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WATERBUD

A Spreadsheet-Based Model of the Water Budget and Water Management Systems of the Upper San Pedro River Basin, Arizona

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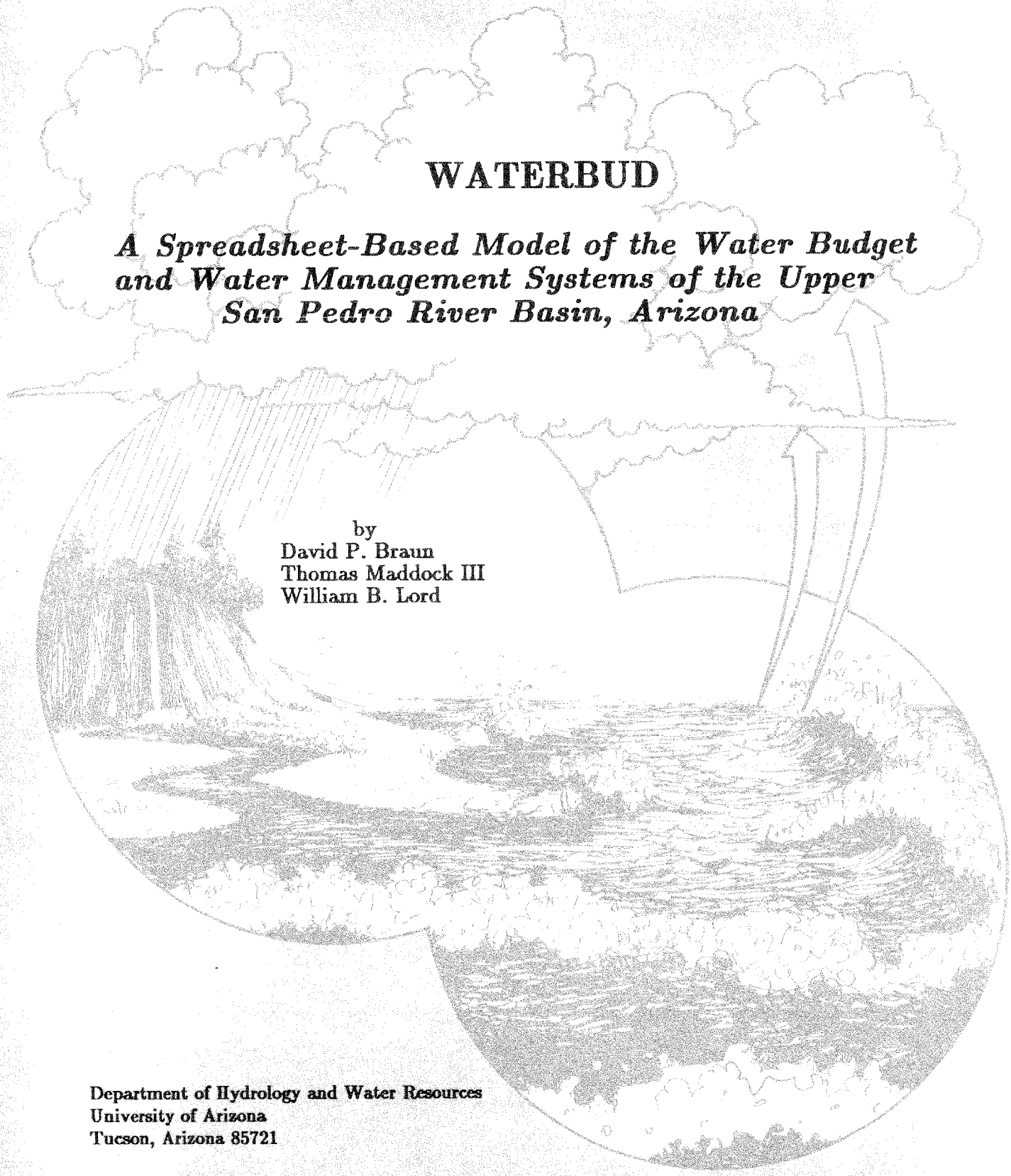

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USF200010239

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Table of Contents

Acknowledgments i

Table of Contents iii

List of Tables vii

List of Figures viii

Chapter 1: Introduction 1-1

1.1 Physical Setting 1-3

1.2 Water Consumption 1-8

1.3 Water Management Issues 1-9

1.4 The University of Arizona, Water Resources Research Center, Interdisciplinary Study 1-11

1.5 Specific Purposes and Capabilities of WATERBUD 1-13

1.6 Scenarios and Policy Options 1-15

1.6.1 Scenarios 1-17

1.6.2 Policy Options 1-19

1.7 A Guide to the Remaining Chapters 1-21

Chapter 2: Principles of the Model 2-1

2.1 Water Budget Accounting 2-1

2.1.1 Natural Water Budget of the Upper San Pedro Basin 2-1

2.1.2 Human Impacts on the Water Budget of the Upper San Pedro Basin 2-4

2.1.3 Modeling the Water Budget of the Upper San Pedro Basin 2-7

2.2 Limitations of Water Budget Modeling 2-9

2.3 Inputs and Outputs in the Water Budget 2-11

USF200010241

2.4 Internal Organization of the Model 2-15

Chapter 3: Parameters for the Model 3-1

3.1 Inflow from Mexico 3-2

3.2 Sub-basin Natural Characteristics 3-3

3.2.1 Precipitation and Runoff 3-3

3.2.2 Aquifers 3-6

3.2.3 Stream-Aquifer Interactions 3-14

3.2.4 Evaporation 3-17

3.3 Basin-Wide Cultural Supply and Demand 3-24

3.4 Special Sierra Vista City Activities 3-27

3.5 Domestic Consumption 3-29

3.6 Miscellaneous Domestic Consumption Parameters 3-40

3.7 Agricultural Consumption 3-43

3.8 Riparian Habitat and Management Status 3-52

3.9 Industrial Consumption 3-59

3.10 Reservoirs and Stockponds 3-63

3.11 Options 3-64

Chapter 4: Projection Equations for the Model 4-1

4.1 Socioeconomic Conditions 4-2

4.2 Gross Hydrological and Ecological Status Indicators 4-9

4.3 Inflows to the Sierra Vista Sub-basin 4-24

4.4 Sierra Vista Sub-basin Losses to Storage 4-26

4.5 Sierra Vista Sub-basin Recharge and Returns to Storage 4-51

USF200010242

4.6 Inflows to the Benson Sub-basin 4-61
4.7 Benson Sub-basin Losses to Storage 4-63
4.8 Benson Sub-basin Recharge and Returns to Storage 4-76
4.9 Seasonal and Annual Hydrological Changes 4-78
4.10 Net Annual Socioeconomic Changes 4-81

