10	272.70	1.84	1.99
65	1.90	36.88	10.18	368.90	1.90	9.67
66	1.84	35.69	19.26	378.87	1.84	18.30
67	1.90	36.88	23.03	365.22	1.90	21.88
68	1.90	36.88	19.53	347.66	1.90	18.55
69	1.84	35.69	9.69	339.77	1.84	9.21
70	1.90	36.88	5.25	337.08	2.04	4.99
71	1.84	35.69	2.07	303.81	35.69	2.07
72	1.90	36.88	2.04	276.75	27.08	1.93
73	1.90	36.88	2.09	252.15	24.12	1.98
74	1.72	33.31	1.91	225.09	26.91	1.82
75	1.90	36.88	2.14	222.64	2.40	2.04
76	1.84	35.69	2.10	339.67	1.84	1.99
77	1.90	36.88	10.18	361.54	1.90	9.67
78	1.84	35.69	19.26	386.66	1.84	18.30
79	1.90	36.88	23.03	392.12	1.90	21.88
80	1.90	36.88	19.53	376.72	1.90	18.55
81	1.84	35.69	9.69	371.44	1.84	9.21
82	1.90	36.88	5.25	369.58	1.90	4.99
83	1.84	35.69	2.07	367.29	1.84	1.97
84	1.90	36.88	2.04	364.60	1.90	1.93
85	1.90	36.88	2.09	361.49	1.90	1.98
86	1.72	33.31	1.91	358.84	1.72	1.82
87	1.90	36.88	2.14	355.92	1.90	2.04
88	1.84	35.69	2.10	367.16	1.84	1.99
89	1.90	36.88	10.18	363.19	1.90	9.67
90	1.84	35.69	19.26	345.43	1.84	18.30
91	1.90	36.88	23.03	323.87	1.90	21.88
92	1.90	36.88	19.53	305.03	1.90	18.55
93	1.84	35.69	9.69	297.52	1.84	9.21
94	1.90	36.88	5.25	295.22	1.90	4.99
95	1.84	35.69	2.07	294.17	1.84	1.97
96	1.90	36.88	2.04	292.08	1.90	1.93

Appendix C: Compromise Solution (s = 2) for the Given Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

97	1.90	36.88	2.09	289.54	1.90	1.98
98	1.72	33.31	1.91	286.94	1.72	1.82
99	1.90	36.88	2.14	284.63	1.90	2.04
100	1.84	35.69	2.10	303.31	1.84	1.99
101	1.90	36.88	10.18	305.56	1.90	9.67
102	1.84	35.69	19.26	289.78	1.84	18.30
103	1.90	36.88	23.03	268.81	1.90	21.88
104	1.90	36.88	19.53	249.09	1.90	18.55
105	1.84	35.69	9.69	238.93	1.84	9.21
106	1.90	36.88	5.25	233.63	1.90	4.99
107	1.84	35.69	2.07	231.93	1.84	1.97
108	1.90	36.88	2.04	229.42	1.90	1.93
109	1.90	36.88	2.09	226.47	1.90	1.98
110	1.72	33.31	1.91	223.75	1.72	1.82
111	1.90	36.88	2.14	220.61	1.90	2.04
112	1.84	35.69	2.10	272.42	1.84	1.99
113	1.90	36.88	10.18	376.73	1.90	9.67
114	1.84	35.69	19.26	382.47	1.84	18.30
115	1.90	36.88	23.03	362.63	1.90	21.88
116	1.90	36.88	19.53	343.42	1.90	18.55
117	1.84	35.69	9.69	333.78	1.84	9.21
118	1.90	36.88	5.25	328.06	1.90	4.99
119	1.84	35.69	2.07	326.21	1.84	1.97
120	1.90	36.88	2.04	323.62	1.90	1.93
121	1.90	36.88	2.09	320.94	1.90	1.98
122	1.72	33.31	1.91	318.53	1.72	1.82
123	1.90	36.88	2.14	315.84	1.90	2.04
124	1.84	35.69	2.10	349.82	1.84	1.99
125	1.90	36.88	10.18	346.67	1.90	9.67
126	1.84	35.69	19.26	328.18	1.84	18.30
127	1.90	36.88	23.03	305.67	1.90	21.88
128	1.90	36.88	19.53	286.30	1.90	18.55
129	1.84	35.69	9.69	276.21	1.84	9.21
130	1.90	36.88	5.25	270.76	1.90	4.99
131	1.84	35.69	2.07	268.68	1.84	1.97
132	1.90	36.88	2.04	265.68	1.90	1.93
133	1.90	36.88	2.09	262.32	1.90	1.98
134	1.72	33.31	1.91	259.38	1.72	1.82
135	1.90	36.88	2.14	260.26	1.90	2.04
136	1.84	35.69	2.10	265.52	1.84	1.99
137	1.90	36.88	10.18	258.38	1.90	9.67
138	1.84	35.69	19.26	241.72	1.84	18.30
139	1.90	36.88	23.03	220.65	1.90	21.88
140	1.90	36.88	19.53	201.72	1.90	18.55
141	1.84	35.69	9.69	191.38	1.84	9.21
142	1.90	36.88	5.25	187.18	1.90	4.99
143	1.84	35.69	2.07	186.33	1.84	1.97
144	1.90	36.88	2.04	183.62	1.90	1.93
145	1.90	36.88	2.09	180.16	1.90	1.98
146	1.72	33.31	1.91	177.16	1.72	1.82
147	1.90	36.88	2.14	173.95	1.90	2.04
148	1.84	35.69	2.10	185.01	1.84	1.99
149	1.90	36.88	10.18	181.61	1.90	9.67
150	1.84	35.69	19.26	164.81	1.84	18.30
151	1.90	36.88	23.03	150.62	1.90	21.88
152	1.90	36.88	19.53	133.15	1.90	18.55
153	1.84	35.69	9.69	122.65	1.84	9.21
154	1.90	36.88	5.25	117.23	1.90	4.99
155	1.84	35.69	2.07	115.11	1.84	1.97
156	1.90	36.88	2.04	112.18	1.90	1.93
157	1.90	36.88	2.09	109.35	1.90	1.98

Appendix C: Compromise Solution (s = 2) for the Given Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

158	1.72	33.31	1.91	106.94	1.72	1.82
159	1.90	36.88	2.14	104.05	1.90	2.04
160	1.84	35.69	2.10	135.64	1.84	1.99
161	1.90	36.88	10.18	171.36	1.90	9.67
162	1.84	35.69	19.26	167.25	1.84	18.30
163	1.90	36.88	23.03	161.42	1.90	21.88
164	1.90	36.88	19.53	145.68	1.90	18.55
165	1.84	35.69	9.69	135.60	1.84	9.21
166	1.90	36.88	5.25	130.18	1.90	4.99
167	1.84	35.69	2.07	128.52	1.84	1.97
168	1.90	36.88	2.04	126.24	1.90	1.93
169	1.90	36.88	2.09	123.31	1.90	1.98
170	1.72	33.31	1.91	120.75	1.72	1.82
171	1.90	36.88	2.14	126.52	1.90	2.04
172	1.84	35.69	2.10	146.50	1.84	1.99
173	1.90	36.88	10.18	149.86	1.90	9.67
174	1.84	35.69	19.26	144.71	1.84	18.30
175	1.90	36.88	23.03	128.97	1.90	21.88
176	1.90	36.88	19.53	109.39	1.90	18.55
177	1.84	35.69	9.69	99.17	1.84	9.21
178	1.90	36.88	5.25	94.72	1.90	4.99
179	1.84	35.69	2.07	92.90	1.84	1.97
180	1.90	36.88	2.04	91.67	1.90	1.93

Appendix C: Compromise Solution (s = 100) for the Given Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

Table C-13 Optimal Objective Function Values

Required Active Storage (10^6 m^3)	Sum of Storage Deviations (10^6 m^3)
456.69	15949.35

Table C-14 Minimum and Maximum Constraint Bounds

Maximum Storage (10^6 m^3)	Minimum Storage (10^6 m^3)	Minimum Fraction of Target Water Supply	Maximum Fration of Target Water Supply
477.36	12.34	0.95	1.00

Table C-15 Optimal Decision Variables, Minimum and Maximum Downstream Reservoir Releases, and Monthly Target Water Supply Levels, (10^6 m^3)

Time (months)	Minimum Release	Maximum Release	Target Water Supply	Optimal Reservoir Storage	Optimal Reservoir Release	Optimal Reservoir Water Supply
1	1.90	36.88	2.09	153.55	1.90	1.98
2	1.72	33.31	1.91	151.12	1.72	1.82
3	1.90	36.88	2.14	149.48	1.90	2.04
4	1.84	35.69	2.10	195.02	1.84	1.99
5	1.90	36.88	10.18	220.53	1.90	9.67
6	1.84	35.69	19.26	214.58	1.84	18.30
7	1.90	36.88	23.03	198.35	1.90	21.88
8	1.90	36.88	19.53	180.35	1.90	18.55
9	1.84	35.69	9.69	171.18	1.84	9.21
10	1.90	36.88	5.25	166.94	1.90	4.99
11	1.84	35.69	2.07	165.44	1.84	1.97
12	1.90	36.88	2.04	163.20	1.90	1.93
13	1.90	36.88	2.09	160.89	1.90	1.98
14	1.72	33.31	1.91	158.75	1.72	1.82
15	1.90	36.88	2.14	156.05	1.90	2.04
16	1.84	35.69	2.10	237.99	1.84	1.99
17	1.90	36.88	10.18	252.45	1.90	9.67
18	1.84	35.69	19.26	243.37	1.84	18.30
19	1.90	36.88	23.03	225.55	1.90	21.88
20	1.90	36.88	19.53	208.81	1.90	18.55
21	1.84	35.69	9.69	198.51	1.84	9.21
22	1.90	36.88	5.25	193.52	1.90	4.99
23	1.84	35.69	2.07	192.08	1.84	1.97
24	1.90	36.88	2.04	190.24	1.90	1.93
25	1.90	36.88	2.09	188.13	1.90	1.98
26	1.72	33.31	1.91	185.98	1.72	1.82
27	1.90	36.88	2.14	183.92	1.90	2.04
28	1.84	35.69	2.10	258.68	1.84	1.99
29	1.90	36.88	10.18	323.81	1.90	9.67
30	1.84	35.69	19.26	310.97	1.84	18.30
31	1.90	36.88	23.03	290.67	1.90	21.88
32	1.90	36.88	19.53	271.45	1.90	18.55
33	1.84	35.69	9.69	261.06	1.84	9.21
34	1.90	36.88	5.25	255.13	1.90	4.99
35	1.84	35.69	2.07	252.50	1.84	1.97

Appendix C: Compromise Solution (s = 100) for the Given Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

36	1.90	36.88	2.04	249.39	1.90	1.93
37	1.90	36.88	2.09	245.88	1.90	1.98
38	1.72	33.31	1.91	242.72	1.72	1.82
39	1.90	36.88	2.14	240.34	1.90	2.04
40	1.84	35.69	2.10	246.43	1.84	1.99
41	1.90	36.88	10.18	242.77	1.90	9.67
42	1.84	35.69	19.26	234.51	1.84	18.30
43	1.90	36.88	23.03	222.04	1.90	21.88
44	1.90	36.88	19.53	203.68	1.90	18.55
45	1.84	35.69	9.69	194.55	1.84	9.21
46	1.90	36.88	5.25	189.58	1.90	4.99
47	1.84	35.69	2.07	187.65	1.84	1.97
48	1.90	36.88	2.04	185.57	1.90	1.93
49	1.90	36.88	2.09	182.91	1.90	1.98
50	1.72	33.31	1.91	180.53	1.72	1.82
51	1.90	36.88	2.14	177.83	1.90	2.04
52	1.84	35.69	2.10	239.33	1.84	1.99
53	1.90	36.88	10.18	320.60	1.90	9.67
54	1.84	35.69	19.26	340.70	1.84	18.30
55	1.90	36.88	23.03	321.77	1.90	21.88
56	1.90	36.88	19.53	303.88	1.90	18.55
57	1.84	35.69	9.69	296.29	1.84	9.21
58	1.90	36.88	5.25	294.05	1.90	4.99
59	1.84	35.69	2.07	293.69	1.84	1.97
60	1.90	36.88	2.04	276.75	17.62	1.93
61	1.90	36.88	2.09	252.15	24.53	1.98
62	1.72	33.31	1.91	250.38	1.72	1.82
63	1.90	36.88	2.14	248.12	1.90	2.04
64	1.84	35.69	2.10	298.92	1.84	1.99
65	1.90	36.88	10.18	395.12	1.90	9.67
66	1.84	35.69	19.26	405.10	1.84	18.30
67	1.90	36.88	23.03	391.44	1.90	21.88
68	1.90	36.88	19.53	373.88	1.90	18.55
69	1.84	35.69	9.69	365.99	1.84	9.21
70	1.90	36.88	5.25	328.47	36.88	4.99
71	1.84	35.69	2.07	295.30	35.69	1.97
72	1.90	36.88	2.04	293.41	1.90	1.93
73	1.90	36.88	2.09	291.02	1.90	1.98
74	1.72	33.31	1.91	289.16	1.72	1.82
75	1.90	36.88	2.14	287.20	1.90	2.04
76	1.84	35.69	2.10	404.24	1.84	1.99
77	1.90	36.88	10.18	426.11	1.90	9.67
78	1.84	35.69	19.26	451.23	1.84	18.30
79	1.90	36.88	23.03	456.69	1.90	21.88
80	1.90	36.88	19.53	441.29	1.90	18.55
81	1.84	35.69	9.69	436.01	1.84	9.21
82	1.90	36.88	5.25	434.15	1.90	4.99
83	1.84	35.69	2.07	431.86	1.84	1.97
84	1.90	36.88	2.04	429.17	1.90	1.93
85	1.90	36.88	2.09	426.06	1.90	1.98
86	1.72	33.31	1.91	423.40	1.72	1.82
87	1.90	36.88	2.14	420.49	1.90	2.04
88	1.84	35.69	2.10	431.73	1.84	1.99
89	1.90	36.88	10.18	427.76	1.90	9.67
90	1.84	35.69	19.26	409.99	1.84	18.30
91	1.90	36.88	23.03	388.44	1.90	21.88
92	1.90	36.88	19.53	369.60	1.90	18.55
93	1.84	35.69	9.69	362.09	1.84	9.21
94	1.90	36.88	5.25	359.79	1.90	4.99
95	1.84	35.69	2.07	358.74	1.84	1.97
96	1.90	36.88	2.04	356.64	1.90	1.93

Appendix C: Compromise Solution (s = 100) for the Given Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

97	1.90	36.88	2.09	354.11	1.90	1.98
98	1.72	33.31	1.91	351.51	1.72	1.82
99	1.90	36.88	2.14	349.20	1.90	2.04
100	1.84	35.69	2.10	367.87	1.84	1.99
101	1.90	36.88	10.18	370.13	1.90	9.67
102	1.84	35.69	19.26	354.35	1.84	18.30
103	1.90	36.88	23.03	333.38	1.90	21.88
104	1.90	36.88	19.53	313.66	1.90	18.55
105	1.84	35.69	9.69	303.50	1.84	9.21
106	1.90	36.88	5.25	298.20	1.90	4.99
107	1.84	35.69	2.07	296.50	1.84	1.97
108	1.90	36.88	2.04	293.99	1.90	1.93
109	1.90	36.88	2.09	291.04	1.90	1.98
110	1.72	33.31	1.91	288.32	1.72	1.82
111	1.90	36.88	2.14	285.18	1.90	2.04
112	1.84	35.69	2.10	336.99	1.84	1.99
113	1.90	36.88	10.18	441.29	1.90	9.67
114	1.84	35.69	19.26	447.04	1.84	18.30
115	1.90	36.88	23.03	427.19	1.90	21.88
116	1.90	36.88	19.53	407.98	1.90	18.55
117	1.84	35.69	9.69	398.34	1.84	9.21
118	1.90	36.88	5.25	392.62	1.90	4.99
119	1.84	35.69	2.07	390.77	1.84	1.97
120	1.90	36.88	2.04	388.19	1.90	1.93
121	1.90	36.88	2.09	385.50	1.90	1.98
122	1.72	33.31	1.91	383.10	1.72	1.82
123	1.90	36.88	2.14	380.41	1.90	2.04
124	1.84	35.69	2.10	414.39	1.84	1.99
125	1.90	36.88	10.18	411.24	1.90	9.67
126	1.84	35.69	19.26	392.75	1.84	18.30
127	1.90	36.88	23.03	370.24	1.90	21.88
128	1.90	36.88	19.53	350.87	1.90	18.55
129	1.84	35.69	9.69	340.78	1.84	9.21
130	1.90	36.88	5.25	335.33	1.90	4.99
131	1.84	35.69	2.07	333.25	1.84	1.97
132	1.90	36.88	2.04	330.25	1.90	1.93
133	1.90	36.88	2.09	326.88	1.90	1.98
134	1.72	33.31	1.91	323.95	1.72	1.82
135	1.90	36.88	2.14	324.82	1.90	2.04
136	1.84	35.69	2.10	330.09	1.84	1.99
137	1.90	36.88	10.18	322.95	1.90	9.67
138	1.84	35.69	19.26	306.28	1.84	18.30
139	1.90	36.88	23.03	285.22	1.90	21.88
140	1.90	36.88	19.53	266.29	1.90	18.55
141	1.84	35.69	9.69	255.95	1.84	9.21
142	1.90	36.88	5.25	251.75	1.90	4.99
143	1.84	35.69	2.07	250.90	1.84	1.97
144	1.90	36.88	2.04	248.18	1.90	1.93
145	1.90	36.88	2.09	244.73	1.90	1.98
146	1.72	33.31	1.91	241.72	1.72	1.82
147	1.90	36.88	2.14	238.52	1.90	2.04
148	1.84	35.69	2.10	249.58	1.84	1.99
149	1.90	36.88	10.18	246.18	1.90	9.67
150	1.84	35.69	19.26	229.37	1.84	18.30
151	1.90	36.88	23.03	215.19	1.90	21.88
152	1.90	36.88	19.53	197.72	1.90	18.55
153	1.84	35.69	9.69	187.22	1.84	9.21
154	1.90	36.88	5.25	181.80	1.90	4.99
155	1.84	35.69	2.07	179.68	1.84	1.97
156	1.90	36.88	2.04	176.75	1.90	1.93
157	1.90	36.88	2.09	173.92	1.90	1.98

Appendix C: Compromise Solution (s = 100) for the Given Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

158	1.72	33.31	1.91	171.51	1.72	1.82
159	1.90	36.88	2.14	168.62	1.90	2.04
160	1.84	35.69	2.10	200.20	1.84	1.99
161	1.90	36.88	10.18	235.92	1.90	9.67
162	1.84	35.69	19.26	231.82	1.84	18.30
163	1.90	36.88	23.03	225.98	1.90	21.88
164	1.90	36.88	19.53	210.25	1.90	18.55
165	1.84	35.69	9.69	200.17	1.84	9.21
166	1.90	36.88	5.25	194.74	1.90	4.99
167	1.84	35.69	2.07	193.08	1.84	1.97
168	1.90	36.88	2.04	190.81	1.90	1.93
169	1.90	36.88	2.09	187.88	1.90	1.98
170	1.72	33.31	1.91	185.32	1.72	1.82
171	1.90	36.88	2.14	191.09	1.90	2.04
172	1.84	35.69	2.10	211.07	1.84	1.99
173	1.90	36.88	10.18	214.43	1.90	9.67
174	1.84	35.69	19.26	209.28	1.84	18.30
175	1.90	36.88	23.03	193.54	1.90	21.88
176	1.90	36.88	19.53	173.95	1.90	18.55
177	1.84	35.69	9.69	163.73	1.84	9.21
178	1.90	36.88	5.25	159.29	1.90	4.99
179	1.84	35.69	2.07	157.47	1.84	1.97
180	1.90	36.88	2.04	156.24	1.90	1.93