Chapter 5: Calibration and Applications 5-1
5.1 Calibration 5-1
5.1.1 Step 1: Calibration of Steady-State River-Aquifer Interactions 5-3
5.1.2 Step 2: Calibration of River-Aquifer Interactions in 1990 5-7
5.1.3 Step 3: Calibration of Steady-State Aquifer-Aquifer Interactions 5-8
5.1.4 Step 4: Calibration of Regional-Floodplain Aquifer Interactions in 1990 .. 5-8
5.1.5 Calibration Results and Limitations 5-10
5.2 Application: Scenarios and Policy Options 5-12
5.2.1 Scenarios 5-12
5.2.2 Policy Options 5-14
5.3 Application Results 5-17
5.3.1 General Patterns in Results 5-17
5.3.2 Policy 1 Results 5-22
5.3.3 Floodplain Aquifer Storage under Policies 2, 3, 4, and 5 5-31
5.3.4 Regional Aquifer Storage under Policies 2, 3, 4, and 5 5-31
5.3.5 River Discharges under Policies 2, 3, 4, and 5 5-36
5.3.6 Riparian Acreage under Policies 2, 3, 4, and 5 5-39
5.3.7 Irrigated Acreage under Policies 2, 3, 4, and 5 5-39
5.3.8 Median Household Income under Policies 2, 3, 4, and 5 5-44

USF200010243

5.4 Summary of Application Results 5-44

Chapter 6: Evaluation and Conclusions 6-1

6.1 Evaluation: Model Performance 6-1

6.1.1 Tabulation of Overall Water Budget for 1990 6-1

6.1.2 Allocation of Water for 1990 6-4

6.1.3 Tabulations in Projected Future Water Budgets 6-6

6.1.1 Allocation in Projected Future Water Budgets 6-9

6.2 Evaluation: Limitations in the Modeling Methods 6-12

6.2.1 Spreadsheet Programming 6-12

6.2.2 Lumped Parameter Modeling 6-15

6.3 Evaluation: Capabilities of the Model 6-16

6.4 Conclusions 6-18

Chapter 7: References 7-1

Appendix A: A-1

Appendix B: B-1

Appendix C: C-1

Appendix D: D-1

USF200010244

List of Tables

Table 2-1 Summary Annual Water Budget Computed by Model..... 2-8

Table 2-2 List of Input/Output Nodes, Sierra Vista Sub-basin 2-12

Table 2-3 List of Input/Output Nodes, Benson Sub-basin.....2-13

Table 2-4 Linkages Among Nodes, Sierra Vista Sub-basin 2-14

Table 2-5 Linkages Among Nodes, Benson Sub-basin 2-15

Table 3-1 Recommended Values, Domestic Consumption Parameters.....3-31

Table 3-2 Weighted Average Effective Precipitation Values, by Sub-basin 3-45

Table 5-1 Summary of Model Results for all Scenarios and Policy Options 5-23

Table 6-1 Summary Water Budget as Computed by ADWR (1991)..... 6-2

Table 6-2 Summary of MODSIM results (Summerside, 1991)..... 6-7

USF200010245

List of Figures

Figure 1-1 General Map of San Pedro River Basin, Arizona 1-4

Figure 1-2 Detailed Map of Upper San Pedro Basin, Arizona 1-6

Figure 2-1 Generalized Geologic Cross-section, Upper San Pedro Basin, Arizona .. 2-3

Figure 2-2 Schematic Water Budget Model for a Single Basin 2-10

Figure 2-3 Organization of the WATERBUD Spreadsheet 2-16

Figure 3-1 River Stage vs. Discharge, Sierra Vista Sub-basin 3-18

Figure 3-2 River Stage vs. Discharge, Benson Sub-basin 3-19

Figure 3-3 River Width vs. Discharge, Sierra Vista Sub-basin 3-22

Figure 3-4 River Width vs. Discharge, Benson Sub-basin 3-23

Figure 3-5 Riparian Corridor Width vs. Streamflow 3-56

Figure 3-6 Change in Riparian Corridor Width per Unit Change in Streamflow 3-58

Figure 4-1 Diagram of River-Riverbed-Aquifer Head Relationships 4-20

Figure 4-2 River-Floodplain Aquifer Discharge Behavior, Sierra Vista Sub-basin . 4-45

Figure 4-3 Discharge per Head Difference vs. River Stage, Sierra Vista Sub-basin 4-46

Figure 4-4 Discharge "Leveling-off" Behavior, Sierra Vista Sub-basin 4-47

Figure 4-5 River-Floodplain Aquifer Discharge Behavior, Benson Sub-basin 4-72

Figure 4-6 Discharge per Head Difference vs. River Stage, Benson Sub-basin 4-73

Figure 4-7 Discharge "Leveling-off" Behavior, Benson Sub-basin 4-74

Figure 5-1 Projected Trends in Floodplain Aquifer Storage 5-18

Figure 5-2 Projected Trends in Regional Aquifer Storage 5-19

Figure 5-3 Projected Trends in Annual River Discharge 5-20

Figure 5-4 Projected Total Urban and Rural Populations After 20 Years 5-24

Figure 5-5 Projected Change in Floodplain Aquifer Storage, by Scenario 5-25

Figure 5-6 Projected Change in Regional Aquifer Storage, by Scenario 5-26

USF200010247

Figure 5-7 Projected Annual Discharge of San Pedro River, by Scenario.....5-27
Figure 5-8 Projected Change in Area of Riparian Vegetation, by Scenario 5-28
Figure 5-9 Projected Change in Effective Irrigated Acreage, by Scenario 5-29
Figure 5-10 Projected Policy Effects on Floodplain Aquifer Storage, Scenario A ..5-32
Figure 5-11 Projected Policy Effects on Floodplain Aquifer Storage, Scenario D ..5-33
Figure 5-12 Projected Policy Effects on Regional Aquifer Storage, Scenario A 5-34
Figure 5-13 Projected Policy Effects on Regional Aquifer Storage, Scenario D 5-35
Figure 5-14 Projected Policy Effects on River Discharge, Scenario A.....5-37
Figure 5-15 Projected Policy Effects on River Discharge, Scenario D 5-38
Figure 5-16 Projected Policy Effects on Area of Riparian Vegetation, Scenario A .5-40
Figure 5-17 Projected Policy Effects on Area of Riparian Vegetation, Scenario D .5-41
Figure 5-18 Projected Policy Effects on Effective Irrigated Acreage, Scenario A ..5-42
Figure 5-19 Projected Policy Effects on Effective Irrigated Acreage, Scenario D ..5-43
Figure 5-20 Projected Policy Effects on Median Household Income.....5-45

USF200010248

Chapter 1
Introduction

This report describes the development and application of a spreadsheet-based model of the water budget and water management systems of the Upper San Pedro River Basin in southeastern Arizona. The model has been given the name, WATERBUD.

WATERBUD has two purposes: (1) to provide an accurate representation of the water budget of the basin and the effects of hydrologic, demographic, climatic, and economic conditions on that budget; and (2) to serve as a tool for examining how water management policies may affect the water budget over the next twenty years. The model separates the upper basin into a Mexican sub-basin and two sub-basins in the U.S., each containing a portion of the basin-fill or "regional" aquifer, a portion of the alluvial or "floodplain" aquifer, and a segment of the river. The two U.S. sub-basins are labeled the Sierra Vista and Benson sub-basins. WATERBUD keeps account of the water entering and leaving the upper basin, including storm precipitation and runoff, on a quarterly and an annual basis.