Appendix D GAMS Input File Code for the De Novo Reservoir System

```
**********************************************************************
*  This file provides the basic input data file into GAMS for the    *
*  De Novo Reservoir System.  The De Novo Reservoir System is        *
*  defined by the system constraints.  Eight objectives were used to*
*  create eight solutions: that which provides the minimum required *
*  active storage, minimum sum of storage deviations, compromise     *
*  solutions between two primary objectives (s = 1, s = 2, and       *
*  s = 100 cases, metaoptimum measured with respect to the de novo   *
*  reservoir system)                                                 *
*                                                                    *
*  The objective functions for each solution were substituted into   *
*  the constraint called OF..                                        *
*  The following equations provide a summary of each objective       *
*  function used with respect to the DE NOVO RESERVOIR SYSTEM.       *
*                                                                    *
*  1.  Minimization of the Required Active Storage                   *
*      OF..  OF1 = E = K;                                            *
*                                                                    *
*  2.  Minimization of the Sum of Storage Deviations                 *
*      OF..  OF2 = E = SUM(T,V(T)+U(T));                             *
*                                                                    *
*  3.  Compromise between 1. and 2., s = 1, de novo metaoptimum      *
*      OF..  DISTANCE=E= POWER(((K-194.4)/(439.10-194.4)),1)         *
*            +POWER(((OF2-9378.5)/(37684.90-9378.5)),1);             *
*      ( as given in the following data file )                       *
*                                                                    *
*  4.  Compromise between 1. and 2., s = 2, de novo metaoptimum      *
*      OF..  DISTANCE=E= POWER(((K-194.4)/(439.10-194.4)),2)         *
*            +POWER(((OF2-9378.5)/(37684.90-9378.5)),2);             *
*                                                                    *
*  5.  Compromise between 1. and 2., s = 100, de novo metaoptimum    *
*      OF..  DISTANCE=E= POWER(((K-194.4)/(439.10-194.4)),100)       *
*            +POWER(((OF2-9378.5)/(37684.90-9378.5)),100);           *
*                                                                    *
*                                                                    *
**********************************************************************


**********************************************************************
*  This routine is supplied the following input:                     *
*                                                                    *
*  15 years of monthly inflow in to the Shellmouth Reservoir         *
*  12 Monthly water supply targets                                   *
*  12 Monthly lower bounds on the water supply                       *
*  12 Storage targets based on the Shellmouth operating rule curve   *
*                                                                    *
**********************************************************************

OPTION ITERLIM = 50000;
OPTION RESLIM = 50000;
OPTION LIMROW = 0;
OPTION LIMCOL = 0;

SETS
  T time period in years /1*180/

FILE FO /D1.OUT/;

SCALARS LOWB lower bound on water supply;

LOWB=0.95;
```

```
PARAMETERS  INFLOW(T)   monthly inflow in to shellmouth reservoir
/       1     1.2                60    2.62                     119    1.96
        2     1.1                61    1.91                     120    1.25
        3     2.3                62    1.76                     121     1.2
        4   49.37                63    1.68                     122    1.13
        5   37.08                64   54.64                     123    1.25
        6   14.19                65  107.77                     124   37.81
        7    7.55                66   30.11                     125    8.42
        8    2.45                67   10.13                     126    1.65
        9    1.88                68    2.89                     127    1.27
       10    2.65                69    3.16                     128    1.08
       11    2.31                70    4.34                     129    0.96
       12     1.6                71    4.49                     130    1.44
       13    1.57                72    1.95                     131    1.73
       14     1.4                73     1.5                     132    0.84
       15    1.23                74    1.67                     133    0.52
       16   85.78                75    1.98                     134     0.6
       17   26.03                76  120.87                     135    4.81
       18   11.06                77   33.44                     136     9.1
       19    5.96                78   45.26                     137    4.43
       20    3.71                79   29.24                     138    3.47
       21    0.75                80    5.05                     139    2.72
       22     1.9                81    5.77                     140    1.52
       23    2.37                82    5.03                     141    0.71
       24       2                83    1.52                     142    2.69
       25    1.77                84    1.15                     143    2.96
       26    1.39                85    0.77                     144    1.12
       27    1.87                86    0.88                     145    0.43
       28    78.6                87    1.02                     146    0.53
       29    76.7                88   15.08                     147    0.73
       30    7.29                89     7.6                     148    14.9
       31    3.49                90    2.37                     149    8.17
       32    1.23                91    2.23                     150    3.33
       33    0.66                92    1.61                     151     9.6
       34    0.96                93    3.54                     152    2.98
       35    1.18                94    4.59                     153    0.55
       36    0.72                95    2.76                     154    1.47
       37    0.38                96    1.74                     155    1.69
       38    0.37                97    1.35                     156     0.9
       39    1.56                98    0.93                     157    1.06
       40    9.93                99    1.63                     158    1.12
       41    7.91               100   22.51                     159    1.05
       42   11.87               101   13.83                     160   35.42
       43   11.32               102    4.35                     161   47.29
       44    2.09               103    2.82                     162   16.03
       45    1.92               104    0.73                     163   17.95
       46    1.92               105    0.89                     164    4.72
       47    1.88               106    1.59                     165    0.97
       48    1.75               107    2.11                     166    1.46
       49    1.23               108    1.32                     167    2.15
       50    1.15               109    0.94                     168    1.56
       51    1.24               110    0.81                     169    0.96
       52   65.33               111     0.8                     170    0.97
       53   92.84               112   55.64                     171    9.71
       54   40.24               113  115.88                     172   23.81
       55    4.85               114   25.88                     173   14.93
       56    2.57               115    3.94                     174   14.99
       57    3.45               116    1.24                     175    8.04
       58    4.65               117    1.41                     176    0.87
       59    3.45               118    1.17                     177    0.83
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      178    2.44                      179    1.99                     180    2.61/
STAR(T)  monthly reservoir target storage
/       1  252.15                       60  276.75                     119  303.81
        2  225.09                       61  252.15                     120  276.75
        3   196.8                       62  225.09                     121  252.15
        4  276.75                       63   196.8                     122  225.09
        5     396                       64  276.75                     123   196.8
        6     396                       65     396                     124  276.75
        7     396                       66     396                     125     396
        8     396                       67     396                     126     396
        9     396                       68     396                     127     396
       10  338.25                       69     396                     128     396
       11  303.81                       70  338.25                     129     396
       12  276.75                       71  303.81                     130  338.25
       13  252.15                       72  276.75                     131  303.81
       14  225.09                       73  252.15                     132  276.75
       15   196.8                       74  225.09                     133  252.15
       16  276.75                       75   196.8                     134  225.09
       17     396                       76  276.75                     135   196.8
       18     396                       77     396                     136  276.75
       19     396                       78     396                     137     396
       20     396                       79     396                     138     396
       21     396                       80     396                     139     396
       22  338.25                       81     396                     140     396
       23  303.81                       82  338.25                     141     396
       24  276.75                       83  303.81                     142  338.25
       25  252.15                       84  276.75                     143  303.81
       26  225.09                       85  252.15                     144  276.75
       27   196.8                       86  225.09                     145  252.15
       28  276.75                       87   196.8                     146  225.09
       29     396                       88  276.75                     147   196.8
       30     396                       89     396                     148  276.75
       31     396                       90     396                     149     396
       32     396                       91     396                     150     396
       33     396                       92     396                     151     396
       34  338.25                       93     396                     152     396
       35  303.81                       94  338.25                     153     396
       36  276.75                       95  303.81                     154  338.25
       37  252.15                       96  276.75                     155  303.81
       38  225.09                       97  252.15                     156  276.75
       39   196.8                       98  225.09                     157  252.15
       40  276.75                       99   196.8                     158  225.09
       41     396                      100  276.75                     159   196.8
       42     396                      101     396                     160  276.75
       43     396                      102     396                     161     396
       44     396                      103     396                     162     396
       45     396                      104     396                     163     396
       46  338.25                      105     396                     164     396
       47  303.81                      106  338.25                     165     396
       48  276.75                      107  303.81                     166  338.25
       49  252.15                      108  276.75                     167  303.81
       50  225.09                      109  252.15                     168  276.75
       51   196.8                      110  225.09                     169  252.15
       52  276.75                      111   196.8                     170  225.09
       53     396                      112  276.75                     171   196.8
       54     396                      113     396                     172  276.75
       55     396                      114     396                     173     396
       56     396                      115     396                     174     396
       57     396                      116     396                     175     396
       58  338.25                      117     396                     176     396
       59  303.81                      118  338.25                     177     396
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     178  338.25              179  303.81               180  276.75/
DTAR(T)  monthly demand target level
/       1 2.089152              60 2.035584             119  2.0736
        2 1.911168              61 2.089152             120 2.035584
        3  2.14272              62 1.911168             121 2.089152
        4  2.09952              63  2.14272             122 1.911168
        5 10.17792              64  2.09952             123 2.14272
        6 19.25856              65 10.17792             124 2.09952
        7 23.03424              66 19.25856             125 10.17792
        8 19.52554              67 23.03424             126 19.25856
        9  9.69408              68 19.52554             127 23.03424
       10  5.249664             69   9.69408            128 19.52554
       11    2.0736             70  5.249664            129 9.69408
       12  2.035584             71   2.0736             130 5.249664
       13  2.089152             72 2.035584             131  2.0736
       14  1.911168             73 2.089152             132 2.035584
       15   2.14272             74 1.911168             133 2.089152
       16     2.09952           75  2.14272             134 1.911168
       17   10.17792            76  2.09952             135 2.14272
       18   19.25856            77 10.17792             136 2.09952
       19   23.03424            78 19.25856             137 10.17792
       20   19.52554            79  23.03424            138 19.25856
       21   9.69408             80  19.52554            139 23.03424
       22  5.249664             81   9.69408            140 19.52554
       23     2.0736            82  5.249664            141 9.69408
       24  2.035584             83    2.0736            142 5.249664
       25  2.089152             84  2.035584            143  2.0736
       26  1.911168             85  2.089152            144 2.035584
       27   2.14272             86  1.911168            145 2.089152
       28   2.09952             87   2.14272            146 1.911168
       29  10.17792             88   2.09952            147 2.14272
       30   19.25856            89  10.17792            148 2.09952
       31  23.03424             90 19.25856             149 10.17792
       32  19.52554             91 23.03424             150 19.25856
       33   9.69408             92  19.52554            151 23.03424
       34  5.249664             93   9.69408            152 19.52554
       35    2.0736             94  5.249664            153 9.69408
       36  2.035584             95    2.0736            154 5.249664
       37 2.089152              96  2.035584            155  2.0736
       38 1.911168              97  2.089152            156 2.035584
       39   2.14272             98  1.911168            157 2.089152
       40   2.09952             99   2.14272            158 1.911168
       41  10.17792            100  2.09952             159 2.14272
       42  19.25856            101  10.17792            160 2.09952
       43  23.03424            102  19.25856            161 10.17792
       44  19.52554            103  23.03424            162 19.25856
       45   9.69408            104  19.52554            163 23.03424
       46  5.249664            105  9.69408             164 19.52554
       47    2.0736            106  5.249664            165 9.69408
       48  2.035584            107   2.0736             166 5.249664
       49  2.089152            108  2.035584            167  2.0736
       50    1.911168          109  2.089152            168 2.035584
       51   2.14272            110  1.911168            169 2.089152
       52   2.09952            111  2.14272             170 1.911168
       53  10.17792            112  2.09952             171 2.14272
       54  19.25856            113 10.17792             172 2.09952
       55  23.03424            114 19.25856             173 10.17792
       56  19.52554            115 23.03424             174 19.25856
       57   9.69408            116 19.52554             175 23.03424
       58  5.249664            117 9.69408              176 19.52554
       59    2.0736            118 5.249664             177 9.69408
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     178 5.249664             179  2.0736               180  2.035584/;

VARIABLES
OF2  objective function two
START  starting storage of the reservoir
S(T) monthly reservoir storage
R(T) monthly reservoir downstream release
WS(T) monthly reservoir water supply level
RLOW(T)  monthly lower release bound
RHIGH(T)  monthly upper release bound
SDEAD  minimum storage
SSPIL  maximum storage
UP(T)  monthly upper water supply bound
BASE1
BASE2
BASE3
BASE4
BASE5
BASE6
BASE7
BASE8
BASE9
BASE10
BASE11
BASE12
RXBASE1
RXBASE2
RXBASE3
RXBASE4
RXBASE5
RXBASE6
RXBASE7
RXBASE8
RXBASE9
RXBASE10
RXBASE11
RXBASE12
UPWSBASE1
UPWSBASE2
UPWSBASE3
UPWSBASE4
UPWSBASE5
UPWSBASE6
UPWSBASE7
UPWSBASE8
UPWSBASE9
UPWSBASE10
UPWSBASE11
UPWSBASE12
K the required active storage of the reservoir
V(T) positive storage deviation
U(T) negative storage deviation
DISTANCE

POSITIVE VARIABLES OF2,START,S(T),R(T),WS(T),K,V(T),U(T);
POSITIVE VARIABLES RLOW(T),RHIGH(T),SDEAD,SSPIL,UB(T);
POSITIVE VARIABLES
BASE1,BASE2,BASE3,BASE4,BASE5,BASE6,BASE7,BASE8,BASE9,BASE10,BASE11,BASE
12;
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POSITIVE VARIABLES
RXBASE1,RXBASE2,RXBASE3,RXBASE4,RXBASE5,RXBASE6,RXBASE7,RXBASE8,RXBASE9,
RXBASE10,RXBASE11,RXBASE12;
POSITIVE VARIABLES
UPWSBASE1,UPWSBASE2,UPWSBASE3,UPWSBASE4,UPWSBASE5,UPWSBASE6,UPWSBASE7,UP
WSBASE8,UPWSBASE9,UPWSBASE10,UPWSBASE11,UPWSBASE12;

K.UP=439.10;
OF2.UP=37684.90;

K.LO=194.4;
OF2.LO=9378.5;

S.UP(T)=1000;
START.UP=1000;
R.UP(T)=1000;
WS.UP(T)=1000;
RLOW.UP(T)=1000;
RHIGH.UP(T)=1000;
SDEAD.UP=1000;
SSPIL.UP=5000;
UB.UP(T)=100;
V.UP(T)=1000;
U.UP(T)=1000;

EQUATIONS
CONTIN(T)       continuity equation
CONTINF(T)      continuity of inflow
RAS(T)          required active storage must exceed monthly storage
LOWREL(T)       minimum release bounds
RN1(T)                    RN32(T)                   RN63(T)
RN2(T)                    RN33(T)                   RN64(T)
RN3(T)                    RN34(T)                   RN65(T)
RN4(T)                    RN35(T)                   RN66(T)
RN5(T)                    RN36(T)                   RN67(T)
RN6(T)                    RN37(T)                   RN68(T)
RN7(T)                    RN38(T)                   RN69(T)
RN8(T)                    RN39(T)                   RN70(T)
RN9(T)                    RN40(T)                   RN71(T)
RN10(T)                   RN41(T)                   RN72(T)
RN11(T)                   RN42(T)                   RN73(T)
RN12(T)                   RN43(T)                   RN74(T)
RN13(T)                   RN44(T)                   RN75(T)
RN14(T)                   RN45(T)                   RN76(T)
RN15(T)                   RN46(T)                   RN77(T)
RN16(T)                   RN47(T)                   RN78(T)
RN17(T)                   RN48(T)                   RN79(T)
RN18(T)                   RN49(T)                   RN80(T)
RN19(T)                   RN50(T)                   RN81(T)
RN20(T)                   RN51(T)                   RN82(T)
RN21(T)                   RN52(T)                   RN83(T)
RN22(T)                   RN53(T)                   RN84(T)
RN23(T)                   RN54(T)                   RN85(T)
RN24(T)                   RN55(T)                   RN86(T)
RN25(T)                   RN56(T)                   RN87(T)
RN26(T)                   RN57(T)                   RN88(T)
RN27(T)                   RN58(T)                   RN89(T)
RN28(T)                   RN59(T)                   RN90(T)
RN29(T)                   RN60(T)                   RN91(T)
RN30(T)                   RN61(T)                   RN92(T)
RN31(T)                   RN62(T)                   RN93(T)
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UPWS95(T)
UPWS96(T)
UPWS97(T)
UPWS98(T)
UPWS99(T)
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UPWS100(T)                  UPWS127(T)                  UPWS154(T)
UPWS101(T)                  UPWS128(T)                  UPWS155(T)
UPWS102(T)                  UPWS129(T)                  UPWS156(T)
UPWS103(T)                  UPWS130(T)                  UPWS157(T)
UPWS104(T)                  UPWS131(T)                  UPWS158(T)
UPWS105(T)                  UPWS132(T)                  UPWS159(T)
UPWS106(T)                  UPWS133(T)                  UPWS160(T)
UPWS107(T)                  UPWS134(T)                  UPWS161(T)
UPWS108(T)                  UPWS135(T)                  UPWS162(T)
UPWS109(T)                  UPWS136(T)                  UPWS163(T)
UPWS110(T)                  UPWS137(T)                  UPWS164(T)
UPWS111(T)                  UPWS138(T)                  UPWS165(T)
UPWS112(T)                  UPWS139(T)                  UPWS166(T)
UPWS113(T)                  UPWS140(T)                  UPWS167(T)
UPWS114(T)                  UPWS141(T)                  UPWS168(T)
UPWS115(T)                  UPWS142(T)                  UPWS169(T)
UPWS116(T)                  UPWS143(T)                  UPWS170(T)
UPWS117(T)                  UPWS144(T)                  UPWS171(T)
UPWS118(T)                  UPWS145(T)                  UPWS172(T)
UPWS119(T)                  UPWS146(T)                  UPWS173(T)
UPWS120(T)                  UPWS147(T)                  UPWS174(T)
UPWS121(T)                  UPWS148(T)                  UPWS175(T)
UPWS122(T)                  UPWS149(T)                  UPWS176(T)
UPWS123(T)                  UPWS150(T)                  UPWS177(T)
UPWS124(T)                  UPWS151(T)                  UPWS178(T)
UPWS125(T)                  UPWS152(T)                  UPWS179(T)
UPWS126(T)                  UPWS153(T)                  UPWS180(T)

HIGHREL(T)        maximum release bounds
MINSTO(T)        minimum storage bound
MINWS(T)         minimum water supply bounds
MAXWS(T)         maximum water supply bounds
MAXSTO(T)        maximum storage bound
STOTAR(T)        storage target deviation constraints
SECOND           the sum of storage deviations
OF               distance to the metaoptimum;

CONTIN(T)..  S(T)=E=[START+INFLOW(T)-R(T)-WS(T)]$(ORD(T) EQ 1)
                  + [S(T-1)+INFLOW(T)-R(T)-WS(T)]$(ORD(T) GT 1);
CONTINF(T)$(ORD(T) EQ 180)..  START=E=S(T);
RAS(T)..  S(T)=L=K;
LOWREL(T)..  RLOW(T)=L=R(T);


RN1(T)$(ORD(T) EQ 1)..                RN9(T)$(ORD(T) EQ 97)..
RLOW(T)=E=BASE1;                      RLOW(T)=E=BASE1;
RN2(T)$(ORD(T) EQ 13)..               RN10(T)$(ORD(T) EQ 109)..
RLOW(T)=E=BASE1;                      RLOW(T)=E=BASE1;
RN3(T)$(ORD(T) EQ 25)..               RN11(T)$(ORD(T) EQ 121)..
RLOW(T)=E=BASE1;                      RLOW(T)=E=BASE1;
RN4(T)$(ORD(T) EQ 37)..               RN12(T)$(ORD(T) EQ 133)..
RLOW(T)=E=BASE1;                      RLOW(T)=E=BASE1;
RN5(T)$(ORD(T) EQ 49)..               RN13(T)$(ORD(T) EQ 145)..
RLOW(T)=E=BASE1;                      RLOW(T)=E=BASE1;
RN6(T)$(ORD(T) EQ 61)..               RN14(T)$(ORD(T) EQ 157)..
RLOW(T)=E=BASE1;                      RLOW(T)=E=BASE1;
RN7(T)$(ORD(T) EQ 73)..               RN15(T)$(ORD(T) EQ 169)..
RLOW(T)=E=BASE1;                      RLOW(T)=E=BASE1;
RN8(T)$(ORD(T) EQ 85)..               RN16(T)$(ORD(T) EQ 2)..
RLOW(T)=E=BASE1;                      RLOW(T)=E=BASE2;
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RN17(T)$(ORD(T) EQ 14)..
RLOW(T)=E=BASE2;
RN18(T)$(ORD(T) EQ 26)..
RLOW(T)=E=BASE2;
RN19(T)$(ORD(T) EQ 38)..
RLOW(T)=E=BASE2;
RN20(T)$(ORD(T) EQ 50)..
RLOW(T)=E=BASE2;
RN21(T)$(ORD(T) EQ 62)..
RLOW(T)=E=BASE2;
RN22(T)$(ORD(T) EQ 74)..
RLOW(T)=E=BASE2;
RN23(T)$(ORD(T) EQ 86)..
RLOW(T)=E=BASE2;
RN24(T)$(ORD(T) EQ 98)..
RLOW(T)=E=BASE2;
RN25(T)$(ORD(T) EQ 110)..
RLOW(T)=E=BASE2;
RN26(T)$(ORD(T) EQ 122)..
RLOW(T)=E=BASE2;
RN27(T)$(ORD(T) EQ 134)..
RLOW(T)=E=BASE2;
RN28(T)$(ORD(T) EQ 146)..
RLOW(T)=E=BASE2;
RN29(T)$(ORD(T) EQ 158)..
RLOW(T)=E=BASE2;
RN30(T)$(ORD(T) EQ 170)..
RLOW(T)=E=BASE2;
RN31(T)$(ORD(T) EQ 3)..
RLOW(T)=E=BASE3;
RN32(T)$(ORD(T) EQ 15)..
RLOW(T)=E=BASE3;
RN33(T)$(ORD(T) EQ 27)..
RLOW(T)=E=BASE3;
RN34(T)$(ORD(T) EQ 39)..
RLOW(T)=E=BASE3;
RN35(T)$(ORD(T) EQ 51)..
RLOW(T)=E=BASE3;
RN36(T)$(ORD(T) EQ 63)..
RLOW(T)=E=BASE3;
RN37(T)$(ORD(T) EQ 75)..
RLOW(T)=E=BASE3;
RN38(T)$(ORD(T) EQ 87)..
RLOW(T)=E=BASE3;
RN39(T)$(ORD(T) EQ 99)..
RLOW(T)=E=BASE3;
RN40(T)$(ORD(T) EQ 111)..
RLOW(T)=E=BASE3;
RN41(T)$(ORD(T) EQ 123)..
RLOW(T)=E=BASE3;
RN42(T)$(ORD(T) EQ 135)..
RLOW(T)=E=BASE3;
RN43(T)$(ORD(T) EQ 147)..
RLOW(T)=E=BASE3;
RN44(T)$(ORD(T) EQ 159)..
RLOW(T)=E=BASE3;
RN45(T)$(ORD(T) EQ 171)..
RLOW(T)=E=BASE3;
RN46(T)$(ORD(T) EQ 4)..
RLOW(T)=E=BASE4;
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RN47(T)$(ORD(T) EQ 16)..
RLOW(T)=E=BASE4;
RN48(T)$(ORD(T) EQ 28)..
RLOW(T)=E=BASE4;
RN49(T)$(ORD(T) EQ 40)..
RLOW(T)=E=BASE4;
RN50(T)$(ORD(T) EQ 52)..
RLOW(T)=E=BASE4;
RN51(T)$(ORD(T) EQ 64)..
RLOW(T)=E=BASE4;
RN52(T)$(ORD(T) EQ 76)..
RLOW(T)=E=BASE4;
RN53(T)$(ORD(T) EQ 88)..
RLOW(T)=E=BASE4;
RN54(T)$(ORD(T) EQ 100)..
RLOW(T)=E=BASE4;
RN55(T)$(ORD(T) EQ 112)..
RLOW(T)=E=BASE4;
RN56(T)$(ORD(T) EQ 124)..
RLOW(T)=E=BASE4;
RN57(T)$(ORD(T) EQ 136)..
RLOW(T)=E=BASE4;
RN58(T)$(ORD(T) EQ 148)..
RLOW(T)=E=BASE4;
RN59(T)$(ORD(T) EQ 160)..
RLOW(T)=E=BASE4;
RN60(T)$(ORD(T) EQ 172)..
RLOW(T)=E=BASE4;
RN61(T)$(ORD(T) EQ 5)..
RLOW(T)=E=BASE5;
RN62(T)$(ORD(T) EQ 17)..
RLOW(T)=E=BASE5;
RN63(T)$(ORD(T) EQ 29)..
RLOW(T)=E=BASE5;
RN64(T)$(ORD(T) EQ 41)..
RLOW(T)=E=BASE5;
RN65(T)$(ORD(T) EQ 53)..
RLOW(T)=E=BASE5;
RN66(T)$(ORD(T) EQ 65)..
RLOW(T)=E=BASE5;
RN67(T)$(ORD(T) EQ 77)..
RLOW(T)=E=BASE5;
RN68(T)$(ORD(T) EQ 89)..
RLOW(T)=E=BASE5;
RN69(T)$(ORD(T) EQ 101)..
RLOW(T)=E=BASE5;
RN70(T)$(ORD(T) EQ 113)..
RLOW(T)=E=BASE5;
RN71(T)$(ORD(T) EQ 125)..
RLOW(T)=E=BASE5;
RN72(T)$(ORD(T) EQ 137)..
RLOW(T)=E=BASE5;
RN73(T)$(ORD(T) EQ 149)..
RLOW(T)=E=BASE5;
RN74(T)$(ORD(T) EQ 161)..
RLOW(T)=E=BASE5;
RN75(T)$(ORD(T) EQ 173)..
RLOW(T)=E=BASE5;
RN76(T)$(ORD(T) EQ 6)..
RLOW(T)=E=BASE6;
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```
RN77(T)$(ORD(T)  EQ 18)..
RLOW(T)=E=BASE6;
RN78(T)$(ORD(T)  EQ 30)..
RLOW(T)=E=BASE6;
RN79(T)$(ORD(T)  EQ 42)..
RLOW(T)=E=BASE6;
RN80(T)$(ORD(T)  EQ 54)..
RLOW(T)=E=BASE6;
RN81(T)$(ORD(T)  EQ 66)..
RLOW(T)=E=BASE6;
RN82(T)$(ORD(T)  EQ 78)..
RLOW(T)=E=BASE6;
RN83(T)$(ORD(T)  EQ 90)..
RLOW(T)=E=BASE6;
RN84(T)$(ORD(T)  EQ 102)..
RLOW(T)=E=BASE6;
RN85(T)$(ORD(T)  EQ 114)..
RLOW(T)=E=BASE6;
RN86(T)$(ORD(T)  EQ 126)..
RLOW(T)=E=BASE6;
RN87(T)$(ORD(T)  EQ 138)..
RLOW(T)=E=BASE6;
RN88(T)$(ORD(T)  EQ 150)..
RLOW(T)=E=BASE6;
RN89(T)$(ORD(T)  EQ 162)..
RLOW(T)=E=BASE6;
RN90(T)$(ORD(T)  EQ 174)..
RLOW(T)=E=BASE6;
RN91(T)$(ORD(T)  EQ 7)..
RLOW(T)=E=BASE7;
RN92(T)$(ORD(T)  EQ 19)..
RLOW(T)=E=BASE7;
RN93(T)$(ORD(T)  EQ 31)..
RLOW(T)=E=BASE7;
RN94(T)$(ORD(T)  EQ 43)..
RLOW(T)=E=BASE7;
RN95(T)$(ORD(T)  EQ 55)..
RLOW(T)=E=BASE7;
RN96(T)$(ORD(T)  EQ 67)..
RLOW(T)=E=BASE7;
RN97(T)$(ORD(T)  EQ 79)..
RLOW(T)=E=BASE7;
RN98(T)$(ORD(T)  EQ 91)..
RLOW(T)=E=BASE7;
RN99(T)$(ORD(T)  EQ 103)..
RLOW(T)=E=BASE7;
RN100(T)$(ORD(T)  EQ 115)..
RLOW(T)=E=BASE7;
RN101(T)$(ORD(T)  EQ 127)..
RLOW(T)=E=BASE7;
RN102(T)$(ORD(T)  EQ 139)..
RLOW(T)=E=BASE7;
RN103(T)$(ORD(T)  EQ 151)..
RLOW(T)=E=BASE7;
RN104(T)$(ORD(T)  EQ 163)..
RLOW(T)=E=BASE7;
RN105(T)$(ORD(T)  EQ 175)..
RLOW(T)=E=BASE7;
RN106(T)$(ORD(T)  EQ 8)..
RLOW(T)=E=BASE8;
RN107(T)$(ORD(T)  EQ 20)..
RLOW(T)=E=BASE8;
RN108(T)$(ORD(T)  EQ 32)..
RLOW(T)=E=BASE8;
RN109(T)$(ORD(T)  EQ 44)..
RLOW(T)=E=BASE8;
RN110(T)$(ORD(T)  EQ 56)..
RLOW(T)=E=BASE8;
RN111(T)$(ORD(T)  EQ 68)..
RLOW(T)=E=BASE8;
RN112(T)$(ORD(T)  EQ 80)..
RLOW(T)=E=BASE8;
RN113(T)$(ORD(T)  EQ 92)..
RLOW(T)=E=BASE8;
RN114(T)$(ORD(T)  EQ 104)..
RLOW(T)=E=BASE8;
RN115(T)$(ORD(T)  EQ 116)..
RLOW(T)=E=BASE8;
RN116(T)$(ORD(T)  EQ 128)..
RLOW(T)=E=BASE8;
RN117(T)$(ORD(T)  EQ 140)..
RLOW(T)=E=BASE8;
RN118(T)$(ORD(T)  EQ 152)..
RLOW(T)=E=BASE8;
RN119(T)$(ORD(T)  EQ 164)..
RLOW(T)=E=BASE8;
RN120(T)$(ORD(T)  EQ 176)..
RLOW(T)=E=BASE8;
RN121(T)$(ORD(T)  EQ 9)..
RLOW(T)=E=BASE9;
RN122(T)$(ORD(T)  EQ 21)..
RLOW(T)=E=BASE9;
RN123(T)$(ORD(T)  EQ 33)..
RLOW(T)=E=BASE9;
RN124(T)$(ORD(T)  EQ 45)..
RLOW(T)=E=BASE9;
RN125(T)$(ORD(T)  EQ 57)..
RLOW(T)=E=BASE9;
RN126(T)$(ORD(T)  EQ 69)..
RLOW(T)=E=BASE9;
RN127(T)$(ORD(T)  EQ 81)..
RLOW(T)=E=BASE9;
RN128(T)$(ORD(T)  EQ 93)..
RLOW(T)=E=BASE9;
RN129(T)$(ORD(T)  EQ 105)..
RLOW(T)=E=BASE9;
RN130(T)$(ORD(T)  EQ 117)..
RLOW(T)=E=BASE9;
RN131(T)$(ORD(T)  EQ 129)..
RLOW(T)=E=BASE9;
RN132(T)$(ORD(T)  EQ 141)..
RLOW(T)=E=BASE9;
RN133(T)$(ORD(T)  EQ 153)..
RLOW(T)=E=BASE9;
RN134(T)$(ORD(T)  EQ 165)..
RLOW(T)=E=BASE9;
RN135(T)$(ORD(T)  EQ 177)..
RLOW(T)=E=BASE9;
RN136(T)$(ORD(T)  EQ 10)..
RLOW(T)=E=BASE10;
```

```
RN137(T)$(ORD(T) EQ 22)..
RLOW(T)=E=BASE10;
RN138(T)$(ORD(T) EQ 34)..
RLOW(T)=E=BASE10;
RN139(T)$(ORD(T) EQ 46)..
RLOW(T)=E=BASE10;
RN140(T)$(ORD(T) EQ 58)..
RLOW(T)=E=BASE10;
RN141(T)$(ORD(T) EQ 70)..
RLOW(T)=E=BASE10;
RN142(T)$(ORD(T) EQ 82)..
RLOW(T)=E=BASE10;
RN143(T)$(ORD(T) EQ 94)..
RLOW(T)=E=BASE10;
RN144(T)$(ORD(T) EQ 106)..
RLOW(T)=E=BASE10;
RN145(T)$(ORD(T) EQ 118)..
RLOW(T)=E=BASE10;
RN146(T)$(ORD(T) EQ 130)..
RLOW(T)=E=BASE10;
RN147(T)$(ORD(T) EQ 142)..
RLOW(T)=E=BASE10;
RN148(T)$(ORD(T) EQ 154)..
RLOW(T)=E=BASE10;
RN149(T)$(ORD(T) EQ 166)..
RLOW(T)=E=BASE10;
RN150(T)$(ORD(T) EQ 178)..
RLOW(T)=E=BASE10;
RN151(T)$(ORD(T) EQ 11)..
RLOW(T)=E=BASE11;
RN152(T)$(ORD(T) EQ 23)..
RLOW(T)=E=BASE11;
RN153(T)$(ORD(T) EQ 35)..
RLOW(T)=E=BASE11;
RN154(T)$(ORD(T) EQ 47)..
RLOW(T)=E=BASE11;
RN155(T)$(ORD(T) EQ 59)..
RLOW(T)=E=BASE11;
RN156(T)$(ORD(T) EQ 71)..
RLOW(T)=E=BASE11;
RN157(T)$(ORD(T) EQ 83)..
RLOW(T)=E=BASE11;
RN158(T)$(ORD(T) EQ 95)..
RLOW(T)=E=BASE11;
RN159(T)$(ORD(T) EQ 107)..
RLOW(T)=E=BASE11;
RN160(T)$(ORD(T) EQ 119)..
RLOW(T)=E=BASE11;
RN161(T)$(ORD(T) EQ 131)..
RLOW(T)=E=BASE11;
RN162(T)$(ORD(T) EQ 143)..
RLOW(T)=E=BASE11;
RN163(T)$(ORD(T) EQ 155)..
RLOW(T)=E=BASE11;
RN164(T)$(ORD(T) EQ 167)..
RLOW(T)=E=BASE11;
RN165(T)$(ORD(T) EQ 179)..
RLOW(T)=E=BASE11;
RN166(T)$(ORD(T) EQ 12)..
RLOW(T)=E=BASE12;
RN167(T)$(ORD(T) EQ 24)..
RLOW(T)=E=BASE12;
RN168(T)$(ORD(T) EQ 36)..
RLOW(T)=E=BASE12;
RN169(T)$(ORD(T) EQ 48)..
RLOW(T)=E=BASE12;
RN170(T)$(ORD(T) EQ 60)..
RLOW(T)=E=BASE12;
RN171(T)$(ORD(T) EQ 72)..
RLOW(T)=E=BASE12;
RN172(T)$(ORD(T) EQ 84)..
RLOW(T)=E=BASE12;
RN173(T)$(ORD(T) EQ 96)..
RLOW(T)=E=BASE12;
RN174(T)$(ORD(T) EQ 108)..
RLOW(T)=E=BASE12;
RN175(T)$(ORD(T) EQ 120)..
RLOW(T)=E=BASE12;
RN176(T)$(ORD(T) EQ 132)..
RLOW(T)=E=BASE12;
RN177(T)$(ORD(T) EQ 144)..
RLOW(T)=E=BASE12;
RN178(T)$(ORD(T) EQ 156)..
RLOW(T)=E=BASE12;
RN179(T)$(ORD(T) EQ 168)..
RLOW(T)=E=BASE12;
RN180(T)$(ORD(T) EQ 180)..
RLOW(T)=E=BASE12;
RX1(T)$(ORD(T) EQ 1)..
RHIGH(T)=E=RXBASE1;
RX2(T)$(ORD(T) EQ 13)..
RHIGH(T)=E=RXBASE1;
RX3(T)$(ORD(T) EQ 25)..
RHIGH(T)=E=RXBASE1;
RX4(T)$(ORD(T) EQ 37)..
RHIGH(T)=E=RXBASE1;
RX5(T)$(ORD(T) EQ 49)..
RHIGH(T)=E=RXBASE1;
RX6(T)$(ORD(T) EQ 61)..
RHIGH(T)=E=RXBASE1;
RX7(T)$(ORD(T) EQ 73)..
RHIGH(T)=E=RXBASE1;
RX8(T)$(ORD(T) EQ 85)..
RHIGH(T)=E=RXBASE1;
RX9(T)$(ORD(T) EQ 97)..
RHIGH(T)=E=RXBASE1;
RX10(T)$(ORD(T) EQ 109)..
RHIGH(T)=E=RXBASE1;
RX11(T)$(ORD(T) EQ 121)..
RHIGH(T)=E=RXBASE1;
RX12(T)$(ORD(T) EQ 133)..
RHIGH(T)=E=RXBASE1;
RX13(T)$(ORD(T) EQ 145)..
RHIGH(T)=E=RXBASE1;
RX14(T)$(ORD(T) EQ 157)..
RHIGH(T)=E=RXBASE1;
RX15(T)$(ORD(T) EQ 169)..
RHIGH(T)=E=RXBASE1;
RX16(T)$(ORD(T) EQ 2)..
RHIGH(T)=E=RXBASE2;
```

```
RX17(T)$(ORD(T) EQ 14)..
RHIGH(T)=E=RXBASE2;
RX18(T)$(ORD(T) EQ 26)..
RHIGH(T)=E=RXBASE2;
RX19(T)$(ORD(T) EQ 38)..
RHIGH(T)=E=RXBASE2;
RX20(T)$(ORD(T) EQ 50)..
RHIGH(T)=E=RXBASE2;
RX21(T)$(ORD(T) EQ 62)..
RHIGH(T)=E=RXBASE2;
RX22(T)$(ORD(T) EQ 74)..
RHIGH(T)=E=RXBASE2;
RX23(T)$(ORD(T) EQ 86)..
RHIGH(T)=E=RXBASE2;
RX24(T)$(ORD(T) EQ 98)..
RHIGH(T)=E=RXBASE2;
RX25(T)$(ORD(T) EQ 110)..
RHIGH(T)=E=RXBASE2;
RX26(T)$(ORD(T) EQ 122)..
RHIGH(T)=E=RXBASE2;
RX27(T)$(ORD(T) EQ 134)..
RHIGH(T)=E=RXBASE2;
RX28(T)$(ORD(T) EQ 146)..
RHIGH(T)=E=RXBASE2;
RX29(T)$(ORD(T) EQ 158)..
RHIGH(T)=E=RXBASE2;
RX30(T)$(ORD(T) EQ 170)..
RHIGH(T)=E=RXBASE2;
RX31(T)$(ORD(T) EQ 3)..
RHIGH(T)=E=RXBASE3;
RX32(T)$(ORD(T) EQ 15)..
RHIGH(T)=E=RXBASE3;
RX33(T)$(ORD(T) EQ 27)..
RHIGH(T)=E=RXBASE3;
RX34(T)$(ORD(T) EQ 39)..
RHIGH(T)=E=RXBASE3;
RX35(T)$(ORD(T) EQ 51)..
RHIGH(T)=E=RXBASE3;
RX36(T)$(ORD(T) EQ 63)..
RHIGH(T)=E=RXBASE3;
RX37(T)$(ORD(T) EQ 75)..
RHIGH(T)=E=RXBASE3;
RX38(T)$(ORD(T) EQ 87)..
RHIGH(T)=E=RXBASE3;
RX39(T)$(ORD(T) EQ 99)..
RHIGH(T)=E=RXBASE3;
RX40(T)$(ORD(T) EQ 111)..
RHIGH(T)=E=RXBASE3;
RX41(T)$(ORD(T) EQ 123)..
RHIGH(T)=E=RXBASE3;
RX42(T)$(ORD(T) EQ 135)..
RHIGH(T)=E=RXBASE3;
RX43(T)$(ORD(T) EQ 147)..
RHIGH(T)=E=RXBASE3;
RX44(T)$(ORD(T) EQ 159)..
RHIGH(T)=E=RXBASE3;
RX45(T)$(ORD(T) EQ 171)..
RHIGH(T)=E=RXBASE3;
RX46(T)$(ORD(T) EQ 4)..
RHIGH(T)=E=RXBASE4;
```

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RX47(T)$(ORD(T) EQ 16)..
RHIGH(T)=E=RXBASE4;
RX48(T)$(ORD(T) EQ 28)..
RHIGH(T)=E=RXBASE4;
RX49(T)$(ORD(T) EQ 40)..
RHIGH(T)=E=RXBASE4;
RX50(T)$(ORD(T) EQ 52)..
RHIGH(T)=E=RXBASE4;
RX51(T)$(ORD(T) EQ 64)..
RHIGH(T)=E=RXBASE4;
RX52(T)$(ORD(T) EQ 76)..
RHIGH(T)=E=RXBASE4;
RX53(T)$(ORD(T) EQ 88)..
RHIGH(T)=E=RXBASE4;
RX54(T)$(ORD(T) EQ 100)..
RHIGH(T)=E=RXBASE4;
RX55(T)$(ORD(T) EQ 112)..
RHIGH(T)=E=RXBASE4;
RX56(T)$(ORD(T) EQ 124)..
RHIGH(T)=E=RXBASE4;
RX57(T)$(ORD(T) EQ 136)..
RHIGH(T)=E=RXBASE4;
RX58(T)$(ORD(T) EQ 148)..
RHIGH(T)=E=RXBASE4;
RX59(T)$(ORD(T) EQ 160)..
RHIGH(T)=E=RXBASE4;
RX60(T)$(ORD(T) EQ 172)..
RHIGH(T)=E=RXBASE4;
RX61(T)$(ORD(T) EQ 5)..
RHIGH(T)=E=RXBASE5;
RX62(T)$(ORD(T) EQ 17)..
RHIGH(T)=E=RXBASE5;
RX63(T)$(ORD(T) EQ 29)..
RHIGH(T)=E=RXBASE5;
RX64(T)$(ORD(T) EQ 41)..
RHIGH(T)=E=RXBASE5;
RX65(T)$(ORD(T) EQ 53)..
RHIGH(T)=E=RXBASE5;
RX66(T)$(ORD(T) EQ 65)..
RHIGH(T)=E=RXBASE5;
RX67(T)$(ORD(T) EQ 77)..
RHIGH(T)=E=RXBASE5;
RX68(T)$(ORD(T) EQ 89)..
RHIGH(T)=E=RXBASE5;
RX69(T)$(ORD(T) EQ 101)..
RHIGH(T)=E=RXBASE5;
RX70(T)$(ORD(T) EQ 113)..
RHIGH(T)=E=RXBASE5;
RX71(T)$(ORD(T) EQ 125)..
RHIGH(T)=E=RXBASE5;
RX72(T)$(ORD(T) EQ 137)..
RHIGH(T)=E=RXBASE5;
RX73(T)$(ORD(T) EQ 149)..
RHIGH(T)=E=RXBASE5;
RX74(T)$(ORD(T) EQ 161)..
RHIGH(T)=E=RXBASE5;
RX75(T)$(ORD(T) EQ 173)..
RHIGH(T)=E=RXBASE5;
RX76(T)$(ORD(T) EQ 6)..
RHIGH(T)=E=RXBASE6;
```

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RX77(T)$(ORD(T) EQ 18)..
RHIGH(T)=E=RXBASE6;
RX78(T)$(ORD(T) EQ 30)..
RHIGH(T)=E=RXBASE6;
RX79(T)$(ORD(T) EQ 42)..
RHIGH(T)=E=RXBASE6;
RX80(T)$(ORD(T) EQ 54)..
RHIGH(T)=E=RXBASE6;
RX81(T)$(ORD(T) EQ 66)..
RHIGH(T)=E=RXBASE6;
RX82(T)$(ORD(T) EQ 78)..
RHIGH(T)=E=RXBASE6;
RX83(T)$(ORD(T) EQ 90)..
RHIGH(T)=E=RXBASE6;
RX84(T)$(ORD(T) EQ 102)..
RHIGH(T)=E=RXBASE6;
RX85(T)$(ORD(T) EQ 114)..
RHIGH(T)=E=RXBASE6;
RX86(T)$(ORD(T) EQ 126)..
RHIGH(T)=E=RXBASE6;
RX87(T)$(ORD(T) EQ 138)..
RHIGH(T)=E=RXBASE6;
RX88(T)$(ORD(T) EQ 150)..
RHIGH(T)=E=RXBASE6;
RX89(T)$(ORD(T) EQ 162)..
RHIGH(T)=E=RXBASE6;
RX90(T)$(ORD(T) EQ 174)..
RHIGH(T)=E=RXBASE6;
RX91(T)$(ORD(T) EQ 7)..
RHIGH(T)=E=RXBASE7;
RX92(T)$(ORD(T) EQ 19)..
RHIGH(T)=E=RXBASE7;
RX93(T)$(ORD(T) EQ 31)..
RHIGH(T)=E=RXBASE7;
RX94(T)$(ORD(T) EQ 43)..
RHIGH(T)=E=RXBASE7;
RX95(T)$(ORD(T) EQ 55)..
RHIGH(T)=E=RXBASE7;
RX96(T)$(ORD(T) EQ 67)..
RHIGH(T)=E=RXBASE7;
RX97(T)$(ORD(T) EQ 79)..
RHIGH(T)=E=RXBASE7;
RX98(T)$(ORD(T) EQ 91)..
RHIGH(T)=E=RXBASE7;
RX99(T)$(ORD(T) EQ 103)..
RHIGH(T)=E=RXBASE7;
RX100(T)$(ORD(T) EQ 115)..
RHIGH(T)=E=RXBASE7;
RX101(T)$(ORD(T) EQ 127)..
RHIGH(T)=E=RXBASE7;
RX102(T)$(ORD(T) EQ 139)..
RHIGH(T)=E=RXBASE7;
RX103(T)$(ORD(T) EQ 151)..
RHIGH(T)=E=RXBASE7;
RX104(T)$(ORD(T) EQ 163)..
RHIGH(T)=E=RXBASE7;
RX105(T)$(ORD(T) EQ 175)..
RHIGH(T)=E=RXBASE7;
RX106(T)$(ORD(T) EQ 8)..
RHIGH(T)=E=RXBASE8;
RX107(T)$(ORD(T) EQ 20)..
RHIGH(T)=E=RXBASE8;
RX108(T)$(ORD(T) EQ 32)..
RHIGH(T)=E=RXBASE8;
RX109(T)$(ORD(T) EQ 44)..
RHIGH(T)=E=RXBASE8;
RX110(T)$(ORD(T) EQ 56)..
RHIGH(T)=E=RXBASE8;
RX111(T)$(ORD(T) EQ 68)..
RHIGH(T)=E=RXBASE8;
RX112(T)$(ORD(T) EQ 80)..
RHIGH(T)=E=RXBASE8;
RX113(T)$(ORD(T) EQ 92)..
RHIGH(T)=E=RXBASE8;
RX114(T)$(ORD(T) EQ 104)..
RHIGH(T)=E=RXBASE8;
RX115(T)$(ORD(T) EQ 116)..
RHIGH(T)=E=RXBASE8;
RX116(T)$(ORD(T) EQ 128)..
RHIGH(T)=E=RXBASE8;
RX117(T)$(ORD(T) EQ 140)..
RHIGH(T)=E=RXBASE8;
RX118(T)$(ORD(T) EQ 152)..
RHIGH(T)=E=RXBASE8;
RX119(T)$(ORD(T) EQ 164)..
RHIGH(T)=E=RXBASE8;
RX120(T)$(ORD(T) EQ 176)..
RHIGH(T)=E=RXBASE8;
RX121(T)$(ORD(T) EQ 9)..
RHIGH(T)=E=RXBASE9;
RX122(T)$(ORD(T) EQ 21)..
RHIGH(T)=E=RXBASE9;
RX123(T)$(ORD(T) EQ 33)..
RHIGH(T)=E=RXBASE9;
RX124(T)$(ORD(T) EQ 45)..
RHIGH(T)=E=RXBASE9;
RX125(T)$(ORD(T) EQ 57)..
RHIGH(T)=E=RXBASE9;
RX126(T)$(ORD(T) EQ 69)..
RHIGH(T)=E=RXBASE9;
RX127(T)$(ORD(T) EQ 81)..
RHIGH(T)=E=RXBASE9;
RX128(T)$(ORD(T) EQ 93)..
RHIGH(T)=E=RXBASE9;
RX129(T)$(ORD(T) EQ 105)..
RHIGH(T)=E=RXBASE9;
RX130(T)$(ORD(T) EQ 117)..
RHIGH(T)=E=RXBASE9;
RX131(T)$(ORD(T) EQ 129)..
RHIGH(T)=E=RXBASE9;
RX132(T)$(ORD(T) EQ 141)..
RHIGH(T)=E=RXBASE9;
RX133(T)$(ORD(T) EQ 153)..
RHIGH(T)=E=RXBASE9;
RX134(T)$(ORD(T) EQ 165)..
RHIGH(T)=E=RXBASE9;
RX135(T)$(ORD(T) EQ 177)..
RHIGH(T)=E=RXBASE9;
RX136(T)$(ORD(T) EQ 10)..
RHIGH(T)=E=RXBASE10;
```

```
RX137(T)$(ORD(T) EQ 22)..
RHIGH(T)=E=RXBASE10;
RX138(T)$(ORD(T) EQ 34)..
RHIGH(T)=E=RXBASE10;
RX139(T)$(ORD(T) EQ 46)..
RHIGH(T)=E=RXBASE10;
RX140(T)$(ORD(T) EQ 58)..
RHIGH(T)=E=RXBASE10;
RX141(T)$(ORD(T) EQ 70)..
RHIGH(T)=E=RXBASE10;
RX142(T)$(ORD(T) EQ 82)..
RHIGH(T)=E=RXBASE10;
RX143(T)$(ORD(T) EQ 94)..
RHIGH(T)=E=RXBASE10;
RX144(T)$(ORD(T) EQ 106)..
RHIGH(T)=E=RXBASE10;
RX145(T)$(ORD(T) EQ 118)..
RHIGH(T)=E=RXBASE10;
RX146(T)$(ORD(T) EQ 130)..
RHIGH(T)=E=RXBASE10;
RX147(T)$(ORD(T) EQ 142)..
RHIGH(T)=E=RXBASE10;
RX148(T)$(ORD(T) EQ 154)..
RHIGH(T)=E=RXBASE10;
RX149(T)$(ORD(T) EQ 166)..
RHIGH(T)=E=RXBASE10;
RX150(T)$(ORD(T) EQ 178)..
RHIGH(T)=E=RXBASE10;
RX151(T)$(ORD(T) EQ 11)..
RHIGH(T)=E=RXBASE11;
RX152(T)$(ORD(T) EQ 23)..
RHIGH(T)=E=RXBASE11;
RX153(T)$(ORD(T) EQ 35)..
RHIGH(T)=E=RXBASE11;
RX154(T)$(ORD(T) EQ 47)..
RHIGH(T)=E=RXBASE11;
RX155(T)$(ORD(T) EQ 59)..
RHIGH(T)=E=RXBASE11;
RX156(T)$(ORD(T) EQ 71)..
RHIGH(T)=E=RXBASE11;
RX157(T)$(ORD(T) EQ 83)..
RHIGH(T)=E=RXBASE11;
RX158(T)$(ORD(T) EQ 95)..
RHIGH(T)=E=RXBASE11;
RX159(T)$(ORD(T) EQ 107)..
RHIGH(T)=E=RXBASE11;
RX160(T)$(ORD(T) EQ 119)..
RHIGH(T)=E=RXBASE11;
RX161(T)$(ORD(T) EQ 131)..
RHIGH(T)=E=RXBASE11;
RX162(T)$(ORD(T) EQ 143)..
RHIGH(T)=E=RXBASE11;
RX163(T)$(ORD(T) EQ 155)..
RHIGH(T)=E=RXBASE11;
RX164(T)$(ORD(T) EQ 167)..
RHIGH(T)=E=RXBASE11;
RX165(T)$(ORD(T) EQ 179)..
RHIGH(T)=E=RXBASE11;
RX166(T)$(ORD(T) EQ 12)..
RHIGH(T)=E=RXBASE12;
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```
RX167(T)$(ORD(T) EQ 24)..
RHIGH(T)=E=RXBASE12;
RX168(T)$(ORD(T) EQ 36)..
RHIGH(T)=E=RXBASE12;
RX169(T)$(ORD(T) EQ 48)..
RHIGH(T)=E=RXBASE12;
RX170(T)$(ORD(T) EQ 60)..
RHIGH(T)=E=RXBASE12;
RX171(T)$(ORD(T) EQ 72)..
RHIGH(T)=E=RXBASE12;
RX172(T)$(ORD(T) EQ 84)..
RHIGH(T)=E=RXBASE12;
RX173(T)$(ORD(T) EQ 96)..
RHIGH(T)=E=RXBASE12;
RX174(T)$(ORD(T) EQ 108)..
RHIGH(T)=E=RXBASE12;
RX175(T)$(ORD(T) EQ 120)..
RHIGH(T)=E=RXBASE12;
RX176(T)$(ORD(T) EQ 132)..
RHIGH(T)=E=RXBASE12;
RX177(T)$(ORD(T) EQ 144)..
RHIGH(T)=E=RXBASE12;
RX178(T)$(ORD(T) EQ 156)..
RHIGH(T)=E=RXBASE12;
RX179(T)$(ORD(T) EQ 168)..
RHIGH(T)=E=RXBASE12;
RX180(T)$(ORD(T) EQ 180)..
RHIGH(T)=E=RXBASE12;
UPWS1(T)$(ORD(T) EQ 1)..
UP(T)=E=UPWSBASE1;
UPWS2(T)$(ORD(T) EQ 13)..
UP(T)=E=UPWSBASE1;
UPWS3(T)$(ORD(T) EQ 25)..
UP(T)=E=UPWSBASE1;
UPWS4(T)$(ORD(T) EQ 37)..
UP(T)=E=UPWSBASE1;
UPWS5(T)$(ORD(T) EQ 49)..
UP(T)=E=UPWSBASE1;
UPWS6(T)$(ORD(T) EQ 61)..
UP(T)=E=UPWSBASE1;
UPWS7(T)$(ORD(T) EQ 73)..
UP(T)=E=UPWSBASE1;
UPWS8(T)$(ORD(T) EQ 85)..
UP(T)=E=UPWSBASE1;
UPWS9(T)$(ORD(T) EQ 97)..
UP(T)=E=UPWSBASE1;
UPWS10(T)$(ORD(T) EQ 109)..
UP(T)=E=UPWSBASE1;
UPWS11(T)$(ORD(T) EQ 121)..
UP(T)=E=UPWSBASE1;
UPWS12(T)$(ORD(T) EQ 133)..
UP(T)=E=UPWSBASE1;
UPWS13(T)$(ORD(T) EQ 145)..
UP(T)=E=UPWSBASE1;
UPWS14(T)$(ORD(T) EQ 157)..
UP(T)=E=UPWSBASE1;
UPWS15(T)$(ORD(T) EQ 169)..
UP(T)=E=UPWSBASE1;
UPWS16(T)$(ORD(T) EQ 2)..
UP(T)=E=UPWSBASE2;
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UPWS17(T)$(ORD(T) EQ 14)..
UP(T)=E=UPWSBASE2;
UPWS18(T)$(ORD(T) EQ 26)..
UP(T)=E=UPWSBASE2;
UPWS19(T)$(ORD(T) EQ 38)..
UP(T)=E=UPWSBASE2;
UPWS20(T)$(ORD(T) EQ 50)..
UP(T)=E=UPWSBASE2;
UPWS21(T)$(ORD(T) EQ 62)..
UP(T)=E=UPWSBASE2;
UPWS22(T)$(ORD(T) EQ 74)..
UP(T)=E=UPWSBASE2;
UPWS23(T)$(ORD(T) EQ 86)..
UP(T)=E=UPWSBASE2;
UPWS24(T)$(ORD(T) EQ 98)..
UP(T)=E=UPWSBASE2;
UPWS25(T)$(ORD(T) EQ 110)..
UP(T)=E=UPWSBASE2;
UPWS26(T)$(ORD(T) EQ 122)..
UP(T)=E=UPWSBASE2;
UPWS27(T)$(ORD(T) EQ 134)..
UP(T)=E=UPWSBASE2;
UPWS28(T)$(ORD(T) EQ 146)..
UP(T)=E=UPWSBASE2;
UPWS29(T)$(ORD(T) EQ 158)..
UP(T)=E=UPWSBASE2;
UPWS30(T)$(ORD(T) EQ 170)..
UP(T)=E=UPWSBASE2;
UPWS31(T)$(ORD(T) EQ 3)..
UP(T)=E=UPWSBASE3;
UPWS32(T)$(ORD(T) EQ 15)..
UP(T)=E=UPWSBASE3;
UPWS33(T)$(ORD(T) EQ 27)..
UP(T)=E=UPWSBASE3;
UPWS34(T)$(ORD(T) EQ 39)..
UP(T)=E=UPWSBASE3;
UPWS35(T)$(ORD(T) EQ 51)..
UP(T)=E=UPWSBASE3;
UPWS36(T)$(ORD(T) EQ 63)..
UP(T)=E=UPWSBASE3;
UPWS37(T)$(ORD(T) EQ 75)..
UP(T)=E=UPWSBASE3;
UPWS38(T)$(ORD(T) EQ 87)..
UP(T)=E=UPWSBASE3;
UPWS39(T)$(ORD(T) EQ 99)..
UP(T)=E=UPWSBASE3;
UPWS40(T)$(ORD(T) EQ 111)..
UP(T)=E=UPWSBASE3;
UPWS41(T)$(ORD(T) EQ 123)..
UP(T)=E=UPWSBASE3;
UPWS42(T)$(ORD(T) EQ 135)..
UP(T)=E=UPWSBASE3;
UPWS43(T)$(ORD(T) EQ 147)..
UP(T)=E=UPWSBASE3;
UPWS44(T)$(ORD(T) EQ 159)..
UP(T)=E=UPWSBASE3;
UPWS45(T)$(ORD(T) EQ 171)..
UP(T)=E=UPWSBASE3;
UPWS46(T)$(ORD(T) EQ 4)..
UP(T)=E=UPWSBASE4;
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UPWS47(T)$(ORD(T) EQ 16)..
UP(T)=E=UPWSBASE4;
UPWS48(T)$(ORD(T) EQ 28)..
UP(T)=E=UPWSBASE4;
UPWS49(T)$(ORD(T) EQ 40)..
UP(T)=E=UPWSBASE4;
UPWS50(T)$(ORD(T) EQ 52)..
UP(T)=E=UPWSBASE4;
UPWS51(T)$(ORD(T) EQ 64)..
UP(T)=E=UPWSBASE4;
UPWS52(T)$(ORD(T) EQ 76)..
UP(T)=E=UPWSBASE4;
UPWS53(T)$(ORD(T) EQ 88)..
UP(T)=E=UPWSBASE4;
UPWS54(T)$(ORD(T) EQ 100)..
UP(T)=E=UPWSBASE4;
UPWS55(T)$(ORD(T) EQ 112)..
UP(T)=E=UPWSBASE4;
UPWS56(T)$(ORD(T) EQ 124)..
UP(T)=E=UPWSBASE4;
UPWS57(T)$(ORD(T) EQ 136)..
UP(T)=E=UPWSBASE4;
UPWS58(T)$(ORD(T) EQ 148)..
UP(T)=E=UPWSBASE4;
UPWS59(T)$(ORD(T) EQ 160)..
UP(T)=E=UPWSBASE4;
UPWS60(T)$(ORD(T) EQ 172)..
UP(T)=E=UPWSBASE4;
UPWS61(T)$(ORD(T) EQ 5)..
UP(T)=E=UPWSBASE5;
UPWS62(T)$(ORD(T) EQ 17)..
UP(T)=E=UPWSBASE5;
UPWS63(T)$(ORD(T) EQ 29)..
UP(T)=E=UPWSBASE5;
UPWS64(T)$(ORD(T) EQ 41)..
UP(T)=E=UPWSBASE5;
UPWS65(T)$(ORD(T) EQ 53)..
UP(T)=E=UPWSBASE5;
UPWS66(T)$(ORD(T) EQ 65)..
UP(T)=E=UPWSBASE5;
UPWS67(T)$(ORD(T) EQ 77)..
UP(T)=E=UPWSBASE5;
UPWS68(T)$(ORD(T) EQ 89)..
UP(T)=E=UPWSBASE5;
UPWS69(T)$(ORD(T) EQ 101)..
UP(T)=E=UPWSBASE5;
UPWS70(T)$(ORD(T) EQ 113)..
UP(T)=E=UPWSBASE5;
UPWS71(T)$(ORD(T) EQ 125)..
UP(T)=E=UPWSBASE5;
UPWS72(T)$(ORD(T) EQ 137)..
UP(T)=E=UPWSBASE5;
UPWS73(T)$(ORD(T) EQ 149)..
UP(T)=E=UPWSBASE5;
UPWS74(T)$(ORD(T) EQ 161)..
UP(T)=E=UPWSBASE5;
UPWS75(T)$(ORD(T) EQ 173)..
UP(T)=E=UPWSBASE5;
UPWS76(T)$(ORD(T) EQ 6)..
UP(T)=E=UPWSBASE6;
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UPWS77(T)$(ORD(T) EQ 18)..
UP(T)=E=UPWSBASE6;
UPWS78(T)$(ORD(T) EQ 30)..
UP(T)=E=UPWSBASE6;
UPWS79(T)$(ORD(T) EQ 42)..
UP(T)=E=UPWSBASE6;
UPWS80(T)$(ORD(T) EQ 54)..
UP(T)=E=UPWSBASE6;
UPWS81(T)$(ORD(T) EQ 66)..
UP(T)=E=UPWSBASE6;
UPWS82(T)$(ORD(T) EQ 78)..
UP(T)=E=UPWSBASE6;
UPWS83(T)$(ORD(T) EQ 90)..
UP(T)=E=UPWSBASE6;
UPWS84(T)$(ORD(T) EQ 102)..
UP(T)=E=UPWSBASE6;
UPWS85(T)$(ORD(T) EQ 114)..
UP(T)=E=UPWSBASE6;
UPWS86(T)$(ORD(T) EQ 126)..
UP(T)=E=UPWSBASE6;
UPWS87(T)$(ORD(T) EQ 138)..
UP(T)=E=UPWSBASE6;
UPWS88(T)$(ORD(T) EQ 150)..
UP(T)=E=UPWSBASE6;
UPWS89(T)$(ORD(T) EQ 162)..
UP(T)=E=UPWSBASE6;
UPWS90(T)$(ORD(T) EQ 174)..
UP(T)=E=UPWSBASE6;
UPWS91(T)$(ORD(T) EQ 7)..
UP(T)=E=UPWSBASE7;
UPWS92(T)$(ORD(T) EQ 19)..
UP(T)=E=UPWSBASE7;
UPWS93(T)$(ORD(T) EQ 31)..
UP(T)=E=UPWSBASE7;
UPWS94(T)$(ORD(T) EQ 43)..
UP(T)=E=UPWSBASE7;
UPWS95(T)$(ORD(T) EQ 55)..
UP(T)=E=UPWSBASE7;
UPWS96(T)$(ORD(T) EQ 67)..
UP(T)=E=UPWSBASE7;
UPWS97(T)$(ORD(T) EQ 79)..
UP(T)=E=UPWSBASE7;
UPWS98(T)$(ORD(T) EQ 91)..
UP(T)=E=UPWSBASE7;
UPWS99(T)$(ORD(T) EQ 103)..
UP(T)=E=UPWSBASE7;
UPWS100(T)$(ORD(T) EQ 115)..
UP(T)=E=UPWSBASE7;
UPWS101(T)$(ORD(T) EQ 127)..
UP(T)=E=UPWSBASE7;
UPWS102(T)$(ORD(T) EQ 139)..
UP(T)=E=UPWSBASE7;
UPWS103(T)$(ORD(T) EQ 151)..
UP(T)=E=UPWSBASE7;
UPWS104(T)$(ORD(T) EQ 163)..
UP(T)=E=UPWSBASE7;
UPWS105(T)$(ORD(T) EQ 175)..
UP(T)=E=UPWSBASE7;
UPWS106(T)$(ORD(T) EQ 8)..
UP(T)=E=UPWSBASE8;
UPWS107(T)$(ORD(T) EQ 20)..
UP(T)=E=UPWSBASE8;
UPWS108(T)$(ORD(T) EQ 32)..
UP(T)=E=UPWSBASE8;
UPWS109(T)$(ORD(T) EQ 44)..
UP(T)=E=UPWSBASE8;
UPWS110(T)$(ORD(T) EQ 56)..
UP(T)=E=UPWSBASE8;
UPWS111(T)$(ORD(T) EQ 68)..
UP(T)=E=UPWSBASE8;
UPWS112(T)$(ORD(T) EQ 80)..
UP(T)=E=UPWSBASE8;
UPWS113(T)$(ORD(T) EQ 92)..
UP(T)=E=UPWSBASE8;
UPWS114(T)$(ORD(T) EQ 104)..
UP(T)=E=UPWSBASE8;
UPWS115(T)$(ORD(T) EQ 116)..
UP(T)=E=UPWSBASE8;
UPWS116(T)$(ORD(T) EQ 128)..
UP(T)=E=UPWSBASE8;
UPWS117(T)$(ORD(T) EQ 140)..
UP(T)=E=UPWSBASE8;
UPWS118(T)$(ORD(T) EQ 152)..
UP(T)=E=UPWSBASE8;
UPWS119(T)$(ORD(T) EQ 164)..
UP(T)=E=UPWSBASE8;
UPWS120(T)$(ORD(T) EQ 176)..
UP(T)=E=UPWSBASE8;
UPWS121(T)$(ORD(T) EQ 9)..
UP(T)=E=UPWSBASE9;
UPWS122(T)$(ORD(T) EQ 21)..
UP(T)=E=UPWSBASE9;
UPWS123(T)$(ORD(T) EQ 33)..
UP(T)=E=UPWSBASE9;
UPWS124(T)$(ORD(T) EQ 45)..
UP(T)=E=UPWSBASE9;
UPWS125(T)$(ORD(T) EQ 57)..
UP(T)=E=UPWSBASE9;
UPWS126(T)$(ORD(T) EQ 69)..
UP(T)=E=UPWSBASE9;
UPWS127(T)$(ORD(T) EQ 81)..
UP(T)=E=UPWSBASE9;
UPWS128(T)$(ORD(T) EQ 93)..
UP(T)=E=UPWSBASE9;
UPWS129(T)$(ORD(T) EQ 105)..
UP(T)=E=UPWSBASE9;
UPWS130(T)$(ORD(T) EQ 117)..
UP(T)=E=UPWSBASE9;
UPWS131(T)$(ORD(T) EQ 129)..
UP(T)=E=UPWSBASE9;
UPWS132(T)$(ORD(T) EQ 141)..
UP(T)=E=UPWSBASE9;
UPWS133(T)$(ORD(T) EQ 153)..
UP(T)=E=UPWSBASE9;
UPWS134(T)$(ORD(T) EQ 165)..
UP(T)=E=UPWSBASE9;
UPWS135(T)$(ORD(T) EQ 177)..
UP(T)=E=UPWSBASE9;
UPWS136(T)$(ORD(T) EQ 10)..
UP(T)=E=UPWSBASE10;
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UPWS137(T)$(ORD(T) EQ 22)..
UP(T)=E=UPWSBASE10;
UPWS138(T)$(ORD(T) EQ 34)..
UP(T)=E=UPWSBASE10;
UPWS139(T)$(ORD(T) EQ 46)..
UP(T)=E=UPWSBASE10;
UPWS140(T)$(ORD(T) EQ 58)..
UP(T)=E=UPWSBASE10;
UPWS141(T)$(ORD(T) EQ 70)..
UP(T)=E=UPWSBASE10;
UPWS142(T)$(ORD(T) EQ 82)..
UP(T)=E=UPWSBASE10;
UPWS143(T)$(ORD(T) EQ 94)..
UP(T)=E=UPWSBASE10;
UPWS144(T)$(ORD(T) EQ 106)..
UP(T)=E=UPWSBASE10;
UPWS145(T)$(ORD(T) EQ 118)..
UP(T)=E=UPWSBASE10;
UPWS146(T)$(ORD(T) EQ 130)..
UP(T)=E=UPWSBASE10;
UPWS147(T)$(ORD(T) EQ 142)..
UP(T)=E=UPWSBASE10;
UPWS148(T)$(ORD(T) EQ 154)..
UP(T)=E=UPWSBASE10;
UPWS149(T)$(ORD(T) EQ 166)..
UP(T)=E=UPWSBASE10;
UPWS150(T)$(ORD(T) EQ 178)..
UP(T)=E=UPWSBASE10;
UPWS151(T)$(ORD(T) EQ 11)..
UP(T)=E=UPWSBASE11;
UPWS152(T)$(ORD(T) EQ 23)..
UP(T)=E=UPWSBASE11;
UPWS153(T)$(ORD(T) EQ 35)..
UP(T)=E=UPWSBASE11;
UPWS154(T)$(ORD(T) EQ 47)..
UP(T)=E=UPWSBASE11;
UPWS155(T)$(ORD(T) EQ 59)..
UP(T)=E=UPWSBASE11;
UPWS156(T)$(ORD(T) EQ 71)..
UP(T)=E=UPWSBASE11;
UPWS157(T)$(ORD(T) EQ 83)..
UP(T)=E=UPWSBASE11;
UPWS158(T)$(ORD(T) EQ 95)..
UP(T)=E=UPWSBASE11;
UPWS159(T)$(ORD(T) EQ 107)..
UP(T)=E=UPWSBASE11;
UPWS160(T)$(ORD(T) EQ 119)..
UP(T)=E=UPWSBASE11;
UPWS161(T)$(ORD(T) EQ 131)..
UP(T)=E=UPWSBASE11;
UPWS162(T)$(ORD(T) EQ 143)..
UP(T)=E=UPWSBASE11;
UPWS163(T)$(ORD(T) EQ 155)..
UP(T)=E=UPWSBASE11;
UPWS164(T)$(ORD(T) EQ 167)..
UP(T)=E=UPWSBASE11;
UPWS165(T)$(ORD(T) EQ 179)..
UP(T)=E=UPWSBASE11;
UPWS166(T)$(ORD(T) EQ 12)..
UP(T)=E=UPWSBASE12;
UPWS167(T)$(ORD(T) EQ 24)..
UP(T)=E=UPWSBASE12;
UPWS168(T)$(ORD(T) EQ 36)..
UP(T)=E=UPWSBASE12;
UPWS169(T)$(ORD(T) EQ 48)..
UP(T)=E=UPWSBASE12;
UPWS170(T)$(ORD(T) EQ 60)..
UP(T)=E=UPWSBASE12;
UPWS171(T)$(ORD(T) EQ 72)..
UP(T)=E=UPWSBASE12;
UPWS172(T)$(ORD(T) EQ 84)..
UP(T)=E=UPWSBASE12;
UPWS173(T)$(ORD(T) EQ 96)..
UP(T)=E=UPWSBASE12;
UPWS174(T)$(ORD(T) EQ 108)..
UP(T)=E=UPWSBASE12;
UPWS175(T)$(ORD(T) EQ 120)..
UP(T)=E=UPWSBASE12;
UPWS176(T)$(ORD(T) EQ 132)..
UP(T)=E=UPWSBASE12;
UPWS177(T)$(ORD(T) EQ 144)..
UP(T)=E=UPWSBASE12;
UPWS178(T)$(ORD(T) EQ 156)..
UP(T)=E=UPWSBASE12;
UPWS179(T)$(ORD(T) EQ 168)..
UP(T)=E=UPWSBASE12;
UPWS180(T)$(ORD(T) EQ 180)..
UP(T)=E=UPWSBASE12;
HIGHREL(T)..  R(T)=L=RHIGH(T);
MINSTO(T)..  S(T)=G=SDEAD;
MAXSTO(T)..  S(T)=L=SSPIL;
MINWS(T)..  LOWB=L=((1/DTAR(T))*WS(T));
MAXWS(T)..  ((1/DTAR(T))*WS(T))=L=UP(T);
STOTAR(T)..  S(T)-V(T)+U(T)=E=STAR(T);
SECOND..  OF2=E=SUM(T,V(T)+U(T));


*******************************************************************
OF..  DISTANCE=E= POWER(((K-194.4)/(439.10-194.4)),1)
                +POWER(((OF2-9378.5)/(37684.90-9378.5)),1);
*******************************************************************

MODEL DEBC1 /ALL/;
DEBC1.OPTFILE =1;
```

```
SOLVE DEBC1 USING NLP MINIMIZING DISTANCE;

*  Post Processing
PUT F0;
PUT  '*******************************************'
PUT /'*    SUMMARY OF THE OPTIMAL CONDITIONS    *'
PUT /'*******************************************'
PUT /
PUT /'OF1':>15,'OF2':>15;
PUT / K.L :>15;PUT OF2.L:>15;
PUT /
PUT /'***************************************':>39;
PUT /'MAX STORAGE':>11,'MIN STORAGE':>14,'LOW WS BOUND':>14;
PUT /'***************************************':>39;
PUT /SSPIL.L:>11; PUT SDEAD.L:>14; PUT LOWB:>14;
PUT /
PUT /
PUT
/'********************************************************************':
>68,'****************':>16;
PUT /'TIME':>4,'RMIN':>10,'RMAX':>7,'DTAR':>7,'STAR':>9,'UP/WS':>7,
' *':>2,
'STORAGE':>8,'D/S RELEASE':>14,'WATER SUPPLY':>14;
PUT
/'********************************************************************':
>68,'****************':>16;
PUT /
LOOP(T, PUT / T.TL:>4;
PUT RLOW.L(T):>10; PUT RHIGH.L(T):>7; PUT DTAR(T):>7; PUT STAR(T):>9;
PUT UP.L(T):>7; PUT ' *':>2;
PUT S.L(T):>8; PUT R.L(T):>14; PUT WS.L(T):>14;);
```