WATERBUD is a product of research conducted in 1990 and 1991 by the University of Arizona, Water Resources Research Center (UAWRRC) as part of the project, "A Study of the Water Resources of the San Pedro Basin and Options for Efficient and Equitable Water Management." This project was carried out by a San Pedro Interdisciplinary Study Team, for the San Pedro River Water Management Council, Cochise County Flood Control District, Arizona. This author was responsible for the design, construction, calibration, and operation of WATERBUD within this project, and received extensive feedback from the student and faculty members of the Study Team

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during development of the model. WATERBUD also directly incorporates the results of ancillary research by two other student members of the Study Team, Ali Aljamal and Richard Dorrance. Chapters 3 and 4 specifically identify their contributions. Four other students also have prepared theses based on their research as members of the Study Team; the design of WATERBUD was coordinated closely with these other research efforts by Leticia Vionnet (1991; Vionnet and Maddock, 1992), Scott Summerside (1991), David Gillilan (1992) and Michael Henrich (1992). The Study Team has presented to Cochise County a summary report of its overall findings (UAWRRC, 1991).

The heart of WATERBUD is a series of equations that compute annual water budgets for a twenty-year period of projection, based on a set of initial conditions. Each projected year contains four quarters, for which the equations generate estimates of the flow of water to and from the regional aquifer, the floodplain aquifer, and the river. The equations compute estimates of (1) urban and rural population sizes and median incomes; (2) urban and rural domestic water consumption; (3) agricultural and industrial consumption; (4) return flows of domestic, agricultural, and industrial water; (5) phreatophyte consumption and other evapotranspiration losses; (6) natural surface and ground-water recharges and discharges; (7) head-dependent flows between the floodplain aquifer and the river; (8) head-dependent flows between the two aquifers; and (9) changes in storage in the two aquifers.

The accuracy of the projecting equations depends on their mathematical structure and on their specified initial conditions. WATERBUD therefore contains an initial, "parameters" section, which specifies the initial conditions for each simulation. These parameters provide the information needed to characterize the movement of water to and from municipal, industrial, and agricultural users, natural ecosystems, the two aquifers, and the river. A master copy of the model provides a set of recommended "default"

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values for all parameters, describing conditions in the basin in 1990. Users of the model can specify alternative initial conditions, such as alternative population growth rates or crop irrigation requirements, to see how these conditions affect the overall water balance.

The remainder of this chapter provides background information on the physical setting of the model, its purposes and history of development, and its relationship to other studies of the Upper San Pedro River Basin. Subsequent chapters describe the development of the model in detail, and the results obtained in applying the model.

1.1 PHYSICAL SETTING

The San Pedro River flows northward from northern Sonora, Mexico, through central southeastern Arizona to join the Gila River near the town of Winkelman (Figure 1-1). Conventionally, researchers divide the portion of the San Pedro River Basin that lies within Arizona into two sections: the Upper San Pedro River Basin consists of those portions of the San Pedro River Basin lying between the U.S.-Mexico border and the Narrows, a constriction of the valley located eleven miles north of the city of Benson. The Lower San Pedro River Basin consists of the remainder of the basin extending from the Narrows to the Gila River confluence. Each of these portions of the basin includes roughly 60 miles of the river course. The upper basin lies almost entirely within Cochise County, Arizona, with small extensions into eastern Pima and Santa Cruz Counties. Figure 1-2 shows the upper basin in greater detail.

The San Pedro River flows perennially along several reaches between the international border and Winkelman, and supports riparian corridors along these reaches. The channel of the river is highly braided and is moderately entrenched along several segments. Entrenchment of the channel to its present grade took place during the late

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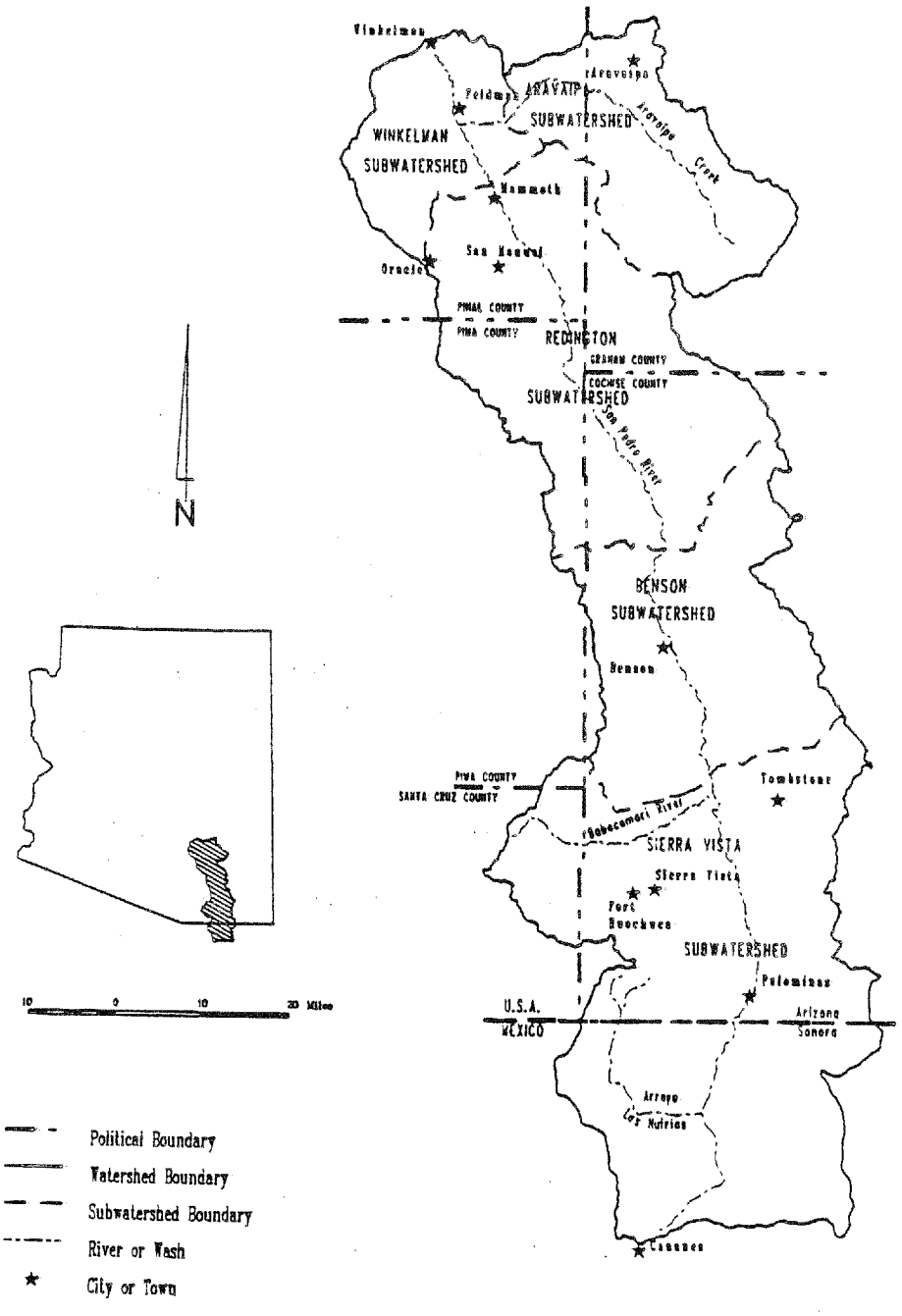
General Map of the San Pedro River Basin, Arizona (after ADWR, 1991:4)
Figure 1-1



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1800s and early 1900s; the present grade has been stable since approximately the late 1930s (BLM, 1987; Hereford, 1991).

Major tributaries with additional perennial flow include the Babocomari River draining the west-center of the upper basin and Aravaipa Creek draining the east side of the lower basin. Additional major intermittent tributaries include Walnut, Tres Alamos, and Ash Creeks in the upper basin; and Kelsey, Paige, and Hot Springs Creeks in the lower basin. The Arizona Department of Water Resources (ADWR) estimates that the extent of perennially flowing reaches was much greater prior to human development of the basin's water resources (Arizona Department of Water Resources [hereafter ADWR], 1991).

The Upper San Pedro Basin is bounded on the east by the watershed divides of the Tombstone Hills, and the Mule, Dragoon, Little Dragoon, Winchester, and southern John Lyons Mountains; and on the west by the divides of the Huachuca, Mustang, Whetstone, and southern Rincon Mountains (Figure 1-2). The basin is typical of alluvial basins in the southwestern Basin and Range geographic province. The basin formed during the early and middle Tertiary, a result of faulting and spreading associated with the Laramide episode of formation of the Rocky Mountains. The basin fill consists of alluvial sediments eroded from the surrounding mountains during Miocene, Pliocene, Pleistocene, and Recent times (Heindl, 1952; Anderson *et al.*, 1990; ADWR, 1991).

The basin fill deposits comprise the principal aquifers of the basin. Natural recharge to these aquifers occurs almost exclusively along the mountain fronts, where runoff from the streams and shallow soils of the mountains encounter the edges of the basin fill sediments (Anderson *et al.*, 1990). The direction of ground-water flow generally lies perpendicular to the mountain fronts, around the margins of the basin, but becomes parallel to the mountain fronts along the valley's central axis (Figure 1-2). The

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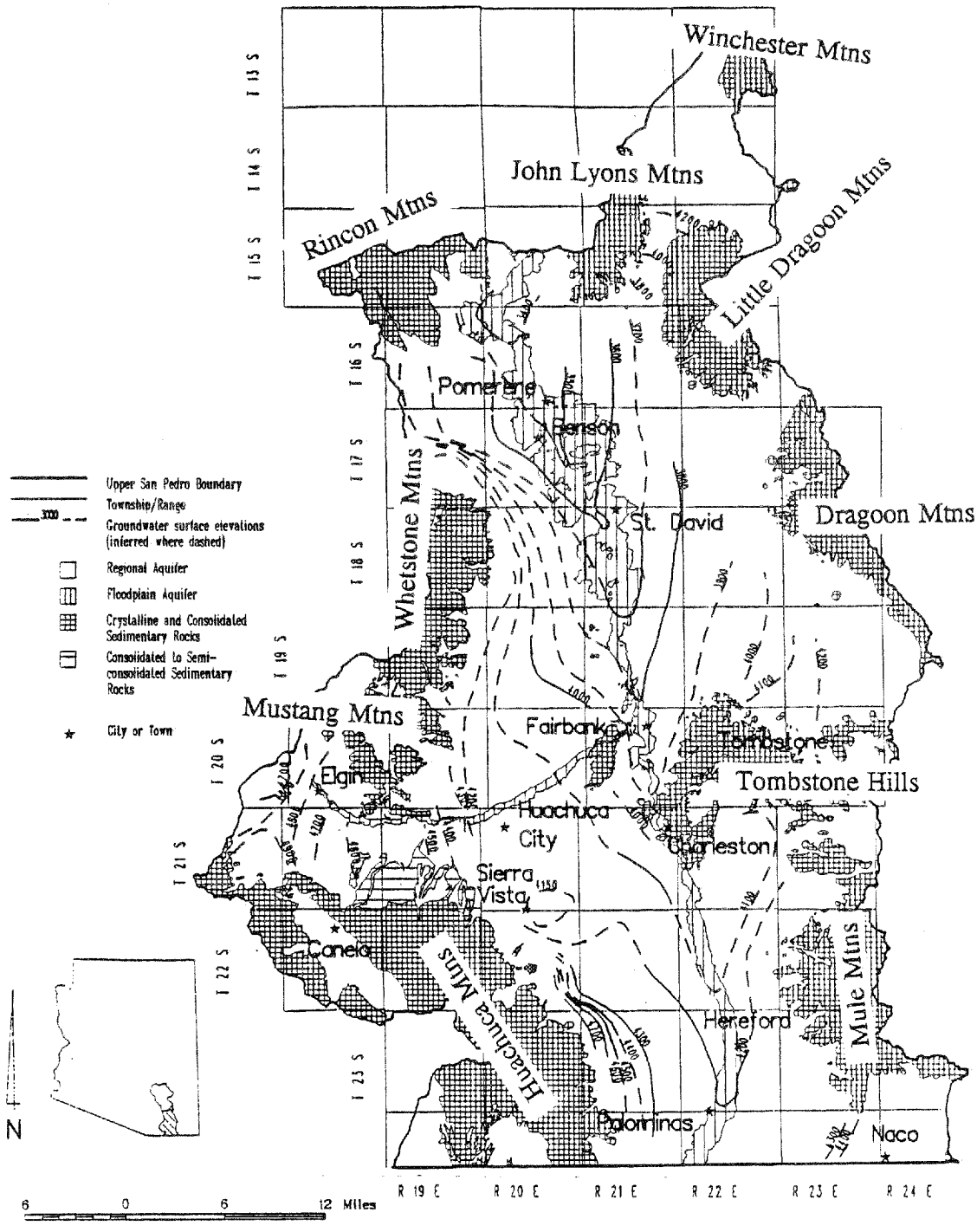
Communities and Ground-water Surface Elevations of the Upper San Pedro Basin (after ADWR, 1991:65)
Figure 1-2



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deeper sediments along the central axis of the valley include several thick layers of clay and silt, which act as aquitards and locally produce both perched and confined aquifer conditions. The confined basin-fill aquifer exhibits flowing artesian hydraulic conditions in the Palominas-Hereford and Benson-St. David areas, due to the overlying clay and silt layers.