□

Appendix E GAMS Output for the De Novo Reservoir System

Table E-1 Optimal Objective Function Values

Required Active Storage (10^6 m^3)	Sum of Storage Deviations (10^6 m^3)
194.44	37807.79

Table E-2 Optimal Maximum and Minimum Storage Levels, and Minimum Fration of Target Water Supply

Optimal Maximum Storage (10^6 m^3)	Optimal Minimum Storage (10^6 m^3)	Minimum Fraction of Target Water Supply
194.44	0	0.95

Please note the following definitions of abbreviations.

Opt. - Optimal
Min. - Minimum
Rel. - Reservoir Release
Max. - Maximum
Stor. - Reservoir Storage
* - Dimensionless

Table E-3 Optimal Decision Variables, and Monthly Target Water Supply and Storage Levels, (10^6 m^3)

Time	Opt. Min. Rel.	Opt. Max. Rel.	Target Water Supply	Target Stor.	Opt. Upper Bound on Water Supply*	Opt. Stor.	Opt. Rel.	Opt. Water Supply
1	0.00	0.00	2.09	252.15	0.95	26.10	0.00	1.98
2	0.00	0.00	1.91	225.09	0.95	25.38	0.00	1.82
3	0.00	0.00	2.14	196.80	0.95	25.65	0.00	2.04
4	0.00	0.00	2.10	276.75	42.21	73.02	0.00	1.99
5	0.00	0.00	10.18	396.00	6.26	100.43	0.00	9.67
6	0.00	0.00	19.26	396.00	2.09	96.33	0.00	18.30
7	0.00	0.00	23.03	396.00	1.13	81.99	0.00	21.88
8	0.00	0.00	19.53	396.00	0.95	65.89	0.00	18.55
9	0.00	0.00	9.69	396.00	0.95	58.57	0.00	9.21
10	0.00	0.00	5.25	338.25	0.95	56.23	0.00	4.99
11	0.00	0.00	2.07	303.81	0.95	56.57	0.00	1.97
12	0.00	0.00	2.04	276.75	0.95	56.23	0.00	1.93
13	0.00	0.00	2.09	252.15	0.95	55.82	0.00	1.98
14	0.00	0.00	1.91	225.09	0.95	55.40	0.00	1.82
15	0.00	0.00	2.14	196.80	0.95	54.60	0.00	2.04
16	0.00	0.00	2.10	276.75	42.21	138.38	0.00	1.99
17	0.00	0.00	10.18	396.00	6.26	154.74	0.00	9.67
18	0.00	0.00	19.26	396.00	2.09	147.51	0.00	18.30
19	0.00	0.00	23.03	396.00	1.13	131.59	0.00	21.88
20	0.00	0.00	19.53	396.00	0.95	116.75	0.00	18.55
21	0.00	0.00	9.69	396.00	0.95	108.29	0.00	9.21

22	0.00	0.00	5.25	338.25	0.95	105.20	0.00	4.99
23	0.00	0.00	2.07	303.81	0.95	105.60	0.00	1.97
24	0.00	0.00	2.04	276.75	0.95	105.67	0.00	1.93
25	0.00	0.00	2.09	252.15	0.95	105.45	0.00	1.98
26	0.00	0.00	1.91	225.09	0.95	105.03	0.00	1.82
27	0.00	0.00	2.14	196.80	0.95	104.86	0.00	2.04
28	0.00	0.00	2.10	276.75	42.21	181.47	0.00	1.99
29	0.00	0.00	10.18	396.00	6.26	194.44	0.00	63.73
30	0.00	0.00	19.26	396.00	2.09	183.43	0.00	18.30
31	0.00	0.00	23.03	396.00	1.13	165.04	0.00	21.88
32	0.00	0.00	19.53	396.00	0.95	147.72	0.00	18.55
33	0.00	0.00	9.69	396.00	0.95	139.17	0.00	9.21
34	0.00	0.00	5.25	338.25	0.95	135.15	0.00	4.99
35	0.00	0.00	2.07	303.81	0.95	134.36	0.00	1.97
36	0.00	0.00	2.04	276.75	0.95	133.14	0.00	1.93
37	0.00	0.00	2.09	252.15	0.95	131.54	0.00	1.98
38	0.00	0.00	1.91	225.09	0.95	130.09	0.00	1.82
39	0.00	0.00	2.14	196.80	0.95	129.62	0.00	2.04
40	0.00	0.00	2.10	276.75	42.21	137.55	0.00	1.99
41	0.00	0.00	10.18	396.00	6.26	135.79	0.00	9.67
42	0.00	0.00	19.26	396.00	2.09	129.37	0.00	18.30
43	0.00	0.00	23.03	396.00	1.13	118.80	0.00	21.88
44	0.00	0.00	19.53	396.00	0.95	102.34	0.00	18.55
45	0.00	0.00	9.69	396.00	0.95	95.06	0.00	9.21
46	0.00	0.00	5.25	338.25	0.95	91.99	0.00	4.99
47	0.00	0.00	2.07	303.81	0.95	91.90	0.00	1.97
48	0.00	0.00	2.04	276.75	0.95	91.71	0.00	1.93
49	0.00	0.00	2.09	252.15	0.95	90.96	0.00	1.98
50	0.00	0.00	1.91	225.09	0.95	90.29	0.00	1.82
51	0.00	0.00	2.14	196.80	0.95	89.50	0.00	2.04
52	0.00	0.00	2.10	276.75	42.21	152.83	0.00	1.99
53	0.00	0.00	10.18	396.00	6.26	194.44	0.00	51.23
54	0.00	0.00	19.26	396.00	2.09	194.44	0.00	40.24
55	0.00	0.00	23.03	396.00	1.13	177.41	0.00	21.88
56	0.00	0.00	19.53	396.00	0.95	161.43	0.00	18.55
57	0.00	0.00	9.69	396.00	0.95	155.67	0.00	9.21
58	0.00	0.00	5.25	338.25	0.95	155.33	0.00	4.99
59	0.00	0.00	2.07	303.81	0.95	156.81	0.00	1.97
60	0.00	0.00	2.04	276.75	0.95	157.50	0.00	1.93
61	0.00	0.00	2.09	252.15	0.95	157.42	0.00	1.98
62	0.00	0.00	1.91	225.09	0.95	157.37	0.00	1.82
63	0.00	0.00	2.14	196.80	0.95	157.01	0.00	2.04
64	0.00	0.00	2.10	276.75	42.21	123.04	0.00	88.61
65	0.00	0.00	10.18	396.00	6.26	182.63	0.00	48.18
66	0.00	0.00	19.26	396.00	2.09	194.44	0.00	18.30
67	0.00	0.00	23.03	396.00	1.13	182.69	0.00	21.88
68	0.00	0.00	19.53	396.00	0.95	167.03	0.00	18.55
69	0.00	0.00	9.69	396.00	0.95	160.98	0.00	9.21
70	0.00	0.00	5.25	338.25	0.95	160.33	0.00	4.99
71	0.00	0.00	2.07	303.81	0.95	162.85	0.00	1.97
72	0.00	0.00	2.04	276.75	0.95	162.87	0.00	1.93
73	0.00	0.00	2.09	252.15	0.95	162.38	0.00	1.98
74	0.00	0.00	1.91	225.09	0.95	162.24	0.00	1.82
75	0.00	0.00	2.14	196.80	0.95	162.18	0.00	2.04
76	0.00	0.00	2.10	276.75	42.21	194.44	0.00	88.61
77	0.00	0.00	10.18	396.00	6.26	164.15	0.00	63.73
78	0.00	0.00	19.26	396.00	2.09	191.12	0.00	18.30
79	0.00	0.00	23.03	396.00	1.13	194.44	0.00	25.92
80	0.00	0.00	19.53	396.00	0.95	180.94	0.00	18.55
81	0.00	0.00	9.69	396.00	0.95	177.50	0.00	9.21
82	0.00	0.00	5.25	338.25	0.95	177.54	0.00	4.99

83	0.00	0.00	2.07	303.81	0.95	177.09	0.00	1.97
84	0.00	0.00	2.04	276.75	0.95	176.31	0.00	1.93
85	0.00	0.00	2.09	252.15	0.95	175.10	0.00	1.98
86	0.00	0.00	1.91	225.09	0.95	174.16	0.00	1.82
87	0.00	0.00	2.14	196.80	0.95	173.14	0.00	2.04
88	0.00	0.00	2.10	276.75	42.21	186.23	0.00	1.99
89	0.00	0.00	10.18	396.00	6.26	184.16	0.00	9.67
90	0.00	0.00	19.26	396.00	2.09	168.23	0.00	18.30
91	0.00	0.00	23.03	396.00	1.13	148.58	0.00	21.88
92	0.00	0.00	19.53	396.00	0.95	131.64	0.00	18.55
93	0.00	0.00	9.69	396.00	0.95	125.97	0.00	9.21
94	0.00	0.00	5.25	338.25	0.95	125.58	0.00	4.99
95	0.00	0.00	2.07	303.81	0.95	126.37	0.00	1.97
96	0.00	0.00	2.04	276.75	0.95	126.17	0.00	1.93
97	0.00	0.00	2.09	252.15	0.95	125.54	0.00	1.98
98	0.00	0.00	1.91	225.09	0.95	124.65	0.00	1.82
99	0.00	0.00	2.14	196.80	0.95	124.25	0.00	2.04
100	0.00	0.00	2.10	276.75	42.21	144.76	0.00	1.99
101	0.00	0.00	10.18	396.00	6.26	148.92	0.00	9.67
102	0.00	0.00	19.26	396.00	2.09	134.98	0.00	18.30
103	0.00	0.00	23.03	396.00	1.13	115.92	0.00	21.88
104	0.00	0.00	19.53	396.00	0.95	98.10	0.00	18.55
105	0.00	0.00	9.69	396.00	0.95	89.78	0.00	9.21
106	0.00	0.00	5.25	338.25	0.95	86.38	0.00	4.99
107	0.00	0.00	2.07	303.81	0.95	86.52	0.00	1.97
108	0.00	0.00	2.04	276.75	0.95	85.91	0.00	1.93
109	0.00	0.00	2.09	252.15	0.95	84.86	0.00	1.98
110	0.00	0.00	1.91	225.09	0.95	83.86	0.00	1.82
111	0.00	0.00	2.14	196.80	0.95	82.62	0.00	2.04
112	0.00	0.00	2.10	276.75	42.21	136.27	0.00	1.99
113	0.00	0.00	10.18	396.00	6.26	188.42	0.00	63.73
114	0.00	0.00	19.26	396.00	2.09	194.44	0.00	19.86
115	0.00	0.00	23.03	396.00	1.13	176.50	0.00	21.88
116	0.00	0.00	19.53	396.00	0.95	159.19	0.00	18.55
117	0.00	0.00	9.69	396.00	0.95	151.39	0.00	9.21
118	0.00	0.00	5.25	338.25	0.95	147.57	0.00	4.99
119	0.00	0.00	2.07	303.81	0.95	147.56	0.00	1.97
120	0.00	0.00	2.04	276.75	0.95	146.88	0.00	1.93
121	0.00	0.00	2.09	252.15	0.95	146.09	0.00	1.98
122	0.00	0.00	1.91	225.09	0.95	145.41	0.00	1.82
123	0.00	0.00	2.14	196.80	0.95	144.62	0.00	2.04
124	0.00	0.00	2.10	276.75	42.21	180.44	0.00	1.99
125	0.00	0.00	10.18	396.00	6.26	179.19	0.00	9.67
126	0.00	0.00	19.26	396.00	2.09	162.54	0.00	18.30
127	0.00	0.00	23.03	396.00	1.13	141.93	0.00	21.88
128	0.00	0.00	19.53	396.00	0.95	124.46	0.00	18.55
129	0.00	0.00	9.69	396.00	0.95	116.21	0.00	9.21
130	0.00	0.00	5.25	338.25	0.95	112.66	0.00	4.99
131	0.00	0.00	2.07	303.81	0.95	112.42	0.00	1.97
132	0.00	0.00	2.04	276.75	0.95	111.33	0.00	1.93
133	0.00	0.00	2.09	252.15	0.95	109.87	0.00	1.98
134	0.00	0.00	1.91	225.09	0.95	108.65	0.00	1.82
135	0.00	0.00	2.14	196.80	0.95	111.42	0.00	2.04
136	0.00	0.00	2.10	276.75	42.21	118.53	0.00	1.99
137	0.00	0.00	10.18	396.00	6.26	113.29	0.00	9.67
138	0.00	0.00	19.26	396.00	2.09	98.47	0.00	18.30
139	0.00	0.00	23.03	396.00	1.13	79.30	0.00	21.88
140	0.00	0.00	19.53	396.00	0.95	62.27	0.00	18.55
141	0.00	0.00	9.69	396.00	0.95	53.77	0.00	9.21
142	0.00	0.00	5.25	338.25	0.95	51.48	0.00	4.99
143	0.00	0.00	2.07	303.81	0.95	52.47	0.00	1.97

144	0.00	0.00	2.04	276.75	0.95	51.65	0.00	1.93
145	0.00	0.00	2.09	252.15	0.95	50.10	0.00	1.98
146	0.00	0.00	1.91	225.09	0.95	48.81	0.00	1.82
147	0.00	0.00	2.14	196.80	0.95	47.51	0.00	2.04
148	0.00	0.00	2.10	276.75	42.21	60.41	0.00	1.99
149	0.00	0.00	10.18	396.00	6.26	58.91	0.00	9.67
150	0.00	0.00	19.26	396.00	2.09	43.95	0.00	18.30
151	0.00	0.00	23.03	396.00	1.13	31.67	0.00	21.88
152	0.00	0.00	19.53	396.00	0.95	16.10	0.00	18.55
153	0.00	0.00	9.69	396.00	0.95	7.44	0.00	9.21
154	0.00	0.00	5.25	338.25	0.95	3.92	0.00	4.99
155	0.00	0.00	2.07	303.81	0.95	3.64	0.00	1.97
156	0.00	0.00	2.04	276.75	0.95	2.61	0.00	1.93
157	0.00	0.00	2.09	252.15	0.95	1.68	0.00	1.98
158	0.00	0.00	1.91	225.09	0.95	0.99	0.00	1.82
159	0.00	0.00	2.14	196.80	0.95	0.00	0.00	2.04
160	0.00	0.00	2.10	276.75	42.21	33.43	0.00	1.99
161	0.00	0.00	10.18	396.00	6.26	71.05	0.00	9.67
162	0.00	0.00	19.26	396.00	2.09	68.78	0.00	18.30
163	0.00	0.00	23.03	396.00	1.13	64.85	0.00	21.88
164	0.00	0.00	19.53	396.00	0.95	51.02	0.00	18.55
165	0.00	0.00	9.69	396.00	0.95	42.78	0.00	9.21
166	0.00	0.00	5.25	338.25	0.95	39.25	0.00	4.99
167	0.00	0.00	2.07	303.81	0.95	39.43	0.00	1.97
168	0.00	0.00	2.04	276.75	0.95	39.06	0.00	1.93
169	0.00	0.00	2.09	252.15	0.95	38.03	0.00	1.98
170	0.00	0.00	1.91	225.09	0.95	37.19	0.00	1.82
171	0.00	0.00	2.14	196.80	0.95	44.86	0.00	2.04
172	0.00	0.00	2.10	276.75	42.21	66.68	0.00	1.99
173	0.00	0.00	10.18	396.00	6.26	71.94	0.00	9.67
174	0.00	0.00	19.26	396.00	2.09	68.63	0.00	18.30
175	0.00	0.00	23.03	396.00	1.13	54.79	0.00	21.88
176	0.00	0.00	19.53	396.00	0.95	37.11	0.00	18.55
177	0.00	0.00	9.69	396.00	0.95	28.73	0.00	9.21
178	0.00	0.00	5.25	338.25	0.95	26.19	0.00	4.99
179	0.00	0.00	2.07	303.81	0.95	26.21	0.00	1.97
180	0.00	0.00	2.04	276.75	0.95	26.88	0.00	1.93

Table E-4 Optimal Objective Function Values

Required Active Storage (10^6 m^3)	Sum of Storage Deviations (10^6 m^3)
439.50	9378.50

Table E-5 Optimal Maximum and Minimum Storage Levels, and Minimum Fration of Target Water Supply

Optimal Maximum Storage (10^6 m^3)	Optimal Minimum Storage (10^6 m^3)	Minimum Fraction of Target Water Supply
439.05	0	0.95

Please note the following definitions of abbreviations.

Opt. - Optimal
Min. - Minimum
Rel. - Reservoir Release
Max. - Maximum
Stor. - Reservoir Storage
* - Dimensionless

Table E-6 Optimal Decision Variables, and Monthly Target Water Supply and Storage Levels, (10^6 m^3)

Time	Opt. Min. Rel.	Opt. Max. Rel.	Target Water Supply	Target Stor.	Opt. Upper Bound on Water Supply*	Opt. Stor.	Opt. Rel.	Opt. Water Supply
1	0.00	24.53	2.09	252.15	0.95	270.71	0.00	1.98
2	0.00	0.00	1.91	225.09	14.32	269.99	0.00	1.82
3	0.00	0.00	2.14	196.80	0.95	270.26	0.00	2.04
4	0.00	0.00	2.10	276.75	0.95	317.63	0.00	1.99
5	0.00	0.00	10.18	396.00	0.95	345.04	0.00	9.67
6	0.00	0.00	19.26	396.00	0.95	340.94	0.00	18.30
7	0.00	0.00	23.03	396.00	0.95	326.61	0.00	21.88
8	0.00	0.00	19.53	396.00	0.95	310.51	0.00	18.55
9	0.00	0.00	9.69	396.00	0.95	303.18	0.00	9.21
10	0.00	0.00	5.25	338.25	5.45	300.84	0.00	4.99
11	0.00	36.96	2.07	303.81	0.95	301.18	0.00	1.97
12	0.00	27.75	2.04	276.75	0.95	289.24	11.61	1.93
13	0.00	24.53	2.09	252.15	0.95	288.82	0.00	1.98
14	0.00	0.00	1.91	225.09	14.32	288.41	0.00	1.82
15	0.00	0.00	2.14	196.80	0.95	287.60	0.00	2.04
16	0.00	0.00	2.10	276.75	0.95	371.39	0.00	1.99
17	0.00	0.00	10.18	396.00	0.95	387.75	0.00	9.67
18	0.00	0.00	19.26	396.00	0.95	380.51	0.00	18.30
19	0.00	0.00	23.03	396.00	0.95	364.59	0.00	21.88
20	0.00	0.00	19.53	396.00	0.95	349.75	0.00	18.55
21	0.00	0.00	9.69	396.00	0.95	341.29	0.00	9.21
22	0.00	0.00	5.25	338.25	5.45	338.21	0.00	4.99
23	0.00	36.96	2.07	303.81	0.95	303.81	34.80	1.97

24	0.00	27.75	2.04	276.75	0.95	276.75	27.13	1.93
25	0.00	24.53	2.09	252.15	0.95	254.50	22.04	1.98
26	0.00	0.00	1.91	225.09	14.32	254.07	0.00	1.82
27	0.00	0.00	2.14	196.80	0.95	253.91	0.00	2.04
28	0.00	0.00	2.10	276.75	0.95	330.51	0.00	1.99
29	0.00	0.00	10.18	396.00	0.95	397.54	0.00	9.67
30	0.00	0.00	19.26	396.00	0.95	386.54	0.00	18.30
31	0.00	0.00	23.03	396.00	0.95	368.15	0.00	21.88
32	0.00	0.00	19.53	396.00	0.95	350.83	0.00	18.55
33	0.00	0.00	9.69	396.00	0.95	342.28	0.00	9.21
34	0.00	0.00	5.25	338.25	5.45	338.25	0.00	4.99
35	0.00	36.96	2.07	303.81	0.95	337.46	0.00	1.97
36	0.00	27.75	2.04	276.75	0.95	336.25	0.00	1.93
37	0.00	24.53	2.09	252.15	0.95	334.64	0.00	1.98
38	0.00	0.00	1.91	225.09	14.32	333.20	0.00	1.82
39	0.00	0.00	2.14	196.80	0.95	332.72	0.00	2.04
40	0.00	0.00	2.10	276.75	0.95	340.66	0.00	1.99
41	0.00	0.00	10.18	396.00	0.95	338.90	0.00	9.67
42	0.00	0.00	19.26	396.00	0.95	332.47	0.00	18.30
43	0.00	0.00	23.03	396.00	0.95	321.91	0.00	21.88
44	0.00	0.00	19.53	396.00	0.95	305.45	0.00	18.55
45	0.00	0.00	9.69	396.00	0.95	298.16	0.00	9.21
46	0.00	0.00	5.25	338.25	5.45	295.09	0.00	4.99
47	0.00	36.96	2.07	303.81	0.95	295.00	0.00	1.97
48	0.00	27.75	2.04	276.75	0.95	276.75	18.07	1.93
49	0.00	24.53	2.09	252.15	0.95	252.15	23.85	1.98
50	0.00	0.00	1.91	225.09	14.32	228.34	0.00	24.96
51	0.00	0.00	2.14	196.80	0.95	227.55	0.00	2.04
52	0.00	0.00	2.10	276.75	0.95	290.88	0.00	1.99
53	0.00	0.00	10.18	396.00	0.95	374.06	0.00	9.67
54	0.00	0.00	19.26	396.00	0.95	396.00	0.00	18.30
55	0.00	0.00	23.03	396.00	0.95	378.97	0.00	21.88
56	0.00	0.00	19.53	396.00	0.95	362.99	0.00	18.55
57	0.00	0.00	9.69	396.00	0.95	357.23	0.00	9.21
58	0.00	0.00	5.25	338.25	5.45	338.25	0.00	23.63
59	0.00	36.96	2.07	303.81	0.95	303.81	35.92	1.97
60	0.00	27.75	2.04	276.75	0.95	276.75	27.75	1.93
61	0.00	24.53	2.09	252.15	0.95	252.15	24.53	1.98
62	0.00	0.00	1.91	225.09	14.32	233.79	0.00	20.12
63	0.00	0.00	2.14	196.80	0.95	233.44	0.00	2.04
64	0.00	0.00	2.10	276.75	0.95	286.08	0.00	1.99
65	0.00	0.00	10.18	396.00	0.95	384.19	0.00	9.67
66	0.00	0.00	19.26	396.00	0.95	396.00	0.00	18.30
67	0.00	0.00	23.03	396.00	0.95	384.25	0.00	21.88
68	0.00	0.00	19.53	396.00	0.95	368.59	0.00	18.55
69	0.00	0.00	9.69	396.00	0.95	362.54	0.00	9.21
70	0.00	0.00	5.25	338.25	5.45	338.25	0.00	28.63
71	0.00	36.96	2.07	303.81	0.95	303.81	36.96	1.97
72	0.00	27.75	2.04	276.75	0.95	276.75	27.08	1.93
73	0.00	24.53	2.09	252.15	0.95	252.15	24.12	1.98
74	0.00	0.00	1.91	225.09	14.32	226.44	0.00	27.38
75	0.00	0.00	2.14	196.80	0.95	226.39	0.00	2.04
76	0.00	0.00	2.10	276.75	0.95	345.26	0.00	1.99
77	0.00	0.00	10.18	396.00	0.95	369.04	0.00	9.67
78	0.00	0.00	19.26	396.00	0.95	396.00	0.00	18.30
79	0.00	0.00	23.03	396.00	0.95	403.36	0.00	21.88
80	0.00	0.00	19.53	396.00	0.95	389.86	0.00	18.55
81	0.00	0.00	9.69	396.00	0.95	386.42	0.00	9.21
82	0.00	0.00	5.25	338.25	5.45	368.39	0.00	23.06
83	0.00	36.96	2.07	303.81	0.95	367.94	0.00	1.97
84	0.00	27.75	2.04	276.75	0.95	367.15	0.00	1.93

85	0.00	24.53	2.09	252.15	0.95	365.94	0.00	1.98
86	0.00	0.00	1.91	225.09	14.32	365.00	0.00	1.82
87	0.00	0.00	2.14	196.80	0.95	363.99	0.00	2.04
88	0.00	0.00	2.10	276.75	0.95	377.07	0.00	1.99
89	0.00	0.00	10.18	396.00	0.95	375.00	0.00	9.67
90	0.00	0.00	19.26	396.00	0.95	359.08	0.00	18.30
91	0.00	0.00	23.03	396.00	0.95	339.43	0.00	21.88
92	0.00	0.00	19.53	396.00	0.95	322.49	0.00	18.55
93	0.00	0.00	9.69	396.00	0.95	316.82	0.00	9.21
94	0.00	0.00	5.25	338.25	5.45	316.42	0.00	4.99
95	0.00	36.96	2.07	303.81	0.95	317.21	0.00	1.97
96	0.00	27.75	2.04	276.75	0.95	317.02	0.00	1.93
97	0.00	24.53	2.09	252.15	0.95	316.38	0.00	1.98
98	0.00	0.00	1.91	225.09	14.32	315.50	0.00	1.82
99	0.00	0.00	2.14	196.80	0.95	315.09	0.00	2.04
100	0.00	0.00	2.10	276.75	0.95	335.61	0.00	1.99
101	0.00	0.00	10.18	396.00	0.95	339.77	0.00	9.67
102	0.00	0.00	19.26	396.00	0.95	325.82	0.00	18.30
103	0.00	0.00	23.03	396.00	0.95	306.76	0.00	21.88
104	0.00	0.00	19.53	396.00	0.95	288.94	0.00	18.55
105	0.00	0.00	9.69	396.00	0.95	280.62	0.00	9.21
106	0.00	0.00	5.25	338.25	5.45	277.22	0.00	4.99
107	0.00	36.96	2.07	303.81	0.95	277.36	0.00	1.97
108	0.00	27.75	2.04	276.75	0.95	276.75	0.00	1.93
109	0.00	24.53	2.09	252.15	0.95	273.85	1.85	1.98
110	0.00	0.00	1.91	225.09	14.32	272.85	0.00	1.82
111	0.00	0.00	2.14	196.80	0.95	271.61	0.00	2.04
112	0.00	0.00	2.10	276.75	0.95	325.26	0.00	1.99
113	0.00	0.00	10.18	396.00	0.95	431.47	0.00	9.67
114	0.00	0.00	19.26	396.00	0.95	439.05	0.00	18.30
115	0.00	0.00	23.03	396.00	0.95	421.11	0.00	21.88
116	0.00	0.00	19.53	396.00	0.95	403.80	0.00	18.55
117	0.00	0.00	9.69	396.00	0.95	396.00	0.00	9.21
118	0.00	0.00	5.25	338.25	5.45	392.18	0.00	4.99
119	0.00	36.96	2.07	303.81	0.95	392.17	0.00	1.97
120	0.00	27.75	2.04	276.75	0.95	391.49	0.00	1.93
121	0.00	24.53	2.09	252.15	0.95	390.70	0.00	1.98
122	0.00	0.00	1.91	225.09	14.32	390.02	0.00	1.82
123	0.00	0.00	2.14	196.80	0.95	389.23	0.00	2.04
124	0.00	0.00	2.10	276.75	0.95	425.05	0.00	1.99
125	0.00	0.00	10.18	396.00	0.95	423.80	0.00	9.67
126	0.00	0.00	19.26	396.00	0.95	407.15	0.00	18.30
127	0.00	0.00	23.03	396.00	0.95	386.54	0.00	21.88
128	0.00	0.00	19.53	396.00	0.95	369.07	0.00	18.55
129	0.00	0.00	9.69	396.00	0.95	360.82	0.00	9.21
130	0.00	0.00	5.25	338.25	5.45	357.28	0.00	4.99
131	0.00	36.96	2.07	303.81	0.95	357.04	0.00	1.97
132	0.00	27.75	2.04	276.75	0.95	355.94	0.00	1.93
133	0.00	24.53	2.09	252.15	0.95	354.48	0.00	1.98
134	0.00	0.00	1.91	225.09	14.32	353.26	0.00	1.82
135	0.00	0.00	2.14	196.80	0.95	356.04	0.00	2.04
136	0.00	0.00	2.10	276.75	0.95	363.14	0.00	1.99
137	0.00	0.00	10.18	396.00	0.95	357.90	0.00	9.67
138	0.00	0.00	19.26	396.00	0.95	343.08	0.00	18.30
139	0.00	0.00	23.03	396.00	0.95	323.91	0.00	21.88
140	0.00	0.00	19.53	396.00	0.95	306.89	0.00	18.55
141	0.00	0.00	9.69	396.00	0.95	298.39	0.00	9.21
142	0.00	0.00	5.25	338.25	5.45	296.09	0.00	4.99
143	0.00	36.96	2.07	303.81	0.95	297.08	0.00	1.97
144	0.00	27.75	2.04	276.75	0.95	296.26	0.00	1.93
145	0.00	24.53	2.09	252.15	0.95	294.71	0.00	1.98

146	0.00	0.00	1.91	225.09	14.32	293.42	0.00	1.82
147	0.00	0.00	2.14	196.80	0.95	292.12	0.00	2.04
148	0.00	0.00	2.10	276.75	0.95	305.02	0.00	1.99
149	0.00	0.00	10.18	396.00	0.95	303.53	0.00	9.67
150	0.00	0.00	19.26	396.00	0.95	288.56	0.00	18.30
151	0.00	0.00	23.03	396.00	0.95	276.28	0.00	21.88
152	0.00	0.00	19.53	396.00	0.95	260.71	0.00	18.55
153	0.00	0.00	9.69	396.00	0.95	252.05	0.00	9.21
154	0.00	0.00	5.25	338.25	5.45	248.53	0.00	4.99
155	0.00	36.96	2.07	303.81	0.95	248.25	0.00	1.97
156	0.00	27.75	2.04	276.75	0.95	247.22	0.00	1.93
157	0.00	24.53	2.09	252.15	0.95	246.29	0.00	1.98
158	0.00	0.00	1.91	225.09	14.32	245.60	0.00	1.82
159	0.00	0.00	2.14	196.80	0.95	244.61	0.00	2.04
160	0.00	0.00	2.10	276.75	0.95	278.04	0.00	1.99
161	0.00	0.00	10.18	396.00	0.95	315.66	0.00	9.67
162	0.00	0.00	19.26	396.00	0.95	313.39	0.00	18.30
163	0.00	0.00	23.03	396.00	0.95	309.46	0.00	21.88
164	0.00	0.00	19.53	396.00	0.95	295.63	0.00	18.55
165	0.00	0.00	9.69	396.00	0.95	287.39	0.00	9.21
166	0.00	0.00	5.25	338.25	5.45	283.86	0.00	4.99
167	0.00	36.96	2.07	303.81	0.95	284.04	0.00	1.97
168	0.00	27.75	2.04	276.75	0.95	283.67	0.00	1.93
169	0.00	24.53	2.09	252.15	0.95	282.65	0.00	1.98
170	0.00	0.00	1.91	225.09	14.32	281.80	0.00	1.82
171	0.00	0.00	2.14	196.80	0.95	289.47	0.00	2.04
172	0.00	0.00	2.10	276.75	0.95	311.29	0.00	1.99
173	0.00	0.00	10.18	396.00	0.95	316.55	0.00	9.67
174	0.00	0.00	19.26	396.00	0.95	313.25	0.00	18.30
175	0.00	0.00	23.03	396.00	0.95	299.40	0.00	21.88
176	0.00	0.00	19.53	396.00	0.95	281.72	0.00	18.55
177	0.00	0.00	9.69	396.00	0.95	273.34	0.00	9.21
178	0.00	0.00	5.25	338.25	5.45	270.80	0.00	4.99
179	0.00	36.96	2.07	303.81	0.95	270.82	0.00	1.97
180	0.00	27.75	2.04	276.75	0.95	271.49	0.00	1.93

Appendix E: Compromise Solution (s = 1) for the De Novo Reservoir System, Metaoptimum measured with respect to the De Novo Reservoir System

Table E-7 Optimal Objective Function Values

Required Active Storage (10^6 m^3)	Sum of Storage Deviations (10^6 m^3)
335.67	15158.66

Table E-8 Optimal Maximum and Minimum Storage Levels, and Minimum Fration of Target Water Supply

Optimal Maximum Storage (10^6 m^3)	Optimal Minimum Storage (10^6 m^3)	Minimum Fraction of Target Water Supply
335.67	0	0.95

Please note the following definitions of abbreviations.

Opt. - Optimal
Min. - Minimum
Rel. - Reservoir Release
Max. - Maximum
Stor. - Reservoir Storage
• - Dimensionless

Table E-9 Optimal Decision Variables, and Monthly Target Water Supply and Storage Levels, (10^6 m^3)

Time	Opt. Min. Rel.	Opt. Max. Rel.	Target Water Supply	Target Stor.	Opt. Upper Bound on Water Supply*	Opt. Stor.	Opt. Rel.	Opt. Water Supply
1	0.00	0.00	2.09	252.15	12.69	167.33	0.00	1.98
2	0.00	0.00	1.91	225.09	15.08	166.62	0.00	1.82
3	0.00	0.75	2.14	196.80	13.78	166.88	0.00	2.04
4	0.00	0.00	2.10	276.75	2.75	214.26	0.00	1.99
5	0.00	0.00	10.18	396.00	5.60	241.67	0.00	9.67
6	0.00	0.00	19.26	396.00	2.35	237.56	0.00	18.30
7	0.00	0.00	23.03	396.00	1.27	223.23	0.00	21.88
8	0.00	0.00	19.53	396.00	0.95	207.13	0.00	18.55
9	0.00	0.00	9.69	396.00	0.95	199.80	0.00	9.21
10	0.00	0.00	5.25	338.25	0.95	197.46	0.00	4.99
11	0.00	0.00	2.07	303.81	1.08	197.80	0.00	1.97
12	0.00	0.00	2.04	276.75	14.25	197.47	0.00	1.93
13	0.00	0.00	2.09	252.15	12.69	197.05	0.00	1.98
14	0.00	0.00	1.91	225.09	15.08	196.64	0.00	1.82
15	0.00	0.75	2.14	196.80	13.78	195.83	0.00	2.04
16	0.00	0.00	2.10	276.75	2.75	279.62	0.00	1.99
17	0.00	0.00	10.18	396.00	5.60	295.98	0.00	9.67
18	0.00	0.00	19.26	396.00	2.35	288.74	0.00	18.30
19	0.00	0.00	23.03	396.00	1.27	272.82	0.00	21.88
20	0.00	0.00	19.53	396.00	0.95	257.98	0.00	18.55
21	0.00	0.00	9.69	396.00	0.95	249.52	0.00	9.21

Appendix E: Compromise Solution (s = 1) for the De Novo Reservoir System, Metaoptimum measured with respect to the De Novo Reservoir System

22	0.00	0.00	5.25	338.25	0.95	246.44	0.00	4.99
23	0.00	0.00	2.07	303.81	1.08	246.84	0.00	1.97
24	0.00	0.00	2.04	276.75	14.25	246.90	0.00	1.93
25	0.00	0.00	2.09	252.15	12.69	246.69	0.00	1.98
26	0.00	0.00	1.91	225.09	15.08	225.09	0.00	22.99
27	0.00	0.75	2.14	196.80	13.78	196.80	0.64	29.52
28	0.00	0.00	2.10	276.75	2.75	273.41	0.00	1.99
29	0.00	0.00	10.18	396.00	5.60	335.67	0.00	14.43
30	0.00	0.00	19.26	396.00	2.35	324.67	0.00	18.30
31	0.00	0.00	23.03	396.00	1.27	306.28	0.00	21.88
32	0.00	0.00	19.53	396.00	0.95	288.96	0.00	18.55
33	0.00	0.00	9.69	396.00	0.95	280.41	0.00	9.21
34	0.00	0.00	5.25	338.25	0.95	276.38	0.00	4.99
35	0.00	0.00	2.07	303.81	1.08	275.59	0.00	1.97
36	0.00	0.00	2.04	276.75	14.25	274.38	0.00	1.93
37	0.00	0.00	2.09	252.15	12.69	272.77	0.00	1.98
38	0.00	0.00	1.91	225.09	15.08	271.33	0.00	1.82
39	0.00	0.75	2.14	196.80	13.78	270.85	0.00	2.04
40	0.00	0.00	2.10	276.75	2.75	278.79	0.00	1.99
41	0.00	0.00	10.18	396.00	5.60	277.03	0.00	9.67
42	0.00	0.00	19.26	396.00	2.35	270.60	0.00	18.30
43	0.00	0.00	23.03	396.00	1.27	260.04	0.00	21.88
44	0.00	0.00	19.53	396.00	0.95	243.58	0.00	18.55
45	0.00	0.00	9.69	396.00	0.95	236.29	0.00	9.21
46	0.00	0.00	5.25	338.25	0.95	233.22	0.00	4.99
47	0.00	0.00	2.07	303.81	1.08	233.13	0.00	1.97
48	0.00	0.00	2.04	276.75	14.25	232.95	0.00	1.93
49	0.00	0.00	2.09	252.15	12.69	232.19	0.00	1.98
50	0.00	0.00	1.91	225.09	15.08	225.09	0.00	8.25
51	0.00	0.75	2.14	196.80	13.78	213.41	0.75	12.17
52	0.00	0.00	2.10	276.75	2.75	276.75	0.00	1.99
53	0.00	0.00	10.18	396.00	5.60	335.67	0.00	33.92
54	0.00	0.00	19.26	396.00	2.35	335.67	0.00	40.24
55	0.00	0.00	23.03	396.00	1.27	318.64	0.00	21.88
56	0.00	0.00	19.53	396.00	0.95	302.66	0.00	18.55
57	0.00	0.00	9.69	396.00	0.95	296.90	0.00	9.21
58	0.00	0.00	5.25	338.25	0.95	296.57	0.00	4.99
59	0.00	0.00	2.07	303.81	1.08	298.05	0.00	1.97
60	0.00	0.00	2.04	276.75	14.25	276.75	0.00	23.92
61	0.00	0.00	2.09	252.15	12.69	252.15	0.00	26.51
62	0.00	0.00	1.91	225.09	15.08	225.09	0.00	28.82
63	0.00	0.75	2.14	196.80	13.78	196.80	0.45	29.52
64	0.00	0.00	2.10	276.75	2.75	249.45	0.00	1.99
65	0.00	0.00	10.18	396.00	5.60	335.67	0.00	21.54
66	0.00	0.00	19.26	396.00	2.35	335.67	0.00	30.11
67	0.00	0.00	23.03	396.00	1.27	323.92	0.00	21.88
68	0.00	0.00	19.53	396.00	0.95	308.26	0.00	18.55
69	0.00	0.00	9.69	396.00	0.95	302.21	0.00	9.21
70	0.00	0.00	5.25	338.25	0.95	301.57	0.00	4.99
71	0.00	0.00	2.07	303.81	1.08	303.81	0.00	2.25
72	0.00	0.00	2.04	276.75	14.25	276.75	0.00	29.01
73	0.00	0.00	2.09	252.15	12.69	252.15	0.00	26.10
74	0.00	0.00	1.91	225.09	15.08	225.09	0.00	28.73
75	0.00	0.75	2.14	196.80	13.78	196.80	0.75	29.52
76	0.00	0.00	2.10	276.75	2.75	311.90	0.00	5.77
77	0.00	0.00	10.18	396.00	5.60	335.67	0.00	9.67
78	0.00	0.00	19.26	396.00	2.35	335.67	0.00	45.26
79	0.00	0.00	23.03	396.00	1.27	335.67	0.00	29.24
80	0.00	0.00	19.53	396.00	0.95	322.17	0.00	18.55
81	0.00	0.00	9.69	396.00	0.95	318.74	0.00	9.21
82	0.00	0.00	5.25	338.25	0.95	318.78	0.00	4.99

Appendix E: Compromise Solution (s = 1) for the De Novo Reservoir System, Metaoptimum measured with respect to the De Novo Reservoir System

83	0.00	0.00	2.07	303.81	1.08	318.33	0.00	1.97
84	0.00	0.00	2.04	276.75	14.25	317.54	0.00	1.93
85	0.00	0.00	2.09	252.15	12.69	316.33	0.00	1.98
86	0.00	0.00	1.91	225.09	15.08	315.39	0.00	1.82
87	0.00	0.75	2.14	196.80	13.78	314.38	0.00	2.04
88	0.00	0.00	2.10	276.75	2.75	327.46	0.00	1.99
89	0.00	0.00	10.18	396.00	5.60	325.40	0.00	9.67
90	0.00	0.00	19.26	396.00	2.35	309.47	0.00	18.30
91	0.00	0.00	23.03	396.00	1.27	289.82	0.00	21.88
92	0.00	0.00	19.53	396.00	0.95	272.88	0.00	18.55
93	0.00	0.00	9.69	396.00	0.95	267.21	0.00	9.21
94	0.00	0.00	5.25	338.25	0.95	266.81	0.00	4.99
95	0.00	0.00	2.07	303.81	1.08	267.60	0.00	1.97
96	0.00	0.00	2.04	276.75	14.25	267.41	0.00	1.93
97	0.00	0.00	2.09	252.15	12.69	266.77	0.00	1.98
98	0.00	0.00	1.91	225.09	15.08	265.89	0.00	1.82
99	0.00	0.75	2.14	196.80	13.78	265.48	0.00	2.04
100	0.00	0.00	2.10	276.75	2.75	286.00	0.00	1.99
101	0.00	0.00	10.18	396.00	5.60	290.16	0.00	9.67
102	0.00	0.00	19.26	396.00	2.35	276.21	0.00	18.30
103	0.00	0.00	23.03	396.00	1.27	257.15	0.00	21.88
104	0.00	0.00	19.53	396.00	0.95	239.33	0.00	18.55
105	0.00	0.00	9.69	396.00	0.95	231.01	0.00	9.21
106	0.00	0.00	5.25	338.25	0.95	227.61	0.00	4.99
107	0.00	0.00	2.07	303.81	1.08	227.75	0.00	1.97
108	0.00	0.00	2.04	276.75	14.25	227.14	0.00	1.93
109	0.00	0.00	2.09	252.15	12.69	226.10	0.00	1.98
110	0.00	0.00	1.91	225.09	15.08	225.09	0.00	1.82
111	0.00	0.75	2.14	196.80	13.78	223.10	0.75	2.04
112	0.00	0.00	2.10	276.75	2.75	276.75	0.00	1.99
113	0.00	0.00	10.18	396.00	5.60	335.67	0.00	56.96
114	0.00	0.00	19.26	396.00	2.35	335.67	0.00	25.88
115	0.00	0.00	23.03	396.00	1.27	317.73	0.00	21.88
116	0.00	0.00	19.53	396.00	0.95	300.42	0.00	18.55
117	0.00	0.00	9.69	396.00	0.95	292.62	0.00	9.21
118	0.00	0.00	5.25	338.25	0.95	288.81	0.00	4.99
119	0.00	0.00	2.07	303.81	1.08	288.80	0.00	1.97
120	0.00	0.00	2.04	276.75	14.25	288.11	0.00	1.93
121	0.00	0.00	2.09	252.15	12.69	287.33	0.00	1.98
122	0.00	0.00	1.91	225.09	15.08	286.64	0.00	1.82
123	0.00	0.75	2.14	196.80	13.78	285.86	0.00	2.04
124	0.00	0.00	2.10	276.75	2.75	321.67	0.00	1.99
125	0.00	0.00	10.18	396.00	5.60	320.42	0.00	9.67
126	0.00	0.00	19.26	396.00	2.35	303.78	0.00	18.30
127	0.00	0.00	23.03	396.00	1.27	283.16	0.00	21.88
128	0.00	0.00	19.53	396.00	0.95	265.70	0.00	18.55
129	0.00	0.00	9.69	396.00	0.95	257.45	0.00	9.21
130	0.00	0.00	5.25	338.25	0.95	253.90	0.00	4.99
131	0.00	0.00	2.07	303.81	1.08	253.66	0.00	1.97
132	0.00	0.00	2.04	276.75	14.25	252.56	0.00	1.93
133	0.00	0.00	2.09	252.15	12.69	251.10	0.00	1.98
134	0.00	0.00	1.91	225.09	15.08	249.88	0.00	1.82
135	0.00	0.75	2.14	196.80	13.78	252.66	0.00	2.04
136	0.00	0.00	2.10	276.75	2.75	259.76	0.00	1.99
137	0.00	0.00	10.18	396.00	5.60	254.53	0.00	9.67
138	0.00	0.00	19.26	396.00	2.35	239.70	0.00	18.30
139	0.00	0.00	23.03	396.00	1.27	220.54	0.00	21.88
140	0.00	0.00	19.53	396.00	0.95	203.51	0.00	18.55
141	0.00	0.00	9.69	396.00	0.95	195.01	0.00	9.21
142	0.00	0.00	5.25	338.25	0.95	192.71	0.00	4.99
143	0.00	0.00	2.07	303.81	1.08	193.70	0.00	1.97