Annual precipitation varies from less than 10 inches along the lowest elevations to more than 30 inches in the mountains (ADWR, 1991). Precipitation occurs mostly during the winter and late summer months with intervening periods of low precipitation. The vegetation in the basin is typical of the northeastern Sonoran Desert region, varying from coniferous forests at the highest elevations to desert scrub at the lowest elevations and narrow corridors of riparian vegetation along the major water courses.

The hydrogeology of the Upper San Pedro Basin has received extensive study, beginning with Lee (1905) and Bryan *et al.* (1934) (see also Heindl, 1952; Davidson and White, 1963; Montgomery, 1963; Hollyday, 1963; Gray, 1965; Brown *et al.*, 1966; Roeske and Werrell, 1973; Konieczki, 1980; Freethey, 1982; Putnam *et al.*, 1987, 1988; ADWR, 1991; Vionnet, 1991; Vionnet and Maddock, 1992). Freethey (1982, n.d.), ADWR (1991), and Vionnet (1991; Vionnet and Maddock, 1992) have carried out detailed modeling of the ground-water dynamics of portions of the upper basin. Additional modeling efforts are also underway (Kraeger-Rovey, 1987, n.d.; Braun, in prep.). The more recent studies all attempt to assess the limits and opportunities for water development in the Fort Huachuca-Sierra Vista area, or to evaluate the system for various parties to the General Adjudication of the Gila River System and Source currently taking place through the Maricopa County (Arizona) Superior Court (ADWR, 1991).

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1.2 WATER CONSUMPTION

A variety of natural processes and human activities all consume water in the Upper San Pedro Basin. Water not consumed either contributes to storage in the aquifers or leaves in the form of river discharges. Little water leaves the upper basin as ground-water underflow. Chapters 2 and 3 provide more detailed information on the ground-water flow regime. Natural losses of water take place along three pathways: (1) evaporation of water from the river and wetted riverbed; (2) interception of runoff water by evapotranspiration before the runoff reaches the water courses; and (3) evapotranspiration by phreatophytes along the main water courses. Human consumption of the upper basin's water resources includes domestic and municipal consumption, irrigation of crops and recreational facilities, and consumption by mining and other industries. Wells and spring water supply the needs of the communities of Sierra Vista, Fort Huachuca, Huachuca City, Tombstone, Naco, Bisbee, St. David, Pomerene, and Benson, as well as the needs of people living in unincorporated areas of the counties. Although lying outside the watershed of the upper basin, the community of Bisbee supplies itself primarily with water pumped from inside the basin. Irrigation consumes both groundwater and surface water. The mining and other water-demanding industries of the upper basin supply themselves exclusively with groundwater.

The development of water resources in the upper basin began with the diversion of river flows and springs by prehistoric and early historic Native American settlers, followed by Spanish colonists during the 1700s, and the U.S. Army (Fort Huachuca) and Mormon settlers in the 1870s. The diversion of surface water has expanded little since then and may have declined since the advent of ground-water consumption. Only a few activities presently result in the diversion of surface waters: Fort Huachuca and the City of

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Tombstone divert water from springs along the flanks of the Huachuca Mountains, the latter by means of an aqueduct across the valley; stockponds capture seasonal runoff; and the St. David and Pomerene irrigation ditches divert water from the river (ADWR, 1991).

The development of ground-water resources began with the growth of the underground mining industry in the 1880s and the discovery of local artesian conditions in the 1890s (Roeske and Werrell, 1973). Changes in well pump technology led to increased irrigation pumping beginning in the 1930s, accompanied by an increase in total irrigated acreage. These same changes in pump technology encouraged an expansion of residential settlement in the upper basin beginning in the 1940s, as well. The rate of withdrawal of groundwater for agriculture declined during the late 1980s. Agricultural activity declined in the Palominas-Hereford area at the extreme southern end of the upper basin, and the establishment of the San Pedro National Riparian Conservation Area (SPRNCA) eliminated additional pumping. The SPRNCA, managed by the U.S. Department of the Interior, Bureau of Land Management, occupies approximately 30 linear miles along the river in the southern half of the upper basin. Its creation resulted in the discontinuation of all significant ground-water pumping within its boundaries. However, irrigation pumping has not declined significantly elsewhere in the upper basin. Further, withdrawals to supply the residents of the upper basin continue to grow, particularly around Fort Huachuca and the City of Sierra Vista (ADWR, 1991).

1.3 WATER MANAGEMENT ISSUES

The Upper San Pedro Basin's residents face challenges to their continued use of the basin's water resources on four scales: local, regional, national, and international. Locally, the communities in the Fort Huachuca-Sierra Vista area face a growing cone of depression of hydraulic heads in the regional aquifer penetrated by their extensive well

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fields (Freethey, 1982; ADWR, 1991; Vionnet, 1991; Vionnet and Maddock, 1992). This cone of depression poses a challenge to the continued development of residential and commercial real estate in this area. The declining hydraulic heads also may lead to a conflict between development of the local non-military economy and development of the military reservation.

Regionally, many uses of water resources in the entire San Pedro basin are undergoing scrutiny in the Maricopa County Superior Court as part of the General Adjudication of the Gila River System and Source (ADWR, 1991). The resolution of claims by the Gila River Indian Community for water reserved to it in principle under federal treaties has the potential to limit the future growth of water consumption in the basin, or even to require reductions in the present levels of consumption. Although the General Adjudication theoretically concerns only claims to surface water, the proceedings also necessarily cover ground-water flows tributary to surface water.

The presence of relatively undisturbed zones of riparian habitat in the upper basin also has focused national attention on the preservation of these zones and on the possible reclamation of additional lands from which such habitat has disappeared due to human encroachment. The creation of the SPRNCA in the upper basin marks a special recognition of the importance of preserving riparian zones by the federal government. National organizations, such as The Nature Conservancy, maintain additional riparian preserves in the upper basin. All of these preserves entail claims to surface waters to maintain in-stream flows. Protection of these claims potentially may conflict with the continued agricultural and municipal withdrawal of tributary groundwater in several areas, particularly in the Palominas-Hereford and Fort Huachuca-Sierra Vista areas (BLM, 1987; ADWR, 1991; UAWRRC, 1991; Vionnet, 1991; Vionnet and Maddock, 1992).

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Finally, on an international scale, both surface and ground-water flows in Mexico are tributary to the hydrologic system of the upper basin in the U.S. Mining, residential, and agricultural activities are expanding in the Mexican portions of the basin. Their expansion potentially could reduce or even locally reverse the direction of ground-water flow and could reduce or even eliminate surface water flows across the international boundary.

1.4 THE UNIVERSITY OF ARIZONA, WATER RESOURCES RESEARCH CENTER INTERDISCIPLINARY STUDY

Upper San Pedro Basin residents have responded to the issues facing their continued use of the basin's water resources in part by establishing the San Pedro River Water Management Council, under the authority of the Cochise County Flood Control District, Arizona. The council subsequently contracted with the University of Arizona, Water Resources Research Center, to assist in evaluating their options. The objectives of the project were "to assist the Council in identifying water management objectives and policy options capable of meeting these objectives and to provide analytical aids to the Council for their task of setting objectives and evaluating policy options" (UAWRRC, 1991:7).

The San Pedro Interdisciplinary Study Team focused on several questions of central concern to the Council (UAWRRC, 1991:13): What are the effects of pumping from the regional aquifer upon stream flows in the river and its tributaries? How can the desires of the community be translated into water management objectives? How might the achievement of a particular water management objective affect the lives of the basin's residents? What specific management options exist? Which of these options might be most effective in achieving the water management objectives of the community?

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Answering such questions requires using analytical tools that can do more than describe current or historic conditions in the hydrologic system. Answering such questions requires tools that can make projections about future hydrologic conditions, as these might be affected by economic, demographic, and climatic conditions and by specific water management policies.

The WATERBUD simulation model was developed for this project as one of four analytical and planning tools provided to the Council. The other three were developed by Vionnet (1991; Vionnet and Maddock, 1992), Summerside (1991), and Henrich (1992):

Vionnet (1991; Vionnet and Maddock, 1992) modified and increased the capabilities of a ground-water flow model that runs with the U.S. Geological Survey program, MODFLOW. Freethey (1982) developed the original version of the model. The U.S. Army Corps of Engineers and the Arizona Department of Water Resources modified the model in several ways (ADWR, 1991) before Vionnet undertook further revisions. The modeled area covers approximately a quarter of the upper basin, encompassing the Fort Huachuca-Sierra Vista area and the segment of the river running from the international border to just south of the Tombstone stream gauge. Freethey (1982) originally developed the model to examine the hydraulic cone of depression in the Fort Huachuca-Sierra Vista area. Vionnet gave the model added capabilities to examine the interaction of the river with both the floodplain and regional aquifers and the interaction of the two aquifers with each other.

Summerside (1991) developed a model of the allocation of water resources in the upper basin using the Colorado State University program, MODSIM. MODSIM is a network optimization program with the capability to simulate hydrologic, economic, and demographic conditions, and water management institutions, facilities, and practices, to forecast the effects of alternative water management practices. It operates on different

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principles than either MODFLOW or WATERBUD and provides a complementary view of potential future conditions in the upper basin. The MODSIM model covers the entire upper basin but divides the landscape into the same two sub-basins used in WATERBUD: the watershed tributary to the river north of the international boundary and south of the Tombstone gauge comprises the Sierra Vista sub-basin; the watershed tributary to the river north of the Tombstone gauge and south of the Narrows comprises the Benson sub-basin. Figure 1-1 shows the location of these two sub-basins.

Finally, Henrich (1992) used the computer program, MATS, to assess the personal values and water management objectives of upper basin residents, as these might affect their preferences among alternative water management policies. Henrich used MATS (Multi-Attribute Tradeoff System) for two purposes. First, Henrich used the program to evaluate the range of values and water management objectives present among residents of the upper basin, and to classify residents according to the weights they placed on different values. Second, Henrich used the program to evaluate how the different classes of residents would likely respond to the general policy options considered by the San Pedro Interdisciplinary Study Team. Henrich's results thus provide decision makers in the upper basin with information on the possible social rather than hydrologic consequences of alternative water management policies.

1.5 SPECIFIC PURPOSES AND CAPABILITIES OF "WATERBUD"

WATERBUD does not provide a detailed analysis of the hydrology of the upper basin. Instead, it shares with MODSIM the capability to examine general or average hydrologic, demographic, and economic conditions in the upper basin, along with the effects of alternative water management practices. As does the MODSIM model, it divides the upper basin into a Sierra Vista and a Benson sub-basin, to incorporate at least

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some spatial information. WATERBUD has more limited capabilities for modeling climatic variability than does the MODSIM model. However, WATERBUD has greater capabilities for examining economic factors and processes than does the MODSIM model. Additionally, its spreadsheet format allows users to carry out "what if" analyses more easily with WATERBUD than with MODSIM.

As noted above, WATERBUD has been designed to examine relationships among nine components of the system: (1) urban and rural population sizes and median incomes; (2) urban and rural domestic water consumption; (3) agricultural and industrial consumption; (4) return flows of domestic, agricultural, and industrial water; (5) phreatophyte consumption and other evapotranspiration losses; (6) natural surface and ground-water recharges and discharges; (7) head-dependent flow between the floodplain aquifer and the river; (8) head-dependent flow between the two aquifers; and (9) changes in storage in the two aquifers. The first five of these components of the system all can affect hydraulic heads and aquifer storage in the system. In turn, water management practices can affect all five. Changes in water pricing policies or the legislation of conservation requirements, for example, could affect median incomes and residential consumption. Changes in water pricing policies or the legislation of conservation or efficiency requirements similarly could affect agricultural consumption and irrigation return flows. WATERBUD therefore has been designed to allow examination of the ways by which water management policies may affect these five components of the system and so affect the last three as well.

WATERBUD necessarily incorporates a description of current conditions for all nine system components listed above. For reference purposes, WATERBUD fixes 1990 as the starting year for the model. The preparation of the Hydrographic Survey Report for the San Pedro River Watershed by the Arizona Department of Water Resources (ADWR,

USF200010262

1991) has produced large quantities of data on the upper basin, current up to 1989-1990. These data provide the basis for all descriptions of the hydrologic system incorporated into WATERBUD. The author provided an initial version of WATERBUD to the San Pedro River Water Management Council in 1991 as part of the completion report by the University of Arizona, Water Resources Research Council (UAWRRC, 1991). That version had been calibrated against a Preliminary Hydrographic Survey Report for the San Pedro River Watershed also prepared by the Arizona Department of Water Resources (ADWR, 1990). Arizona Department of Water Resources changed several estimates of hydrologic conditions between the 1990 and 1991 reports; the present version of WATERBUD incorporates these changes.

1.6 SCENARIOS AND POLICY OPTIONS

WATERBUD and the MODSIM model were used to examine how hydrologic, demographic, and economic conditions in the Upper San Pedro Basin might change, under different combinations of "scenarios" and "policy options." The distinction between "scenarios" and "policy options" recognizes a difference between factors beyond versus within the control of basin residents, that can affect hydrologic conditions. Specifically, three factors lie outside the control of basin residents, that can affect the viability of different policy options. These three factors are (1) population growth rates, (2) climatic conditions, and (3) regional and national economic conditions affecting the feasibility of commercial agriculture. The Study Team reserved the term, "scenario," to refer to combinations of these three factors, against which to compare the effectiveness of different policy options. The Study Team reserved the term, "policy option," in turn, to refer to combinations of actions that the basin residents might take in order to change their patterns

USF200010263

of consumption (UAWRRC, 1991:17-23). This report continues this terminological distinction.