Appendix E: Compromise Solution (s = 1) for the De Novo Reservoir System, Metaoptimum measured with respect to the De Novo Reservoir System

144	0.00	0.00	2.04	276.75	14.25	192.89	0.00	1.93
145	0.00	0.00	2.09	252.15	12.69	191.33	0.00	1.98
146	0.00	0.00	1.91	225.09	15.08	190.05	0.00	1.82
147	0.00	0.75	2.14	196.80	13.78	188.74	0.00	2.04
148	0.00	0.00	2.10	276.75	2.75	201.65	0.00	1.99
149	0.00	0.00	10.18	396.00	5.60	200.15	0.00	9.67
150	0.00	0.00	19.26	396.00	2.35	185.18	0.00	18.30
151	0.00	0.00	23.03	396.00	1.27	172.90	0.00	21.88
152	0.00	0.00	19.53	396.00	0.95	157.33	0.00	18.55
153	0.00	0.00	9.69	396.00	0.95	148.67	0.00	9.21
154	0.00	0.00	5.25	338.25	0.95	145.15	0.00	4.99
155	0.00	0.00	2.07	303.81	1.08	144.87	0.00	1.97
156	0.00	0.00	2.04	276.75	14.25	143.84	0.00	1.93
157	0.00	0.00	2.09	252.15	12.69	142.92	0.00	1.98
158	0.00	0.00	1.91	225.09	15.08	142.22	0.00	1.82
159	0.00	0.75	2.14	196.80	13.78	141.23	0.00	2.04
160	0.00	0.00	2.10	276.75	2.75	174.66	0.00	1.99
161	0.00	0.00	10.18	396.00	5.60	212.28	0.00	9.67
162	0.00	0.00	19.26	396.00	2.35	210.02	0.00	18.30
163	0.00	0.00	23.03	396.00	1.27	206.08	0.00	21.88
164	0.00	0.00	19.53	396.00	0.95	192.25	0.00	18.55
165	0.00	0.00	9.69	396.00	0.95	184.01	0.00	9.21
166	0.00	0.00	5.25	338.25	0.95	180.49	0.00	4.99
167	0.00	0.00	2.07	303.81	1.08	180.67	0.00	1.97
168	0.00	0.00	2.04	276.75	14.25	180.29	0.00	1.93
169	0.00	0.00	2.09	252.15	12.69	179.27	0.00	1.98
170	0.00	0.00	1.91	225.09	15.08	178.42	0.00	1.82
171	0.00	0.75	2.14	196.80	13.78	186.10	0.00	2.04
172	0.00	0.00	2.10	276.75	2.75	207.91	0.00	1.99
173	0.00	0.00	10.18	396.00	5.60	213.17	0.00	9.67
174	0.00	0.00	19.26	396.00	2.35	209.87	0.00	18.30
175	0.00	0.00	23.03	396.00	1.27	196.03	0.00	21.88
176	0.00	0.00	19.53	396.00	0.95	178.35	0.00	18.55
177	0.00	0.00	9.69	396.00	0.95	169.97	0.00	9.21
178	0.00	0.00	5.25	338.25	0.95	167.42	0.00	4.99
179	0.00	0.00	2.07	303.81	1.08	167.44	0.00	1.97
180	0.00	0.00	2.04	276.75	14.25	168.12	0.00	1.93

Appendix E: Compromise Solution (s = 2) for the De Novo Reservoir System, Metaoptimum measured with respect to the De Novo Reservoir System

Table E-10 Optimal Objective Function Values

Required Active Storage (10^6 m^3)	Sum of Storage Deviations (10^6 m^3)
301.65	19556.83

Table E-11 Optimal Maximum and Minimum Storage Levels, and Minimum Fration of Target Water Supply

Optimal Maximum Storage (10^6 m^3)	Optimal Minimum Storage (10^6 m^3)	Minimum Fraction of Target Water Supply
301.65	0	0.95

Please note the following definitions of abbreviations.

Opt.	- Optimal
Min.	- Minimum
Rel.	- Reservoir Release
Max.	- Maximum
Stor.	- Reservoir Storage
*	- Dimensionless

Table E-12 Optimal Decision Variables, and Monthly Target Water Supply and Storage Levels, (10^6 m^3)

Time	Opt. Min. Rel.	Opt. Max. Rel.	Target Water Supply	Target Stor.	Opt. Upper Bound on Water Supply*	Opt. Stor.	Opt. Rel.	Opt. Water Supply
1	0.00	0.00	2.09	252.15	9.30	133.31	0.00	1.98
2	0.00	0.00	1.91	225.09	15.08	132.59	0.00	1.82
3	0.00	0.00	2.14	196.80	14.13	132.86	0.00	2.04
4	0.00	0.00	2.10	276.75	18.95	180.23	0.00	1.99
5	0.00	0.00	10.18	396.00	8.14	207.64	0.00	9.67
6	0.00	0.00	19.26	396.00	2.35	203.54	0.00	18.30
7	0.00	0.00	23.03	396.00	1.27	189.20	0.00	21.88
8	0.00	0.00	19.53	396.00	0.95	173.10	0.00	18.55
9	0.00	0.00	9.69	396.00	0.95	165.78	0.00	9.21
10	0.00	0.00	5.25	338.25	0.95	163.44	0.00	4.99
11	0.00	0.00	2.07	303.81	0.95	163.78	0.00	1.97
12	0.00	0.00	2.04	276.75	0.95	163.44	0.00	1.93
13	0.00	0.00	2.09	252.15	9.30	163.03	0.00	1.98
14	0.00	0.00	1.91	225.09	15.08	162.61	0.00	1.82
15	0.00	0.00	2.14	196.80	14.13	161.81	0.00	2.04
16	0.00	0.00	2.10	276.75	18.95	245.59	0.00	1.99
17	0.00	0.00	10.18	396.00	8.14	261.95	0.00	9.67
18	0.00	0.00	19.26	396.00	2.35	254.72	0.00	18.30
19	0.00	0.00	23.03	396.00	1.27	238.80	0.00	21.88
20	0.00	0.00	19.53	396.00	0.95	223.96	0.00	18.55
21	0.00	0.00	9.69	396.00	0.95	215.50	0.00	9.21

Appendix E: Compromise Solution (s = 2) for the De Novo Reservoir System, Metaoptimum measured with respect to the De Novo Reservoir System

22	0.00	0.00	5.25	338.25	0.95	212.41	0.00	4.99
23	0.00	0.00	2.07	303.81	0.95	212.81	0.00	1.97
24	0.00	0.00	2.04	276.75	0.95	212.88	0.00	1.93
25	0.00	0.00	2.09	252.15	9.30	212.66	0.00	1.98
26	0.00	0.00	1.91	225.09	15.08	212.24	0.00	1.82
27	0.00	0.00	2.14	196.80	14.13	200.14	0.00	13.96
28	0.00	0.00	2.10	276.75	18.95	276.75	0.00	1.99
29	0.00	0.00	10.18	396.00	8.14	301.65	0.00	51.80
30	0.00	0.00	19.26	396.00	2.35	290.64	0.00	18.30
31	0.00	0.00	23.03	396.00	1.27	272.25	0.00	21.88
32	0.00	0.00	19.53	396.00	0.95	254.93	0.00	18.55
33	0.00	0.00	9.69	396.00	0.95	246.38	0.00	9.21
34	0.00	0.00	5.25	338.25	0.95	242.36	0.00	4.99
35	0.00	0.00	2.07	303.81	0.95	241.57	0.00	1.97
36	0.00	0.00	2.04	276.75	0.95	240.35	0.00	1.93
37	0.00	0.00	2.09	252.15	9.30	238.75	0.00	1.98
38	0.00	0.00	1.91	225.09	15.08	237.30	0.00	1.82
39	0.00	0.00	2.14	196.80	14.13	236.83	0.00	2.04
40	0.00	0.00	2.10	276.75	18.95	244.76	0.00	1.99
41	0.00	0.00	10.18	396.00	8.14	243.00	0.00	9.67
42	0.00	0.00	19.26	396.00	2.35	236.58	0.00	18.30
43	0.00	0.00	23.03	396.00	1.27	226.01	0.00	21.88
44	0.00	0.00	19.53	396.00	0.95	209.55	0.00	18.55
45	0.00	0.00	9.69	396.00	0.95	202.27	0.00	9.21
46	0.00	0.00	5.25	338.25	0.95	199.20	0.00	4.99
47	0.00	0.00	2.07	303.81	0.95	199.11	0.00	1.97
48	0.00	0.00	2.04	276.75	0.95	198.92	0.00	1.93
49	0.00	0.00	2.09	252.15	9.30	198.17	0.00	1.98
50	0.00	0.00	1.91	225.09	15.08	197.50	0.00	1.82
51	0.00	0.00	2.14	196.80	14.13	196.71	0.00	2.04
52	0.00	0.00	2.10	276.75	18.95	260.04	0.00	1.99
53	0.00	0.00	10.18	396.00	8.14	301.65	0.00	51.23
54	0.00	0.00	19.26	396.00	2.35	301.65	0.00	40.24
55	0.00	0.00	23.03	396.00	1.27	284.62	0.00	21.88
56	0.00	0.00	19.53	396.00	0.95	268.64	0.00	18.55
57	0.00	0.00	9.69	396.00	0.95	262.88	0.00	9.21
58	0.00	0.00	5.25	338.25	0.95	262.54	0.00	4.99
59	0.00	0.00	2.07	303.81	0.95	264.02	0.00	1.97
60	0.00	0.00	2.04	276.75	0.95	264.71	0.00	1.93
61	0.00	0.00	2.09	252.15	9.30	252.15	0.00	14.47
62	0.00	0.00	1.91	225.09	15.08	225.09	0.00	28.82
63	0.00	0.00	2.14	196.80	14.13	224.10	0.00	2.67
64	0.00	0.00	2.10	276.75	18.95	276.75	0.00	1.99
65	0.00	0.00	10.18	396.00	8.14	301.65	0.00	82.87
66	0.00	0.00	19.26	396.00	2.35	301.65	0.00	30.11
67	0.00	0.00	23.03	396.00	1.27	289.90	0.00	21.88
68	0.00	0.00	19.53	396.00	0.95	274.24	0.00	18.55
69	0.00	0.00	9.69	396.00	0.95	268.19	0.00	9.21
70	0.00	0.00	5.25	338.25	0.95	267.54	0.00	4.99
71	0.00	0.00	2.07	303.81	0.95	270.06	0.00	1.97
72	0.00	0.00	2.04	276.75	0.95	270.08	0.00	1.93
73	0.00	0.00	2.09	252.15	9.30	252.15	0.00	19.43
74	0.00	0.00	1.91	225.09	15.08	225.09	0.00	28.73
75	0.00	0.00	2.14	196.80	14.13	196.80	0.00	30.27
76	0.00	0.00	2.10	276.75	18.95	277.88	0.00	39.79
77	0.00	0.00	10.18	396.00	8.14	301.65	0.00	9.67
78	0.00	0.00	19.26	396.00	2.35	301.65	0.00	45.26
79	0.00	0.00	23.03	396.00	1.27	301.65	0.00	29.24
80	0.00	0.00	19.53	396.00	0.95	288.15	0.00	18.55
81	0.00	0.00	9.69	396.00	0.95	284.71	0.00	9.21
82	0.00	0.00	5.25	338.25	0.95	284.75	0.00	4.99

83	0.00	0.00	2.07	303.81	0.95	284.30	0.00	1.97
84	0.00	0.00	2.04	276.75	0.95	283.52	0.00	1.93
85	0.00	0.00	2.09	252.15	9.30	282.31	0.00	1.98
86	0.00	0.00	1.91	225.09	15.08	281.37	0.00	1.82
87	0.00	0.00	2.14	196.80	14.13	280.35	0.00	2.04
88	0.00	0.00	2.10	276.75	18.95	293.44	0.00	1.99
89	0.00	0.00	10.18	396.00	8.14	291.37	0.00	9.67
90	0.00	0.00	19.26	396.00	2.35	275.44	0.00	18.30
91	0.00	0.00	23.03	396.00	1.27	255.79	0.00	21.88
92	0.00	0.00	19.53	396.00	0.95	238.85	0.00	18.55
93	0.00	0.00	9.69	396.00	0.95	233.18	0.00	9.21
94	0.00	0.00	5.25	338.25	0.95	232.79	0.00	4.99
95	0.00	0.00	2.07	303.81	0.95	233.58	0.00	1.97
96	0.00	0.00	2.04	276.75	0.95	233.38	0.00	1.93
97	0.00	0.00	2.09	252.15	9.30	232.75	0.00	1.98
98	0.00	0.00	1.91	225.09	15.08	231.86	0.00	1.82
99	0.00	0.00	2.14	196.80	14.13	231.46	0.00	2.04
100	0.00	0.00	2.10	276.75	18.95	251.97	0.00	1.99
101	0.00	0.00	10.18	396.00	8.14	256.13	0.00	9.67
102	0.00	0.00	19.26	396.00	2.35	242.19	0.00	18.30
103	0.00	0.00	23.03	396.00	1.27	223.12	0.00	21.88
104	0.00	0.00	19.53	396.00	0.95	205.31	0.00	18.55
105	0.00	0.00	9.69	396.00	0.95	196.99	0.00	9.21
106	0.00	0.00	5.25	338.25	0.95	193.59	0.00	4.99
107	0.00	0.00	2.07	303.81	0.95	193.73	0.00	1.97
108	0.00	0.00	2.04	276.75	0.95	193.12	0.00	1.93
109	0.00	0.00	2.09	252.15	9.30	192.07	0.00	1.98
110	0.00	0.00	1.91	225.09	15.08	191.07	0.00	1.82
111	0.00	0.00	2.14	196.80	14.13	189.83	0.00	2.04
112	0.00	0.00	2.10	276.75	18.95	243.47	0.00	1.99
113	0.00	0.00	10.18	396.00	8.14	301.65	0.00	57.71
114	0.00	0.00	19.26	396.00	2.35	301.65	0.00	25.88
115	0.00	0.00	23.03	396.00	1.27	283.71	0.00	21.88
116	0.00	0.00	19.53	396.00	0.95	266.40	0.00	18.55
117	0.00	0.00	9.69	396.00	0.95	258.60	0.00	9.21
118	0.00	0.00	5.25	338.25	0.95	254.78	0.00	4.99
119	0.00	0.00	2.07	303.81	0.95	254.77	0.00	1.97
120	0.00	0.00	2.04	276.75	0.95	254.09	0.00	1.93
121	0.00	0.00	2.09	252.15	9.30	253.30	0.00	1.98
122	0.00	0.00	1.91	225.09	15.08	252.62	0.00	1.82
123	0.00	0.00	2.14	196.80	14.13	251.83	0.00	2.04
124	0.00	0.00	2.10	276.75	18.95	287.65	0.00	1.99
125	0.00	0.00	10.18	396.00	8.14	286.40	0.00	9.67
126	0.00	0.00	19.26	396.00	2.35	269.75	0.00	18.30
127	0.00	0.00	23.03	396.00	1.27	249.14	0.00	21.88
128	0.00	0.00	19.53	396.00	0.95	231.67	0.00	18.55
129	0.00	0.00	9.69	396.00	0.95	223.42	0.00	9.21
130	0.00	0.00	5.25	338.25	0.95	219.87	0.00	4.99
131	0.00	0.00	2.07	303.81	0.95	219.63	0.00	1.97
132	0.00	0.00	2.04	276.75	0.95	218.54	0.00	1.93
133	0.00	0.00	2.09	252.15	9.30	217.08	0.00	1.98
134	0.00	0.00	1.91	225.09	15.08	215.86	0.00	1.82
135	0.00	0.00	2.14	196.80	14.13	218.63	0.00	2.04
136	0.00	0.00	2.10	276.75	18.95	225.74	0.00	1.99
137	0.00	0.00	10.18	396.00	8.14	220.50	0.00	9.67
138	0.00	0.00	19.26	396.00	2.35	205.67	0.00	18.30
139	0.00	0.00	23.03	396.00	1.27	186.51	0.00	21.88
140	0.00	0.00	19.53	396.00	0.95	169.48	0.00	18.55
141	0.00	0.00	9.69	396.00	0.95	160.98	0.00	9.21
142	0.00	0.00	5.25	338.25	0.95	158.69	0.00	4.99
143	0.00	0.00	2.07	303.81	0.95	159.68	0.00	1.97

Appendix E: Compromise Solution (s = 2) for the De Novo Reservoir System, Metaoptimum measured with respect to the De Novo Reservoir System

144	0.00	0.00	2.04	276.75	0.95	158.86	0.00	1.93
145	0.00	0.00	2.09	252.15	9.30	157.31	0.00	1.98
146	0.00	0.00	1.91	225.09	15.08	156.02	0.00	1.82
147	0.00	0.00	2.14	196.80	14.13	154.72	0.00	2.04
148	0.00	0.00	2.10	276.75	18.95	167.62	0.00	1.99
149	0.00	0.00	10.18	396.00	8.14	166.12	0.00	9.67
150	0.00	0.00	19.26	396.00	2.35	151.16	0.00	18.30
151	0.00	0.00	23.03	396.00	1.27	138.88	0.00	21.88
152	0.00	0.00	19.53	396.00	0.95	123.31	0.00	18.55
153	0.00	0.00	9.69	396.00	0.95	114.65	0.00	9.21
154	0.00	0.00	5.25	338.25	0.95	111.13	0.00	4.99
155	0.00	0.00	2.07	303.81	0.95	110.85	0.00	1.97
156	0.00	0.00	2.04	276.75	0.95	109.82	0.00	1.93
157	0.00	0.00	2.09	252.15	9.30	108.89	0.00	1.98
158	0.00	0.00	1.91	225.09	15.08	108.20	0.00	1.82
159	0.00	0.00	2.14	196.80	14.13	107.21	0.00	2.04
160	0.00	0.00	2.10	276.75	18.95	140.64	0.00	1.99
161	0.00	0.00	10.18	396.00	8.14	178.26	0.00	9.67
162	0.00	0.00	19.26	396.00	2.35	175.99	0.00	18.30
163	0.00	0.00	23.03	396.00	1.27	172.06	0.00	21.88
164	0.00	0.00	19.53	396.00	0.95	158.23	0.00	18.55
165	0.00	0.00	9.69	396.00	0.95	149.99	0.00	9.21
166	0.00	0.00	5.25	338.25	0.95	146.46	0.00	4.99
167	0.00	0.00	2.07	303.81	0.95	146.64	0.00	1.97
168	0.00	0.00	2.04	276.75	0.95	146.27	0.00	1.93
169	0.00	0.00	2.09	252.15	9.30	145.24	0.00	1.98
170	0.00	0.00	1.91	225.09	15.08	144.40	0.00	1.82
171	0.00	0.00	2.14	196.80	14.13	152.07	0.00	2.04
172	0.00	0.00	2.10	276.75	18.95	173.89	0.00	1.99
173	0.00	0.00	10.18	396.00	8.14	179.15	0.00	9.67
174	0.00	0.00	19.26	396.00	2.35	175.84	0.00	18.30
175	0.00	0.00	23.03	396.00	1.27	162.00	0.00	21.88
176	0.00	0.00	19.53	396.00	0.95	144.32	0.00	18.55
177	0.00	0.00	9.69	396.00	0.95	135.94	0.00	9.21
178	0.00	0.00	5.25	338.25	0.95	133.40	0.00	4.99
179	0.00	0.00	2.07	303.81	0.95	133.42	0.00	1.97
180	0.00	0.00	2.04	276.75	0.95	134.09	0.00	1.93

Appendix E: Compromise Solution (s = 100) for the De Novo Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

Table E-13 Optimal Objective Function Values

Required Active Storage (10^6 m^3)	Sum of Storage Deviations (10^6 m^3)
408.56	9782.45

Table E-14 Optimal Maximum and Minimum Storage Levels, and Minimum Fration of Target Water Supply

Optimal Maximum Storage (10^6 m^3)	Optimal Minimum Storage (10^6 m^3)	Minimum Fraction of Target Water Supply
408.56	0	0.95

Please note the following definitions of abbreviations.

Opt. - Optimal
Min. - Minimum
Rel. - Reservoir Release
Max. - Maximum
Stor. - Reservoir Storage
* - Dimensionless

Table E-15 Optimal Decision Variables, Monthly Target Water Supply and Storage Levels, (10^6 m^3)

Time	Opt. Min. Rel.	Opt. Max. Rel.	Target Water Supply	Target Stor.	Opt. Upper Bound on Water Supply*	Opt. Stor.	Opt. Rel.	Opt. Water Supply
1	0.00	0.00	2.09	252.15	12.69	240.21	0.00	1.98
2	0.00	0.00	1.91	225.09	14.32	239.50	0.00	1.82
3	0.00	0.00	2.14	196.80	0.95	239.76	0.00	2.04
4	0.00	0.00	2.10	276.75	0.95	287.14	0.00	1.99
5	0.00	0.00	10.18	396.00	1.07	314.55	0.00	9.67
6	0.00	0.00	19.26	396.00	1.34	310.44	0.00	18.30
7	0.00	0.00	23.03	396.00	0.95	296.11	0.00	21.88
8	0.00	0.00	19.53	396.00	0.95	280.01	0.00	18.55
9	0.00	0.00	9.69	396.00	0.95	272.68	0.00	9.21
10	0.00	0.00	5.25	338.25	7.69	270.34	0.00	4.99
11	0.00	0.00	2.07	303.81	18.77	270.68	0.00	1.97
12	0.00	0.00	2.04	276.75	14.58	270.35	0.00	1.93
13	0.00	0.00	2.09	252.15	12.69	269.94	0.00	1.98
14	0.00	0.00	1.91	225.09	14.32	269.52	0.00	1.82
15	0.00	0.00	2.14	196.80	0.95	268.71	0.00	2.04
16	0.00	0.00	2.10	276.75	0.95	352.50	0.00	1.99
17	0.00	0.00	10.18	396.00	1.07	368.86	0.00	9.67
18	0.00	0.00	19.26	396.00	1.34	361.63	0.00	18.30
19	0.00	0.00	23.03	396.00	0.95	345.70	0.00	21.88
20	0.00	0.00	19.53	396.00	0.95	330.86	0.00	18.55
21	0.00	0.00	9.69	396.00	0.95	322.40	0.00	9.21

Appendix E: Compromise Solution (s = 100) for the De Novo Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

22	0.00	0.00	5.25	338.25	7.69	319.32	0.00	4.99
23	0.00	0.00	2.07	303.81	18.77	303.81	0.00	17.88
24	0.00	0.00	2.04	276.75	14.58	276.75	0.00	29.06
25	0.00	0.00	2.09	252.15	12.69	254.50	0.00	24.02
26	0.00	0.00	1.91	225.09	14.32	254.07	0.00	1.82
27	0.00	0.00	2.14	196.80	0.95	253.91	0.00	2.04
28	0.00	0.00	2.10	276.75	0.95	330.51	0.00	1.99
29	0.00	0.00	10.18	396.00	1.07	397.54	0.00	9.67
30	0.00	0.00	19.26	396.00	1.34	386.54	0.00	18.30
31	0.00	0.00	23.03	396.00	0.95	368.15	0.00	21.88
32	0.00	0.00	19.53	396.00	0.95	350.83	0.00	18.55
33	0.00	0.00	9.69	396.00	0.95	342.28	0.00	9.21
34	0.00	0.00	5.25	338.25	7.69	338.25	0.00	4.99
35	0.00	0.00	2.07	303.81	18.77	337.46	0.00	1.97
36	0.00	0.00	2.04	276.75	14.58	336.25	0.00	1.93
37	0.00	0.00	2.09	252.15	12.69	334.64	0.00	1.98
38	0.00	0.00	1.91	225.09	14.32	333.20	0.00	1.82
39	0.00	0.00	2.14	196.80	0.95	332.72	0.00	2.04
40	0.00	0.00	2.10	276.75	0.95	340.66	0.00	1.99
41	0.00	0.00	10.18	396.00	1.07	338.90	0.00	9.67
42	0.00	0.00	19.26	396.00	1.34	332.47	0.00	18.30
43	0.00	0.00	23.03	396.00	0.95	321.91	0.00	21.88
44	0.00	0.00	19.53	396.00	0.95	305.45	0.00	18.55
45	0.00	0.00	9.69	396.00	0.95	298.16	0.00	9.21
46	0.00	0.00	5.25	338.25	7.69	295.09	0.00	4.99
47	0.00	0.00	2.07	303.81	18.77	295.00	0.00	1.97
48	0.00	0.00	2.04	276.75	14.58	276.75	0.00	20.00
49	0.00	0.00	2.09	252.15	12.69	252.15	0.00	25.83
50	0.00	0.00	1.91	225.09	14.32	228.34	0.00	24.96
51	0.00	0.00	2.14	196.80	0.95	227.55	0.00	2.04
52	0.00	0.00	2.10	276.75	0.95	290.88	0.00	1.99
53	0.00	0.00	10.18	396.00	1.07	374.06	0.00	9.67
54	0.00	0.00	19.26	396.00	1.34	396.00	0.00	18.30
55	0.00	0.00	23.03	396.00	0.95	378.97	0.00	21.88
56	0.00	0.00	19.53	396.00	0.95	362.99	0.00	18.55
57	0.00	0.00	9.69	396.00	0.95	357.23	0.00	9.21
58	0.00	0.00	5.25	338.25	7.69	338.25	0.00	23.63
59	0.00	0.00	2.07	303.81	18.77	303.81	0.00	37.89
60	0.00	0.00	2.04	276.75	14.58	276.75	0.00	29.68
61	0.00	0.00	2.09	252.15	12.69	252.15	0.00	26.51
62	0.00	0.00	1.91	225.09	14.32	245.55	0.00	8.36
63	0.00	0.00	2.14	196.80	0.95	245.19	0.00	2.04
64	0.00	0.00	2.10	276.75	0.95	297.84	0.00	1.99
65	0.00	0.00	10.18	396.00	1.07	395.94	0.00	9.67
66	0.00	0.00	19.26	396.00	1.34	407.75	0.00	18.30
67	0.00	0.00	23.03	396.00	0.95	396.00	0.00	21.88
68	0.00	0.00	19.53	396.00	0.95	380.34	0.00	18.55
69	0.00	0.00	9.69	396.00	0.95	374.29	0.00	9.21
70	0.00	0.00	5.25	338.25	7.69	338.25	0.00	40.38
71	0.00	0.00	2.07	303.81	18.77	303.81	0.00	38.93
72	0.00	0.00	2.04	276.75	14.58	276.75	0.00	29.01
73	0.00	0.00	2.09	252.15	12.69	252.15	0.00	26.10
74	0.00	0.00	1.91	225.09	14.32	226.44	0.00	27.38
75	0.00	0.00	2.14	196.80	0.95	226.39	0.00	2.04
76	0.00	0.00	2.10	276.75	0.95	345.26	0.00	1.99
77	0.00	0.00	10.18	396.00	1.07	369.04	0.00	9.67
78	0.00	0.00	19.26	396.00	1.34	396.00	0.00	18.30
79	0.00	0.00	23.03	396.00	0.95	403.36	0.00	21.88
80	0.00	0.00	19.53	396.00	0.95	389.86	0.00	18.55
81	0.00	0.00	9.69	396.00	0.95	386.42	0.00	9.21
82	0.00	0.00	5.25	338.25	7.69	386.46	0.00	4.99