The Study Team established a range of reasonable variation for population growth rates, climatic conditions, and economic conditions, extending from current conditions to a plausible set of "worst-case" conditions. The Study Team defined the "worst-case" conditions in order to examine how the hydrologic system might change under conditions unfavorable to the achievement of a balance among competing human demands. Demographic, climatic, and economic conditions can and do change, and water management policies will be effective only if they can cope with unfavorable as well as favorable conditions.

The Study Team also established a range of policy options, encompassing those water management practices typically employed in arid western states to encourage people to reduce their consumption. All published estimates of water consumption in the upper basin (e.g., Roeske and Werrell, 1973; Freethey, 1982; Putnam *et al.*, 1988; ADWR, 1991:Chapter 5 and Appendix F; Vionnet, 1991; Vionnet and Maddock, 1992) identify a pattern of continuing reductions in storage in the upper basin's aquifers. Thus, the Study Team recognized from the start that the competing human demands on the hydrologic system cannot be brought into balance without some reduction in the demand for water or augmentation of the water supply.

The Study Team recognized that many different policies can encourage water conservation, but that these policies lie along two scales of variation. One scale ranges from laws requiring people to conform to some imposed standard rate of water consumption, to laws creating a system of (usually) financial incentives that allow people to make their own decisions on what to consume. An imposed rate of consumption can consist of a fixed gallon-per-capita-per-day requirement or a required percentage reduction

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from some historic rate, for domestic consumers; and can consist of a required minimum efficiency or maximal rate of application of water per acre, for irrigators. A system of incentives alternatively can consist of surcharges or taxes imposed on well withdrawals for all users. Consumers can also choose to use the revenues from such surcharges to "buy out" some users, such as irrigators, for whom the present cash value of their water rights may exceed the future value they can anticipate from continuing to irrigate. The second scale covers the possibility that the people of the basin also might seek to increase their capture of water from the hydrologic system, for example by recharging rather than evaporating their effluent waters. The report of the Study Team (UAWRRC, 1991) and the work of Gillilan (1992) discuss the development of policy options in detail.

WATERBUD has the capability to simulate a far wider range of scenarios and policy options, than were examined as part of the project for the San Pedro River Water Management Council. Chapters 2 and 3 describe these additional capabilities. The following paragraphs summarize the specific scenarios and policy options examined with WATERBUD to date. The results of these simulations provide an adequate test of the usefulness and flexibility of the model. The author hopes and expects that Upper San Pedro Basin residents will develop additional scenarios and policy options, and will put WATERBUD and the other planning tools developed by the Study Team to full use.

1.6.1 Scenarios

The Study Team defined five scenarios, representing a range of variation from average to "worst-case" conditions for the three factors of interest. Chapters 5 and 6 discuss the simulation of these five scenarios in further detail. Briefly, the five scenarios are as follows:

USF200010265

1.6.1.1 Scenario A

This scenario projects the effects of current population growth patterns, average climatic conditions, and current economic conditions for agriculture that neither encourage nor discourage further changes in irrigated acreage. The specific numerical values associated with this scenario are the default values for the model parameters, discussed in Chapter 3, below.

1.6.1.2 Scenario B

This scenario projects a 'worse-case' scenario, in which population growth, climatic conditions, and agricultural growth all have high impacts on water use. Population growth is projected at 0.02 greater than current rates, Fort Huachuca is modeled as expanding the size of its staffing; climatic conditions are modeled to match the hottest and driest conditions recorded in the past twenty years; and growth in agricultural acreage is modeled to match the maximal rate of growth in acreage (3.5% per year) recorded during the period 1970-1990. The specific numerical values associated with this scenario are discussed in Chapter 3, below.

1.6.1.3 Scenario C

Demographic conditions in this scenario are modeled using the worst-case specifications of Scenario B, but climatic and agricultural conditions are set as in Scenario A. This scenario thus provides information on the impacts of population growth while holding other stresses constant at historic average levels.

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1.6.1.4 Scenario D

Climatic conditions in this scenario are modeled using the worst-case specifications of Scenario B, but demographic and agricultural conditions are set as in Scenario A. This scenario thus provides information on the impacts of climatic stress while holding other stresses constant at historic average levels.

1.6.1.5 Scenario E

Agricultural conditions in this scenario are modeled using the worst-case specifications of Scenario B, while demographic and climate conditions are set as in Scenario A. This scenario thus provides information on the impacts of agricultural stress while holding other stresses constant at historic average levels.

1.6.2 Policy Options

The Study Team defined five policy options, representing a range of variation from legislatively required to financially encouraged water conservation, and from leaving alone to increasing the capture of water by the hydrologic system. Chapters 5 and 6 discuss the simulation of these five policy options in further detail. The five options, briefly, are as follows:

1.6.2.1 Policy 1

This policy option projects the effects of allowing the status quo to continue with no further management of water resources.

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1.6.2.2 Policy 2

This option projects the effects of enforcing a ceiling on domestic consumption based on a gallons-per-capita-per-day (gpcd) criterion; requiring a minimum irrigation efficiency; and allowing for the purchase and discontinuation of irrigation water rights. No assumption is made as to the source of the capital used to purchase these rights. There are three variants to this option, covering different rates of acquisition and discontinuation of irrigation rights, discussed in detail in Chapters 5 and 6.

1.6.2.3 Policy 3

This option projects the effects of placing a surcharge or "pump tax" on all well withdrawals. There are five variants to this option, covering five different surcharge amounts, discussed in detail in Chapters 5 and 6.

1.6.2.4 Policy 4

This option projects the combined effects of capturing additional water supplies by recharging treated effluent and enhancing precipitation by cloud seeding. Chapters 5 and 6 provide additional information on this option.

1.6.2.5 Policy 5

Finally, this option projects the effects of maximal conservation efforts on the part of both domestic and agricultural users, by simulating a fixed percentage reduction of domestic demand from normal demand levels, and a fixed increase in irrigation efficiencies. This option makes no assumptions as to how these reductions might be

USF200010268

achieved; it is used to examine the limits of what might be achieved through conservation efforts alone.

1.7 A GUIDE TO THE REMAINING CHAPTERS

This report has five additional chapters. Chapter 2 presents the overall logic of the model its main principles of operation. Chapter 3 discusses the initial conditions that need to be specified for a simulation, and explains the settings recommended for these parameters in the model. Chapter 4 develops and explains the equations that generate the quarterly, annual, and twenty-year projections. Chapter 5 describes how the model is calibrated to provide an accurate description of the basin's hydrologic system, and presents the results of simulations of the several scenarios and management policies described above. Chapter 6, finally, evaluates the results of the WATERBUD simulations, as these reflect on the usefulness, accuracy, and sensitivity of the model. There are also four appendixes. Appendix A describes the steps involved in running WATERBUD; Appendix B lists the recommended default parameter settings; Appendix C lists the spreadsheet formulas used in the model; and Appendix D presents the complete numerical results of the simulations summarized in Chapter 5.