Appendix E: Compromise Solution (s = 100) for the De Novo Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

83	0.00	0.00	2.07	303.81	18.77	386.01	0.00	1.97
84	0.00	0.00	2.04	276.75	14.58	385.23	0.00	1.93
85	0.00	0.00	2.09	252.15	12.69	384.01	0.00	1.98
86	0.00	0.00	1.91	225.09	14.32	383.08	0.00	1.82
87	0.00	0.00	2.14	196.80	0.95	382.06	0.00	2.04
88	0.00	0.00	2.10	276.75	0.95	395.15	0.00	1.99
89	0.00	0.00	10.18	396.00	1.07	393.08	0.00	9.67
90	0.00	0.00	19.26	396.00	1.34	377.15	0.00	18.30
91	0.00	0.00	23.03	396.00	0.95	357.50	0.00	21.88
92	0.00	0.00	19.53	396.00	0.95	340.56	0.00	18.55
93	0.00	0.00	9.69	396.00	0.95	334.89	0.00	9.21
94	0.00	0.00	5.25	338.25	7.69	334.49	0.00	4.99
95	0.00	0.00	2.07	303.81	18.77	335.28	0.00	1.97
96	0.00	0.00	2.04	276.75	14.58	335.09	0.00	1.93
97	0.00	0.00	2.09	252.15	12.69	334.46	0.00	1.98
98	0.00	0.00	1.91	225.09	14.32	333.57	0.00	1.82
99	0.00	0.00	2.14	196.80	0.95	333.16	0.00	2.04
100	0.00	0.00	2.10	276.75	0.95	353.68	0.00	1.99
101	0.00	0.00	10.18	396.00	1.07	357.84	0.00	9.67
102	0.00	0.00	19.26	396.00	1.34	343.90	0.00	18.30
103	0.00	0.00	23.03	396.00	0.95	324.83	0.00	21.88
104	0.00	0.00	19.53	396.00	0.95	307.01	0.00	18.55
105	0.00	0.00	9.69	396.00	0.95	298.69	0.00	9.21
106	0.00	0.00	5.25	338.25	7.69	295.30	0.00	4.99
107	0.00	0.00	2.07	303.81	18.77	295.44	0.00	1.97
108	0.00	0.00	2.04	276.75	14.58	276.75	0.00	20.01
109	0.00	0.00	2.09	252.15	12.69	252.15	0.00	25.54
110	0.00	0.00	1.91	225.09	14.32	251.14	0.00	1.82
111	0.00	0.00	2.14	196.80	0.95	249.91	0.00	2.04
112	0.00	0.00	2.10	276.75	0.95	303.55	0.00	1.99
113	0.00	0.00	10.18	396.00	1.07	408.56	0.00	10.88
114	0.00	0.00	19.26	396.00	1.34	408.56	0.00	25.88
115	0.00	0.00	23.03	396.00	0.95	390.61	0.00	21.88
116	0.00	0.00	19.53	396.00	0.95	373.30	0.00	18.55
117	0.00	0.00	9.69	396.00	0.95	365.50	0.00	9.21
118	0.00	0.00	5.25	338.25	7.69	361.69	0.00	4.99
119	0.00	0.00	2.07	303.81	18.77	361.68	0.00	1.97
120	0.00	0.00	2.04	276.75	14.58	360.99	0.00	1.93
121	0.00	0.00	2.09	252.15	12.69	360.21	0.00	1.98
122	0.00	0.00	1.91	225.09	14.32	359.52	0.00	1.82
123	0.00	0.00	2.14	196.80	0.95	358.74	0.00	2.04
124	0.00	0.00	2.10	276.75	0.95	394.55	0.00	1.99
125	0.00	0.00	10.18	396.00	1.07	393.30	0.00	9.67
126	0.00	0.00	19.26	396.00	1.34	376.66	0.00	18.30
127	0.00	0.00	23.03	396.00	0.95	356.05	0.00	21.88
128	0.00	0.00	19.53	396.00	0.95	338.58	0.00	18.55
129	0.00	0.00	9.69	396.00	0.95	330.33	0.00	9.21
130	0.00	0.00	5.25	338.25	7.69	326.78	0.00	4.99
131	0.00	0.00	2.07	303.81	18.77	326.54	0.00	1.97
132	0.00	0.00	2.04	276.75	14.58	325.45	0.00	1.93
133	0.00	0.00	2.09	252.15	12.69	323.98	0.00	1.98
134	0.00	0.00	1.91	225.09	14.32	322.77	0.00	1.82
135	0.00	0.00	2.14	196.80	0.95	325.54	0.00	2.04
136	0.00	0.00	2.10	276.75	0.95	332.65	0.00	1.99
137	0.00	0.00	10.18	396.00	1.07	327.41	0.00	9.67
138	0.00	0.00	19.26	396.00	1.34	312.58	0.00	18.30
139	0.00	0.00	23.03	396.00	0.95	293.42	0.00	21.88
140	0.00	0.00	19.53	396.00	0.95	276.39	0.00	18.55
141	0.00	0.00	9.69	396.00	0.95	267.89	0.00	9.21
142	0.00	0.00	5.25	338.25	7.69	265.59	0.00	4.99
143	0.00	0.00	2.07	303.81	18.77	266.58	0.00	1.97

Appendix E: Compromise Solution (s = 100) for the De Novo Reservoir System, Metaoptimum measured with respect to the Given Reservoir System

144	0.00	0.00	2.04	276.75	14.58	265.77	0.00	1.93
145	0.00	0.00	2.09	252.15	12.69	264.21	0.00	1.98
146	0.00	0.00	1.91	225.09	14.32	262.93	0.00	1.82
147	0.00	0.00	2.14	196.80	0.95	261.62	0.00	2.04
148	0.00	0.00	2.10	276.75	0.95	274.53	0.00	1.99
149	0.00	0.00	10.18	396.00	1.07	273.03	0.00	9.67
150	0.00	0.00	19.26	396.00	1.34	258.06	0.00	18.30
151	0.00	0.00	23.03	396.00	0.95	245.78	0.00	21.88
152	0.00	0.00	19.53	396.00	0.95	230.21	0.00	18.55
153	0.00	0.00	9.69	396.00	0.95	221.55	0.00	9.21
154	0.00	0.00	5.25	338.25	7.69	218.04	0.00	4.99
155	0.00	0.00	2.07	303.81	18.77	217.76	0.00	1.97
156	0.00	0.00	2.04	276.75	14.58	216.72	0.00	1.93
157	0.00	0.00	2.09	252.15	12.69	215.80	0.00	1.98
158	0.00	0.00	1.91	225.09	14.32	215.10	0.00	1.82
159	0.00	0.00	2.14	196.80	0.95	214.12	0.00	2.04
160	0.00	0.00	2.10	276.75	0.95	247.54	0.00	1.99
161	0.00	0.00	10.18	396.00	1.07	285.16	0.00	9.67
162	0.00	0.00	19.26	396.00	1.34	282.90	0.00	18.30
163	0.00	0.00	23.03	396.00	0.95	278.96	0.00	21.88
164	0.00	0.00	19.53	396.00	0.95	265.13	0.00	18.55
165	0.00	0.00	9.69	396.00	0.95	256.90	0.00	9.21
166	0.00	0.00	5.25	338.25	7.69	253.37	0.00	4.99
167	0.00	0.00	2.07	303.81	18.77	253.55	0.00	1.97
168	0.00	0.00	2.04	276.75	14.58	253.17	0.00	1.93
169	0.00	0.00	2.09	252.15	12.69	252.15	0.00	1.98
170	0.00	0.00	1.91	225.09	14.32	251.30	0.00	1.82
171	0.00	0.00	2.14	196.80	0.95	258.98	0.00	2.04
172	0.00	0.00	2.10	276.75	0.95	280.79	0.00	1.99
173	0.00	0.00	10.18	396.00	1.07	286.06	0.00	9.67
174	0.00	0.00	19.26	396.00	1.34	282.75	0.00	18.30
175	0.00	0.00	23.03	396.00	0.95	268.91	0.00	21.88
176	0.00	0.00	19.53	396.00	0.95	251.23	0.00	18.55
177	0.00	0.00	9.69	396.00	0.95	242.85	0.00	9.21
178	0.00	0.00	5.25	338.25	7.69	240.30	0.00	4.99
179	0.00	0.00	2.07	303.81	18.77	240.32	0.00	1.97
180	0.00	0.00	2.04	276.75	14.58	241.00	0.00	1.93

Appendix F GAMS Input for the De Novo Reservoir System, Soft Resources obtained through Rule Curve

```
********************************************************************
*  MODEL:  denovo                                                  *
*                                                                  *
*  This routine is supplied the following input:                   *
*  15 years of monthly inflow in to the Shellmouth Reservoir       *
*  12 Monthly water supply targets                                 *
*  12 Minimum and Maximum monthly release bounds                   *
*  Minimum and Maximum Reservoir Storage                           *
*  Minimum and Maximum Bounds on fraction of water supply target   *
*                                                                  *
*  The model contains the metaoptimum constraints obtained         *
*  from the individual optimization of each objective wrt, the     *
*  given system, AS EQUALITY CONSTRAINTS                           *
*                                                                  *
*  The budget is composed of 12 monthly target storage levels with*
*  unit cost coefficients.                                         *
*                                                                  *
********************************************************************


OPTION ITERLIM = 50000;
OPTION RESLIM = 50000;
OPTION LIMROW = 0;
OPTION LIMCOL = 0;

SETS
  T time period in years /1*180/
DISPLAY T;

SCALARS STOMIN min reservoir storage
        STOMAX max reservoir storage
        LOWB lower bound on water supply
        UPB upper bound on water supply;

STOMIN=12.34 ;
STOMAX=477.3645;
LOWB=0.95;
UPB=1.0;

FILE FO /denovo.OUT/;

PARAMETERS  INFLOW(T)   monthly inflow in to shellmouth reservoir
/     1     1.2                 20    3.71                          39    1.56
      2     1.1                 21    0.75                          40    9.93
      3     2.3                 22     1.9                          41    7.91
      4   49.37                 23    2.37                          42   11.87
      5   37.08                 24       2                          43   11.32
      6   14.19                 25    1.77                          44    2.09
      7    7.55                 26    1.39                          45    1.92
      8    2.45                 27    1.87                          46    1.92
      9    1.88                 28    78.6                          47    1.88
     10    2.65                 29    76.7                          48    1.75
     11    2.31                 30    7.29                          49    1.23
     12     1.6                 31    3.49                          50    1.15
     13    1.57                 32    1.23                          51    1.24
     14     1.4                 33    0.66                          52   65.33
     15    1.23                 34    0.96                          53   92.84
     16   85.78                 35    1.18                          54   40.24
     17   26.03                 36    0.72                          55    4.85
     18   11.06                 37    0.38                          56    2.57
     19    5.96                 38    0.37                          57    3.45
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        58    4.65                99    1.63                140    1.52
        59    3.45               100   22.51                141    0.71
        60    2.62               101   13.83                142    2.69
        61    1.91               102    4.35                143    2.96
        62    1.76               103    2.82                144    1.12
        63    1.68               104    0.73                145    0.43
        64   54.64               105    0.89                146    0.53
        65  107.77               106    1.59                147    0.73
        66   30.11               107    2.11                148    14.9
        67   10.13               108    1.32                149    8.17
        68    2.89               109    0.94                150    3.33
        69    3.16               110    0.81                151     9.6
        70    4.34               111     0.8                152    2.98
        71    4.49               112   55.64                153    0.55
        72    1.95               113  115.88                154    1.47
        73     1.5               114   25.88                155    1.69
        74    1.67               115    3.94                156     0.9
        75    1.98               116    1.24                157    1.06
        76  120.87               117    1.41                158    1.12
        77   33.44               118    1.17                159    1.05
        78   45.26               119    1.96                160   35.42
        79   29.24               120    1.25                161   47.29
        80    5.05               121     1.2                162   16.03
        81    5.77               122    1.13                163   17.95
        82    5.03               123    1.25                164    4.72
        83    1.52               124   37.81                165    0.97
        84    1.15               125    8.42                166    1.46
        85    0.77               126    1.65                167    2.15
        86    0.88               127    1.27                168    1.56
        87    1.02               128    1.08                169    0.96
        88   15.08               129    0.96                170    0.97
        89     7.6               130    1.44                171    9.71
        90    2.37               131    1.73                172   23.81
        91    2.23               132    0.84                173   14.93
        92    1.61               133    0.52                174   14.99
        93    3.54               134     0.6                175    8.04
        94    4.59               135    4.81                176    0.87
        95    2.76               136     9.1                177    0.83
        96    1.74               137    4.43                178    2.44
        97    1.35               138    3.47                179    1.99
        98    0.93               139    2.72                180    2.61/
RMIN(T)  minimum allowable monthly release
/        1  1.9017                20  1.9017               39  1.9017
         2  1.7176                21  1.8403               40  1.8403
         3  1.9017                22  1.9017               41  1.9017
         4  1.8403                23  1.8403               42  1.8403
         5  1.9017                24  1.9017               43  1.9017
         6  1.8403                25  1.9017               44  1.9017
         7  1.9017                26  1.7176               45  1.8403
         8  1.9017                27  1.9017               46  1.9017
         9  1.8403                28  1.8403               47  1.8403
        10  1.9017                29  1.9017               48  1.9017
        11  1.8403                30  1.8403               49  1.9017
        12  1.9017                31  1.9017               50  1.7176
        13  1.9017                32  1.9017               51  1.9017
        14  1.7176                33  1.8403               52  1.8403
        15  1.9017                34  1.9017               53  1.9017
        16  1.8403                35  1.8403               54  1.8403
        17  1.9017                36  1.9017               55  1.9017
        18  1.8403                37  1.9017               56  1.9017
        19  1.9017                38  1.7176               57  1.8403
```

```
        58  1.9017                     99  1.9017                     140  1.9017
        59  1.8403                    100  1.8403                     141  1.8403
        60  1.9017                    101  1.9017                     142  1.9017
        61  1.9017                    102  1.8403                     143  1.8403
        62  1.7176                    103  1.9017                     144  1.9017
        63  1.9017                    104  1.9017                     145  1.9017
        64  1.8403                    105  1.8403                     146  1.7176
        65  1.9017                    106  1.9017                     147  1.9017
        66  1.8403                    107  1.8403                     148  1.8403
        67  1.9017                    108  1.9017                     149  1.9017
        68  1.9017                    109  1.9017                     150  1.8403
        69  1.8403                    110  1.7176                     151  1.9017
        70  1.9017                    111  1.9017                     152  1.9017
        71  1.8403                    112  1.8403                     153  1.8403
        72  1.9017                    113  1.9017                     154  1.9017
        73  1.9017                    114  1.8403                     155  1.8403
        74  1.7176                    115  1.9017                     156  1.9017
        75  1.9017                    116  1.9017                     157  1.9017
        76  1.8403                    117  1.8403                     158  1.7176
        77  1.9017                    118  1.9017                     159  1.9017
        78  1.8403                    119  1.8403                     160  1.8403
        79  1.9017                    120  1.9017                     161  1.9017
        80  1.9017                    121  1.9017                     162  1.8403
        81  1.8403                    122  1.7176                     163  1.9017
        82  1.9017                    123  1.9017                     164  1.9017
        83  1.8403                    124  1.8403                     165  1.8403
        84  1.9017                    125  1.9017                     166  1.9017
        85  1.9017                    126  1.8403                     167  1.8403
        86  1.7176                    127  1.9017                     168  1.9017
        87  1.9017                    128  1.9017                     169  1.9017
        88  1.8403                    129  1.8403                     170  1.7176
        89  1.9017                    130  1.9017                     171  1.9017
        90  1.8403                    131  1.8403                     172  1.8403
        91  1.9017                    132  1.9017                     173  1.9017
        92  1.9017                    133  1.9017                     174  1.8403
        93  1.8403                    134  1.7176                     175  1.9017
        94  1.9017                    135  1.9017                     176  1.9017
        95  1.8403                    136  1.8403                     177  1.8403
        96  1.9017                    137  1.9017                     178  1.9017
        97  1.9017                    138  1.8403                     179  1.8403
        98  1.7176                    139  1.9017                     180  1.9017/
RMAX(T) maximum monthly release
/        1   36.88                     20   36.88                     39   36.88
         2   33.31                     21   35.69                     40   35.69
         3   36.88                     22   36.88                     41   36.88
         4   35.69                     23   35.69                     42   35.69
         5   36.88                     24   36.88                     43   36.88
         6   35.69                     25   36.88                     44   36.88
         7   36.88                     26   33.31                     45   35.69
         8   36.88                     27   36.88                     46   36.88
         9   35.69                     28   35.69                     47   35.69
        10   36.88                     29   36.88                     48   36.88
        11   35.69                     30   35.69                     49   36.88
        12   36.88                     31   36.88                     50   33.31
        13   36.88                     32   36.88                     51   36.88
        14   33.31                     33   35.69                     52   35.69
        15   36.88                     34   36.88                     53   36.88
        16   35.69                     35   35.69                     54   35.69
        17   36.88                     36   36.88                     55   36.88
        18   35.69                     37   36.88                     56   36.88
        19   36.88                     38   33.31                     57   35.69
```

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       58   36.88                99   36.88               140   36.88
       59   35.69               100   35.69               141   35.69
       60   36.88               101   36.88               142   36.88
       61   36.88               102   35.69               143   35.69
       62   33.31               103   36.88               144   36.88
       63   36.88               104   36.88               145   36.88
       64   35.69               105   35.69               146   33.31
       65   36.88               106   36.88               147   36.88
       66   35.69               107   35.69               148   35.69
       67   36.88               108   36.88               149   36.88
       68   36.88               109   36.88               150   35.69
       69   35.69               110   33.31               151   36.88
       70   36.88               111   36.88               152   36.88
       71   35.69               112   35.69               153   35.69
       72   36.88               113   36.88               154   36.88
       73   36.88               114   35.69               155   35.69
       74   33.31               115   36.88               156   36.88
       75   36.88               116   36.88               157   36.88
       76   35.69               117   35.69               158   33.31
       77   36.88               118   36.88               159   36.88
       78   35.69               119   35.69               160   35.69
       79   36.88               120   36.88               161   36.88
       80   36.88               121   36.88               162   35.69
       81   35.69               122   33.31               163   36.88
       82   36.88               123   36.88               164   36.88
       83   35.69               124   35.69               165   35.69
       84   36.88               125   36.88               166   36.88
       85   36.88               126   35.69               167   35.69
       86   33.31               127   36.88               168   36.88
       87   36.88               128   36.88               169   36.88
       88   35.69               129   35.69               170   33.31
       89   36.88               130   36.88               171   36.88
       90   35.69               131   35.69               172   35.69
       91   36.88               132   36.88               173   36.88
       92   36.88               133   36.88               174   35.69
       93   35.69               134   33.31               175   36.88
       94   36.88               135   36.88               176   36.88
       95   35.69               136   35.69               177   35.69
       96   36.88               137   36.88               178   36.88
       97   36.88               138   35.69               179   35.69
       98   33.31               139   36.88               180   36.88/
DTAR(T)   monthly demand target level
/       1 2.089152               20   19.52554             39   2.14272
        2 1.911168               21    9.69408             40   2.09952
        3  2.14272               22  5.249664              41  10.17792
        4  2.09952               23    2.0736              42  19.25856
        5 10.17792               24  2.035584              43  23.03424
        6 19.25856               25  2.089152              44  19.52554
        7 23.03424               26  1.911168              45   9.69408
        8 19.52554               27   2.14272              46  5.249664
        9  9.69408               28   2.09952              47    2.0736
       10  5.249664              29  10.17792              48  2.035584
       11    2.0736              30   19.25856             49  2.089152
       12  2.035584              31  23.03424              50   1.911168
       13  2.089152              32  19.52554              51  2.14272
       14  1.911168              33   9.69408              52  2.09952
       15   2.14272              34  5.249664              53  10.17792
       16    2.09952             35    2.0736              54  19.25856
       17   10.17792             36  2.035584              55  23.03424
       18   19.25856             37 2.089152               56  19.52554
       19   23.03424             38 1.911168               57   9.69408
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       58  5.249664              99   2.14272            140 19.52554
       59    2.0736             100  2.09952             141 9.69408
       60 2.035584              101  10.17792            142 5.249664
       61 2.089152              102  19.25856            143  2.0736
       62 1.911168              103  23.03424            144 2.035584
       63  2.14272              104  19.52554            145 2.089152
       64  2.09952              105  9.69408             146 1.911168
       65 10.17792              106  5.249664            147 2.14272
       66 19.25856              107   2.0736             148 2.09952
       67 23.03424              108  2.035584            149 10.17792
       68 19.52554              109  2.089152            150 19.25856
       69   9.69408             110  1.911168            151 23.03424
       70  5.249664             111  2.14272             152 19.52554
       71   2.0736              112  2.09952             153 9.69408
       72 2.035584              113 10.17792             154 5.249664
       73 2.089152              114 19.25856             155  2.0736
       74 1.911168              115 23.03424             156 2.035584
       75  2.14272              116 19.52554             157 2.089152
       76  2.09952              117 9.69408              158 1.911168
       77 10.17792              118 5.249664             159 2.14272
       78 19.25856              119  2.0736              160 2.09952
       79  23.03424             120 2.035584             161 10.17792
       80  19.52554             121 2.089152             162 19.25856
       81   9.69408             122 1.911168             163 23.03424
       82  5.249664             123 2.14272              164 19.52554
       83    2.0736             124 2.09952              165 9.69408
       84  2.035584             125 10.17792             166 5.249664
       85  2.089152             126 19.25856             167  2.0736
       86  1.911168             127 23.03424             168 2.035584
       87   2.14272             128 19.52554             169 2.089152
       88   2.09952             129 9.69408              170 1.911168
       89  10.17792             130 5.249664             171 2.14272
       90 19.25856              131  2.0736              172 2.09952
       91 23.03424              132 2.035584             173 10.17792
       92  19.52554             133 2.089152             174 19.25856
       93   9.69408             134 1.911168             175 23.03424
       94  5.249664             135 2.14272              176 19.52554
       95    2.0736             136 2.09952              177 9.69408
       96  2.035584             137 10.17792             178 5.249664
       97  2.089152             138 19.25856             179  2.0736
       98  1.911168             139 23.03424             180  2.035584/;

VARIABLES
OF1  objective function one
OF2  objective function two
START  starting storage of the reservoir
S(T) monthly reservoir storage
R(T) monthly reservoir downstream release
WS(T) monthly reservoir water supply level
K the required active storage of the reservoir
V(T) positive storage deviation
U(T) negative storage deviation
STAR(T)
BASE1
BASE2
BASE3
BASE4
BASE5
BASE6
BASE7
BASE8
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BASE9
BASE10
BASE11
BASE12
OF

POSITIVE VARIABLES OF2,START,S(T),R(T),WS(T),K,V(T),U(T);
POSITIVE VARIABLES
BASE1,BASE2,BASE3,BASE4,BASE5,BASE6,BASE7,BASE8,BASE9,BASE10,BASE11,BASE
12;
POSITIVE VARIABLES STAR(T);
S.UP(T)=1000;
START.UP=1000;
R.UP(T)=1000;
WS.UP(T)=1000;
V.UP(T)=1000;
U.UP(T)=1000;

EQUATIONS
CONTIN(T)         continuity equation
CONTINF(T)        continuity of inflow
RAS(T)            required active storage must exceed monthly storage
MINREL(T)         minimum release bounds
MAXREL(T)         maximum release bounds
MINSTO(T)         minimum storage bound
MINWS(T)          minimum water supply bounds
MAXWS(T)          maximum water supply bounds
MAXSTO(T)         maximum storage bound
STOTAR(T)         storage target deviation constraints
STCon1(T)                    STCon33(T)                    STCon65(T)
STCon2(T)                    STCon34(T)                    STCon66(T)
STCon3(T)                    STCon35(T)                    STCon67(T)
STCon4(T)                    STCon36(T)                    STCon68(T)
STCon5(T)                    STCon37(T)                    STCon69(T)
STCon6(T)                    STCon38(T)                    STCon70(T)
STCon7(T)                    STCon39(T)                    STCon71(T)
STCon8(T)                    STCon40(T)                    STCon72(T)
STCon9(T)                    STCon41(T)                    STCon73(T)
STCon10(T)                   STCon42(T)                    STCon74(T)
STCon11(T)                   STCon43(T)                    STCon75(T)
STCon12(T)                   STCon44(T)                    STCon76(T)
STCon13(T)                   STCon45(T)                    STCon77(T)
STCon14(T)                   STCon46(T)                    STCon78(T)
STCon15(T)                   STCon47(T)                    STCon79(T)
STCon16(T)                   STCon48(T)                    STCon80(T)
STCon17(T)                   STCon49(T)                    STCon81(T)
STCon18(T)                   STCon50(T)                    STCon82(T)
STCon19(T)                   STCon51(T)                    STCon83(T)
STCon20(T)                   STCon52(T)                    STCon84(T)
STCon21(T)                   STCon53(T)                    STCon85(T)
STCon22(T)                   STCon54(T)                    STCon86(T)
STCon23(T)                   STCon55(T)                    STCon87(T)
STCon24(T)                   STCon56(T)                    STCon88(T)
STCon25(T)                   STCon57(T)                    STCon89(T)
STCon26(T)                   STCon58(T)                    STCon90(T)
STCon27(T)                   STCon59(T)                    STCon91(T)
STCon28(T)                   STCon60(T)                    STCon92(T)
STCon29(T)                   STCon61(T)                    STCon93(T)
STCon30(T)                   STCon62(T)                    STCon94(T)
STCon31(T)                   STCon63(T)                    STCon95(T)
STCon32(T)                   STCon64(T)                    STCon96(T)
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STCon97(T)                STCon125(T)               STCon153(T)
STCon98(T)                STCon126(T)               STCon154(T)
STCon99(T)                STCon127(T)               STCon155(T)
STCon100(T)               STCon128(T)               STCon156(T)
STCon101(T)               STCon129(T)               STCon157(T)
STCon102(T)               STCon130(T)               STCon158(T)
STCon103(T)               STCon131(T)               STCon159(T)
STCon104(T)               STCon132(T)               STCon160(T)
STCon105(T)               STCon133(T)               STCon161(T)
STCon106(T)               STCon134(T)               STCon162(T)
STCon107(T)               STCon135(T)               STCon163(T)
STCon108(T)               STCon136(T)               STCon164(T)
STCon109(T)               STCon137(T)               STCon165(T)
STCon110(T)               STCon138(T)               STCon166(T)
STCon111(T)               STCon139(T)               STCon167(T)
STCon112(T)               STCon140(T)               STCon168(T)
STCon113(T)               STCon141(T)               STCon169(T)
STCon114(T)               STCon142(T)               STCon170(T)
STCon115(T)               STCon143(T)               STCon171(T)
STCon116(T)               STCon144(T)               STCon172(T)
STCon117(T)               STCon145(T)               STCon173(T)
STCon118(T)               STCon146(T)               STCon174(T)
STCon119(T)               STCon147(T)               STCon175(T)
STCon120(T)               STCon148(T)               STCon176(T)
STCon121(T)               STCon149(T)               STCon177(T)
STCon122(T)               STCon150(T)               STCon178(T)
STCon123(T)               STCon151(T)               STCon179(T)
STCon124(T)               STCon152(T)               STCon180(T)
SECOND          the sum of storage deviations
FIRST           the required active storage
OPT1            optimal value of objective one
OPT2            optimal value of objective two
budget          sum of storage targets;

CONTIN(T)..  S(T)=E=[START+INFLOW(T)-R(T)-WS(T)]$(ORD(T) EQ 1)
                  + [S(T-1)+INFLOW(T)-R(T)-WS(T)]$(ORD(T) GT 1);
CONTINF(T)$(ORD(T) EQ 180)..  START=E=S(T);
RAS(T)..  S(T)=L=K;
MINREL(T)..  RMIN(T)=L=R(T);
MAXREL(T)..  R(T)=L=RMAX(T);
MINSTO(T)..  S(T)=G=STOMIN;
MAXSTO(T)..  S(T)=L=STOMAX;
MINWS(T)..  LOWB=L=((1/DTAR(T))*WS(T));
MAXWS(T)..  ((1/DTAR(T))*WS(T))=L=UPB;
STOTAR(T)..  S(T)-V(T)+U(T)=E=STAR(T);
SECOND..  OF2=E=SUM(T,V(T)+U(T));
FIRST..  OF1=E= K;
OPT1..  OF1=E=319.55;
OPT2..  OF2=E=14945.83;
budget..  OF=E=BASE1+BASE2+BASE3+BASE4+BASE5+
             BASE6+BASE7+BASE8+BASE9+BASE10+
             BASE11+BASE12;

STCon1(T)$(ORD(T) EQ 1)..               STCon5(T)$(ORD(T) EQ 49)..
STAR(T)=E=BASE1;                        STAR(T)=E=BASE1;
STCon2(T)$(ORD(T) EQ 13)..              STCon6(T)$(ORD(T) EQ 61)..
STAR(T)=E=BASE1;                        STAR(T)=E=BASE1;
STCon3(T)$(ORD(T) EQ 25)..              STCon7(T)$(ORD(T) EQ 73)..
STAR(T)=E=BASE1;                        STAR(T)=E=BASE1;
STCon4(T)$(ORD(T) EQ 37)..              STCon8(T)$(ORD(T) EQ 85)..
STAR(T)=E=BASE1;                        STAR(T)=E=BASE1;
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STCon9(T)$(ORD(T) EQ 97)..
STAR(T)=E=BASE1;
STCon10(T)$(ORD(T) EQ 109)..
STAR(T)=E=BASE1;
STCon11(T)$(ORD(T) EQ 121)..
STAR(T)=E=BASE1;
STCon12(T)$(ORD(T) EQ 133)..
STAR(T)=E=BASE1;
STCon13(T)$(ORD(T) EQ 145)..
STAR(T)=E=BASE1;
STCon14(T)$(ORD(T) EQ 157)..
STAR(T)=E=BASE1;
STCon15(T)$(ORD(T) EQ 169)..
STAR(T)=E=BASE1;
STCon16(T)$(ORD(T) EQ 2)..
STAR(T)=E=BASE2;
STCon17(T)$(ORD(T) EQ 14)..
STAR(T)=E=BASE2;
STCon18(T)$(ORD(T) EQ 26)..
STAR(T)=E=BASE2;
STCon19(T)$(ORD(T) EQ 38)..
STAR(T)=E=BASE2;
STCon20(T)$(ORD(T) EQ 50)..
STAR(T)=E=BASE2;
STCon21(T)$(ORD(T) EQ 62)..
STAR(T)=E=BASE2;
STCon22(T)$(ORD(T) EQ 74)..
STAR(T)=E=BASE2;
STCon23(T)$(ORD(T) EQ 86)..
STAR(T)=E=BASE2;
STCon24(T)$(ORD(T) EQ 98)..
STAR(T)=E=BASE2;
STCon25(T)$(ORD(T) EQ 110)..
STAR(T)=E=BASE2;
STCon26(T)$(ORD(T) EQ 122)..
STAR(T)=E=BASE2;
STCon27(T)$(ORD(T) EQ 134)..
STAR(T)=E=BASE2;
STCon28(T)$(ORD(T) EQ 146)..
STAR(T)=E=BASE2;
STCon29(T)$(ORD(T) EQ 158)..
STAR(T)=E=BASE2;
STCon30(T)$(ORD(T) EQ 170)..
STAR(T)=E=BASE2;
STCon31(T)$(ORD(T) EQ 3)..
STAR(T)=E=BASE3;
STCon32(T)$(ORD(T) EQ 15)..
STAR(T)=E=BASE3;
STCon33(T)$(ORD(T) EQ 27)..
STAR(T)=E=BASE3;
STCon34(T)$(ORD(T) EQ 39)..
STAR(T)=E=BASE3;
STCon35(T)$(ORD(T) EQ 51)..
STAR(T)=E=BASE3;
STCon36(T)$(ORD(T) EQ 63)..
STAR(T)=E=BASE3;
STCon37(T)$(ORD(T) EQ 75)..
STAR(T)=E=BASE3;
STCon38(T)$(ORD(T) EQ 87)..
STAR(T)=E=BASE3;
STCon39(T)$(ORD(T) EQ 99)..
STAR(T)=E=BASE3;
STCon40(T)$(ORD(T) EQ 111)..
STAR(T)=E=BASE3;
STCon41(T)$(ORD(T) EQ 123)..
STAR(T)=E=BASE3;
STCon42(T)$(ORD(T) EQ 135)..
STAR(T)=E=BASE3;
STCon43(T)$(ORD(T) EQ 147)..
STAR(T)=E=BASE3;
STCon44(T)$(ORD(T) EQ 159)..
STAR(T)=E=BASE3;
STCon45(T)$(ORD(T) EQ 171)..
STAR(T)=E=BASE3;
STCon46(T)$(ORD(T) EQ 4)..
STAR(T)=E=BASE4;
STCon47(T)$(ORD(T) EQ 16)..
STAR(T)=E=BASE4;
STCon48(T)$(ORD(T) EQ 28)..
STAR(T)=E=BASE4;
STCon49(T)$(ORD(T) EQ 40)..
STAR(T)=E=BASE4;
STCon50(T)$(ORD(T) EQ 52)..
STAR(T)=E=BASE4;
STCon51(T)$(ORD(T) EQ 64)..
STAR(T)=E=BASE4;
STCon52(T)$(ORD(T) EQ 76)..
STAR(T)=E=BASE4;
STCon53(T)$(ORD(T) EQ 88)..
STAR(T)=E=BASE4;
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STAR(T)=E=BASE4;
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STAR(T)=E=BASE4;
STCon56(T)$(ORD(T) EQ 124)..
STAR(T)=E=BASE4;
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STAR(T)=E=BASE4;
STCon58(T)$(ORD(T) EQ 148)..
STAR(T)=E=BASE4;
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STAR(T)=E=BASE5;
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STAR(T)=E=BASE5;
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STAR(T)=E=BASE5;
STCon68(T)$(ORD(T) EQ 89)..
STAR(T)=E=BASE5;
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STCon69(T)$(ORD(T) EQ 101)..
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STAR(T)=E=BASE5;
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STAR(T)=E=BASE5;
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STAR(T)=E=BASE5;
STCon75(T)$(ORD(T) EQ 173)..
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STAR(T)=E=BASE6;
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STAR(T)=E=BASE6;
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STAR(T)=E=BASE6;
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STCon91(T)$(ORD(T) EQ 7)..
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STCon92(T)$(ORD(T) EQ 19)..
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STCon94(T)$(ORD(T) EQ 43)..
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STCon95(T)$(ORD(T) EQ 55)..
STAR(T)=E=BASE7;
STCon96(T)$(ORD(T) EQ 67)..
STAR(T)=E=BASE7;
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STCon105(T)$(ORD(T) EQ 175)..
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STCon108(T)$(ORD(T) EQ 32)..
STAR(T)=E=BASE8;
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STAR(T)=E=BASE8;
STCon110(T)$(ORD(T) EQ 56)..
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STAR(T)=E=BASE8;
STCon112(T)$(ORD(T) EQ 80)..
STAR(T)=E=BASE8;
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STAR(T)=E=BASE8;
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STAR(T)=E=BASE8;
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STAR(T)=E=BASE8;
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STAR(T)=E=BASE8;
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STAR(T)=E=BASE8;
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STAR(T)=E=BASE8;
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STCon126(T)$(ORD(T) EQ 69)..
STAR(T)=E=BASE9;
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STAR(T)=E=BASE9;
STCon128(T)$(ORD(T) EQ 93)..
STAR(T)=E=BASE9;
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STAR(T)=E=BASE9;
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STAR(T)=E=BASE9;
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STAR(T)=E=BASE9;
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STCon135(T)$(ORD(T) EQ 177)..
STAR(T)=E=BASE9;
STCon136(T)$(ORD(T) EQ 10)..
STAR(T)=E=BASE10;
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STAR(T)=E=BASE10;
STCon138(T)$(ORD(T) EQ 34)..
STAR(T)=E=BASE10;
STCon139(T)$(ORD(T) EQ 46)..
STAR(T)=E=BASE10;
STCon140(T)$(ORD(T) EQ 58)..
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STAR(T)=E=BASE10;
STCon142(T)$(ORD(T) EQ 82)..
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STAR(T)=E=BASE10;
STCon144(T)$(ORD(T) EQ 106)..
STAR(T)=E=BASE10;
STCon145(T)$(ORD(T) EQ 118)..
STAR(T)=E=BASE10;
STCon146(T)$(ORD(T) EQ 130)..
STAR(T)=E=BASE10;
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STCon148(T)$(ORD(T) EQ 154)..
STAR(T)=E=BASE10;
STCon149(T)$(ORD(T) EQ 166)..
STAR(T)=E=BASE10;
STCon150(T)$(ORD(T) EQ 178)..
STAR(T)=E=BASE10;
STCon151(T)$(ORD(T) EQ 11)..
STAR(T)=E=BASE11;
STCon152(T)$(ORD(T) EQ 23)..
STAR(T)=E=BASE11;
STCon153(T)$(ORD(T) EQ 35)..
STAR(T)=E=BASE11;
STCon154(T)$(ORD(T) EQ 47)..
STAR(T)=E=BASE11;
STCon155(T)$(ORD(T) EQ 59)..
STAR(T)=E=BASE11;
STCon156(T)$(ORD(T) EQ 71)..
STAR(T)=E=BASE11;
STCon157(T)$(ORD(T) EQ 83)..
STAR(T)=E=BASE11;
STCon158(T)$(ORD(T) EQ 95)..
STAR(T)=E=BASE11;
STCon159(T)$(ORD(T) EQ 107)..
STAR(T)=E=BASE11;
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STAR(T)=E=BASE11;
STCon161(T)$(ORD(T) EQ 131)..
STAR(T)=E=BASE11;
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STAR(T)=E=BASE11;
STCon163(T)$(ORD(T) EQ 155)..
STAR(T)=E=BASE11;
STCon164(T)$(ORD(T) EQ 167)..
STAR(T)=E=BASE11;
STCon165(T)$(ORD(T) EQ 179)..
STAR(T)=E=BASE11;
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STAR(T)=E=BASE12;
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STAR(T)=E=BASE12;
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STAR(T)=E=BASE12;
STCon169(T)$(ORD(T) EQ 48)..
STAR(T)=E=BASE12;
STCon170(T)$(ORD(T) EQ 60)..
STAR(T)=E=BASE12;
STCon171(T)$(ORD(T) EQ 72)..
STAR(T)=E=BASE12;
STCon172(T)$(ORD(T) EQ 84)..
STAR(T)=E=BASE12;
STCon173(T)$(ORD(T) EQ 96)..
STAR(T)=E=BASE12;
STCon174(T)$(ORD(T) EQ 108)..
STAR(T)=E=BASE12;
STCon175(T)$(ORD(T) EQ 120)..
STAR(T)=E=BASE12;
STCon176(T)$(ORD(T) EQ 132)..
STAR(T)=E=BASE12;
STCon177(T)$(ORD(T) EQ 144)..
STAR(T)=E=BASE12;
STCon178(T)$(ORD(T) EQ 156)..
STAR(T)=E=BASE12;
STCon179(T)$(ORD(T) EQ 168)..
STAR(T)=E=BASE12;
STCon180(T)$(ORD(T) EQ 180)..
STAR(T)=E=BASE12;
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MODEL denovo/ALL/;
SOLVE denovo USING LP MINIMIZING OF;



*  Post Processing
PUT F0;
PUT  '********************************************'
PUT /'*    SUMMARY OF THE OPTIMAL CONDITIONS     *'
PUT /'********************************************'
PUT /
PUT/'OF':>15;
PUT/ OF.L;
PUT /'OF1':>15,'OF2':>15;
PUT / K.L :>15;PUT OF2.L:>15;
PUT /
PUT /
PUT
/'********************************************************************':
>68,'****************':>16;
PUT / 'TIME':>4,'STORAGE':>8,'STAR':>10,'DTAR':>14,'RELEASE':>10,
'WATER SUPPLY':>14;
PUT
/'********************************************************************':
>68,'****************':>16;
PUT /
LOOP(T, PUT / T.TL:>4;
PUT S.L(T):>8; PUT STAR.L(T):>10; PUT DTAR(T):>14; PUT R.L(T):>10;
PUT WS.L(T):>14;);
□
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Appendix G GAMS Output for the De Novo Reservoir System, Soft Resources obtained through Rule Curve

Appendix G: GAMS Output for the De Novo Reservoir System, Soft Resources Obtained through Rule Curve

Table G-1 Optimal Objective Function Value, Required Active Storage and Sum of Storage Deviations, (10^6 m^3)

Budget (Sum of Annual Storage Targets)	Required Active Storage	Sum of Storage Deviations
626.74	319.55	14945.83

Table G-2 Minimum and Maximum Constraint Bounds

Maximum Storage (10^6 m^3)	Minimum Storage (10^6 m^3)	Minimum Fraction of Target Water Supply	Maximum Fration of Target Water Supply
477.36	12.34	0.95	1.00

Please note the following definitions of abbreviations.
Opt. - Optimal
Min. - Minimum
Rel. - Reservoir Release
Max. - Maximum
Stor. - Reservoir Storage

Table G-3 Optimal Decision Variables, Monthly Target Water Supply, Minimum and Maximum Reservoir Release, (10^6 m^3)

Time	Opt. Stor.	Opt. Stor. Target	Target Demand	Opt. Water Supply	Min. Rel.	Opt. Rel.	Max. Rel.
1	16.41	32.70	2.09	1.98	1.90	1.90	36.88
2	13.98	30.55	1.91	1.82	1.72	1.72	33.31
3	12.34	28.49	2.14	2.04	1.90	1.90	36.88
4	57.88	73.92	2.10	1.99	1.84	1.84	35.69
5	83.38	97.02	10.18	9.67	1.90	1.90	36.88
6	77.44	87.94	19.26	18.30	1.84	1.84	35.69
7	61.20	70.12	23.03	21.88	1.90	1.90	36.88
8	43.20	53.38	19.53	18.55	1.90	1.90	36.88
9	34.03	43.08	9.69	9.21	1.84	1.84	35.69
10	29.79	38.09	5.25	4.99	1.90	1.90	36.88
11	28.29	36.65	2.07	1.97	1.84	1.84	35.69
12	26.06	34.81	2.04	1.93	1.90	1.90	36.88
13	23.74	32.70	2.09	1.98	1.90	1.90	36.88

14	21.61	30.55	1.91	1.82	1.72	1.72	33.31
15	18.90	28.49	2.14	2.04	1.90	1.90	36.88
16	82.56	73.92	2.10	1.99	1.84	20.13	35.69
17	97.02	97.02	10.18	9.67	1.90	1.90	36.88
18	87.94	87.94	19.26	18.30	1.84	1.84	35.69
19	70.12	70.12	23.03	21.88	1.90	1.90	36.88
20	53.38	53.38	19.53	18.55	1.90	1.90	36.88
21	43.08	43.08	9.69	9.21	1.84	1.84	35.69
22	38.09	38.09	5.25	4.99	1.90	1.90	36.88
23	36.65	36.65	2.07	1.97	1.84	1.84	35.69
24	34.81	34.81	2.04	1.93	1.90	1.90	36.88
25	32.70	32.70	2.09	1.98	1.90	1.90	36.88
26	30.55	30.55	1.91	1.82	1.72	1.72	33.31
27	28.49	28.49	2.14	2.04	1.90	1.90	36.88
28	93.19	73.92	2.10	2.10	1.84	11.79	35.69
29	158.32	97.02	10.18	9.67	1.90	1.90	36.88
30	145.47	87.94	19.26	18.30	1.84	1.84	35.69
31	125.18	70.12	23.03	21.88	1.90	1.90	36.88
32	105.96	53.38	19.53	18.55	1.90	1.90	36.88
33	95.57	43.08	9.69	9.21	1.84	1.84	35.69
34	89.64	38.09	5.25	4.99	1.90	1.90	36.88
35	87.01	36.65	2.07	1.97	1.84	1.84	35.69
36	83.89	34.81	2.04	1.93	1.90	1.90	36.88
37	80.39	32.70	2.09	1.98	1.90	1.90	36.88
38	77.23	30.55	1.91	1.82	1.72	1.72	33.31
39	74.85	28.49	2.14	2.04	1.90	1.90	36.88
40	80.94	73.92	2.10	1.99	1.84	1.84	35.69
41	77.28	97.02	10.18	9.67	1.90	1.90	36.88
42	69.02	87.94	19.26	18.30	1.84	1.84	35.69
43	56.55	70.12	23.03	21.88	1.90	1.90	36.88
44	38.19	53.38	19.53	18.55	1.90	1.90	36.88
45	29.06	43.08	9.69	9.21	1.84	1.84	35.69
46	24.09	38.09	5.25	4.99	1.90	1.90	36.88
47	22.16	36.65	2.07	1.97	1.84	1.84	35.69
48	20.08	34.81	2.04	1.93	1.90	1.90	36.88
49	17.42	32.70	2.09	1.98	1.90	1.90	36.88
50	15.04	30.55	1.91	1.82	1.72	1.72	33.31
51	12.34	28.49	2.14	2.04	1.90	1.90	36.88
52	51.24	73.92	2.10	2.10	1.84	24.33	35.69
53	97.02	97.02	10.18	10.18	1.90	36.88	36.88
54	96.38	87.94	19.26	19.26	1.84	21.61	35.69
55	77.45	70.12	23.03	21.88	1.90	1.90	36.88
56	59.57	53.38	19.53	18.55	1.90	1.90	36.88
57	51.97	43.08	9.69	9.21	1.84	1.84	35.69
58	49.73	38.09	5.25	4.99	1.90	1.90	36.88
59	49.37	36.65	2.07	1.97	1.84	1.84	35.69
60	48.16	34.81	2.04	1.93	1.90	1.90	36.88
61	46.18	32.70	2.09	1.98	1.90	1.90	36.88
62	44.41	30.55	1.91	1.82	1.72	1.72	33.31
63	42.15	28.49	2.14	2.04	1.90	1.90	36.88
64	92.95	73.92	2.10	1.99	1.84	1.84	35.69
65	189.15	97.02	10.18	9.67	1.90	1.90	36.88
66	199.13	87.94	19.26	18.30	1.84	1.84	35.69
67	185.47	70.12	23.03	21.88	1.90	1.90	36.88
68	167.91	53.38	19.53	18.55	1.90	1.90	36.88
69	160.02	43.08	9.69	9.21	1.84	1.84	35.69
70	157.47	38.09	5.25	4.99	1.90	1.90	36.88
71	158.15	36.65	2.07	1.97	1.84	1.84	35.69
72	156.27	34.81	2.04	1.93	1.90	1.90	36.88
73	153.88	32.70	2.09	1.98	1.90	1.90	36.88
74	152.02	30.55	1.91	1.82	1.72	1.72	33.31

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 75    150.06    28.49    2.14    2.04    1.90    1.90    36.88
 76    267.10    73.92    2.10    1.99    1.84    1.84    35.69
 77    288.97    97.02   10.18    9.67    1.90    1.90    36.88
 78    314.09    87.94   19.26   18.30    1.84    1.84    35.69
 79    319.55    70.12   23.03   21.88    1.90    1.90    36.88
 80    304.14    53.38   19.53   18.55    1.90    1.90    36.88
 81    298.86    43.08    9.69    9.21    1.84    1.84    35.69
 82    297.01    38.09    5.25    4.99    1.90    1.90    36.88
 83    294.72    36.65    2.07    1.97    1.84    1.84    35.69
 84    292.03    34.81    2.04    1.93    1.90    1.90    36.88
 85    288.91    32.70    2.09    1.98    1.90    1.90    36.88
 86    286.26    30.55    1.91    1.82    1.72    1.72    33.31
 87    283.34    28.49    2.14    2.04    1.90    1.90    36.88
 88    294.59    73.92    2.10    1.99    1.84    1.84    35.69
 89    290.62    97.02   10.18    9.67    1.90    1.90    36.88
 90    272.85    87.94   19.26   18.30    1.84    1.84    35.69
 91    251.30    70.12   23.03   21.88    1.90    1.90    36.88
 92    232.46    53.38   19.53   18.55    1.90    1.90    36.88
 93    224.95    43.08    9.69    9.21    1.84    1.84    35.69
 94    222.65    38.09    5.25    4.99    1.90    1.90    36.88
 95    221.60    36.65    2.07    1.97    1.84    1.84    35.69
 96    219.50    34.81    2.04    1.93    1.90    1.90    36.88
 97    216.97    32.70    2.09    1.98    1.90    1.90    36.88
 98    214.36    30.55    1.91    1.82    1.72    1.72    33.31
 99    212.06    28.49    2.14    2.04    1.90    1.90    36.88
100    230.73    73.92    2.10    1.99    1.84    1.84    35.69
101    232.99    97.02   10.18    9.67    1.90    1.90    36.88
102    217.20    87.94   19.26   18.30    1.84    1.84    35.69
103    196.24    70.12   23.03   21.88    1.90    1.90    36.88
104    176.52    53.38   19.53   18.55    1.90    1.90    36.88
105    166.36    43.08    9.69    9.21    1.84    1.84    35.69
106    161.06    38.09    5.25    4.99    1.90    1.90    36.88
107    159.36    36.65    2.07    1.97    1.84    1.84    35.69
108    156.84    34.81    2.04    1.93    1.90    1.90    36.88
109    153.90    32.70    2.09    1.98    1.90    1.90    36.88
110    151.17    30.55    1.91    1.82    1.72    1.72    33.31
111    148.04    28.49    2.14    2.04    1.90    1.90    36.88
112    199.84    73.92    2.10    1.99    1.84    1.84    35.69
113    304.15    97.02   10.18    9.67    1.90    1.90    36.88
114    309.90    87.94   19.26   18.30    1.84    1.84    35.69
115    290.05    70.12   23.03   21.88    1.90    1.90    36.88
116    270.84    53.38   19.53   18.55    1.90    1.90    36.88
117    261.20    43.08    9.69    9.21    1.84    1.84    35.69
118    255.48    38.09    5.25    4.99    1.90    1.90    36.88
119    253.63    36.65    2.07    1.97    1.84    1.84    35.69
120    251.05    34.81    2.04    1.93    1.90    1.90    36.88
121    248.36    32.70    2.09    1.98    1.90    1.90    36.88
122    245.96    30.55    1.91    1.82    1.72    1.72    33.31
123    243.27    28.49    2.14    2.04    1.90    1.90    36.88
124    277.24    73.92    2.10    1.99    1.84    1.84    35.69
125    274.09    97.02   10.18    9.67    1.90    1.90    36.88
126    255.61    87.94   19.26   18.30    1.84    1.84    35.69
127    233.09    70.12   23.03   21.88    1.90    1.90    36.88
128    213.72    53.38   19.53   18.55    1.90    1.90    36.88
129    203.63    43.08    9.69    9.21    1.84    1.84    35.69
130    198.18    38.09    5.25    4.99    1.90    1.90    36.88
131    196.10    36.65    2.07    1.97    1.84    1.84    35.69
132    193.11    34.81    2.04    1.93    1.90    1.90    36.88
133    189.74    32.70    2.09    1.98    1.90    1.90    36.88
134    186.81    30.55    1.91    1.82    1.72    1.72    33.31
135    187.68    28.49    2.14    2.04    1.90    1.90    36.88
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136	192.95	73.92	2.10	1.99	1.84	1.84	35.69
137	185.81	97.02	10.18	9.67	1.90	1.90	36.88
138	169.14	87.94	19.26	18.30	1.84	1.84	35.69
139	148.08	70.12	23.03	21.88	1.90	1.90	36.88
140	129.14	53.38	19.53	18.55	1.90	1.90	36.88
141	118.81	43.08	9.69	9.21	1.84	1.84	35.69
142	114.61	38.09	5.25	4.99	1.90	1.90	36.88
143	113.76	36.65	2.07	1.97	1.84	1.84	35.69
144	111.04	34.81	2.04	1.93	1.90	1.90	36.88
145	107.58	32.70	2.09	1.98	1.90	1.90	36.88
146	104.58	30.55	1.91	1.82	1.72	1.72	33.31
147	101.37	28.49	2.14	2.04	1.90	1.90	36.88
148	112.44	73.92	2.10	1.99	1.84	1.84	35.69
149	109.04	97.02	10.18	9.67	1.90	1.90	36.88
150	92.23	87.94	19.26	18.30	1.84	1.84	35.69
151	78.05	70.12	23.03	21.88	1.90	1.90	36.88
152	60.58	53.38	19.53	18.55	1.90	1.90	36.88
153	50.08	43.08	9.69	9.21	1.84	1.84	35.69
154	44.66	38.09	5.25	4.99	1.90	1.90	36.88
155	42.54	36.65	2.07	1.97	1.84	1.84	35.69
156	39.60	34.81	2.04	1.93	1.90	1.90	36.88
157	36.78	32.70	2.09	1.98	1.90	1.90	36.88
158	34.36	30.55	1.91	1.82	1.72	1.72	33.31
159	31.48	28.49	2.14	2.04	1.90	1.90	36.88
160	63.06	73.92	2.10	1.99	1.84	1.84	35.69
161	98.78	97.02	10.18	9.67	1.90	1.90	36.88
162	94.67	87.94	19.26	18.30	1.84	1.84	35.69
163	88.84	70.12	23.03	21.88	1.90	1.90	36.88
164	73.11	53.38	19.53	18.55	1.90	1.90	36.88
165	63.03	43.08	9.69	9.21	1.84	1.84	35.69
166	57.60	38.09	5.25	4.99	1.90	1.90	36.88
167	55.94	36.65	2.07	1.97	1.84	1.84	35.69
168	53.66	34.81	2.04	1.93	1.90	1.90	36.88
169	50.74	32.70	2.09	1.98	1.90	1.90	36.88
170	48.18	30.55	1.91	1.82	1.72	1.72	33.31
171	53.95	28.49	2.14	2.04	1.90	1.90	36.88
172	73.92	73.92	2.10	1.99	1.84	1.84	35.69
173	77.28	97.02	10.18	9.67	1.90	1.90	36.88
174	72.14	87.94	19.26	18.30	1.84	1.84	35.69
175	56.39	70.12	23.03	21.88	1.90	1.90	36.88
176	36.81	53.38	19.53	18.55	1.90	1.90	36.88
177	26.59	43.08	9.69	9.21	1.84	1.84	35.69
178	22.14	38.09	5.25	4.99	1.90	1.90	36.88
179	20.32	36.65	2.07	1.97	1.84	1.84	35.69
180	19.10	34.81	2.04	1.93	1.90	1.90	36.88