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Chapter 2
Principles of the Model

This chapter describes the basic properties of WATERBUD and the salient features of the hydrologic system represented in the model. The chapter begins with a summary of the principles of water budget accounting as these apply to the Upper San Pedro River Basin. Next, the chapter discusses the limitations of water budget modeling and of using spreadsheet programs as tools for simulating aspects of a hydrologic system. Finally, the chapter discusses the input and output relationships among the components of the hydrologic system of the Upper San Pedro River Basin and the kinds of processes that shape these relationships and therefore needed to be represented in the model.

2.1 WATER BUDGET ACCOUNTING

A water budget consists of an accounting of the water entering and leaving a hydrologic system and stored in the system. Any difference between the quantity of water entering versus leaving a system must result in a change in the quantity of water stored. If more water enters than leaves, storage increases; if more water leaves than enters, storage decreases.

2.1.1 Natural Water Budget of the Upper San Pedro Basin

The Upper San Pedro River Basin has water stored in two aquifers: a regional aquifer consisting of basin fill deposits of compacted and cemented gravel, sand, silt, and clay; and a zone of younger alluvial deposits variously known as the inner valley, younger alluvial, or floodplain aquifer (Roeske and Werrell, 1973; Anderson et al., 1990; ADWR,

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1991). The floodplain aquifer thus occupies a narrow band of sediments along the central axis of the valley, cut into the top of the basin fill deposits. Bedrock underlies the regional aquifer and some sections of the floodplain aquifer. Figure 2-1 shows a generalized east-west cross section of the basin sediments.

The natural water budget of the regional aquifer is quite simple. Water enters the regional aquifer almost entirely as a result of the infiltration of snowmelt and rainfall runoff along the faces of the mountains that ring the basin. Most of this water eventually but very slowly moves from the regional to the floodplain aquifer. Small amounts emerge at springs at the base of the mountains, exit as evaporation and vegetative transpiration, or contribute to a slight northward flow of groundwater within the regional aquifer alone.

The natural water budget of the floodplain aquifer is more complex. Water enters the floodplain aquifer from the regional aquifer and from the river. The natural flow from the regional aquifer into the floodplain aquifer is roughly constant year-round. It results from the fact that hydraulic heads generally are higher in the regional aquifer than in the floodplain aquifer. The flow between the river and the floodplain aquifer is more variable. When flow in the river increases, the level (stage) of water in the river may rise above the water table in the floodplain aquifer alongside the river. Water will then seep from the river into the aquifer. When flow in the river decreases, the level (stage) of water in the river may fall below the water table in the floodplain aquifer alongside the river. Water will then seep from the aquifer into the river. This process of interaction between the floodplain aquifer and the river is known as "stream leakage" (Prudic, 1989). The floodplain aquifer also loses large quantities of water to vegetative transpiration (phreatophyte consumption). Smaller quantities evaporate from bare ground, especially along exposed portions of the streambed, or contribute to a slight northward flow of water within this aquifer as well.

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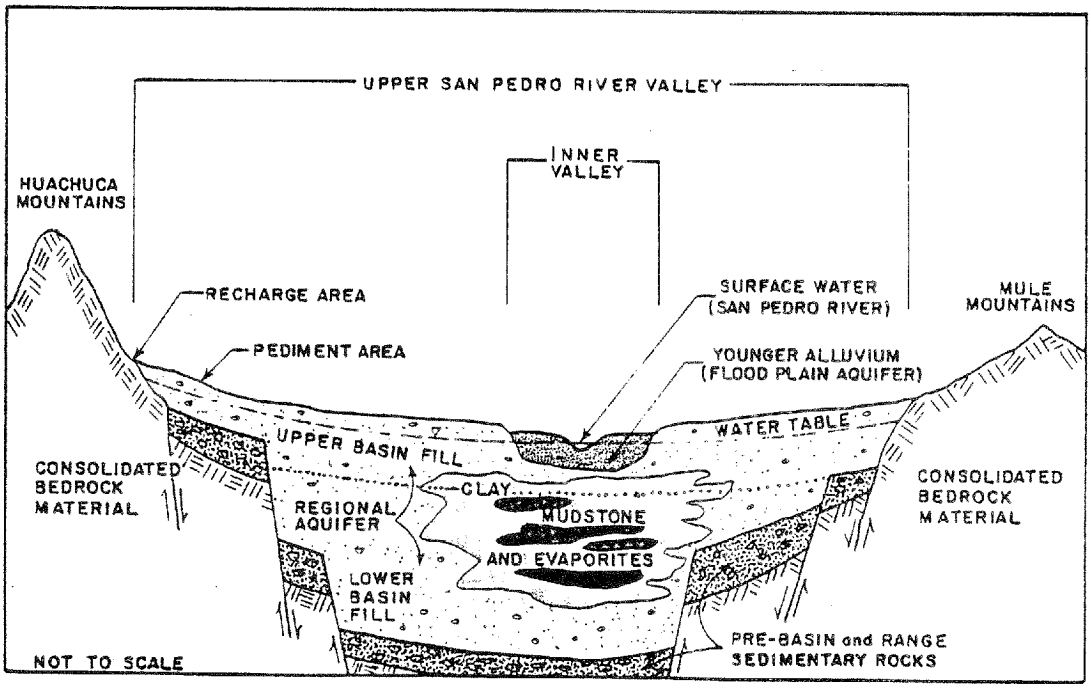
Generalized Geologic Cross-section, Upper San Pedro Basin (after ADWR, 1991:54)
Figure 2-1



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The third major natural component of the hydrologic system is the river itself. The San Pedro River receives water from two sources: runoff from snowmelt and rainfall, and discharges from the floodplain aquifer. Only a small portion of the basin's runoff ever reaches the river; most evaporates or infiltrates long before it reaches even an ephemeral stream channel (Moosburner, 1970). The discharges from the aquifer produce the baseflow of the river; runoff produces storm flows. Most water in the river leaves the upper basin as downstream flow but some seeps into the floodplain aquifer (as noted above) and a small portion simply evaporates.

The San Pedro River also has numerous tributaries along its course through the upper basin. Only the Babocomari River exhibits any baseflow of its own, along its lower reaches (Schwartzman, 1990). The Babocomari River behaves hydrologically similarly to the San Pedro River and contributes its flows to the San Pedro River near the town of Fairbank, approximately two miles south of the Tombstone gauge. Among the remaining tributaries, several flow either seasonally or year-round along their courses in the surrounding mountains but flow only intermittently after emerging onto the basin fill sediments; and the others flow only ephemerally after individual storm events (ADWR, 1991).

2.1.2 Human Impacts on the Water Budget of the Upper San Pedro Basin

Human use of water in the upper basin results in additional losses and gains in the overall water budget. The WATERBUD model classifies human activities as domestic (including municipal), industrial, and agricultural. Each of these kinds of activities involves the removal of water from one or both of the aquifers and, in the case of agriculture, directly from the river as well. A portion of the water diverted for domestic use leaves the basin by evaporation and vegetative transpiration, especially from irrigated

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fields, orchards, gardens, recreational facilities, and yards. After use, the remaining water becomes wastewater that flows into septic tanks or sewers; sewerage goes to wastewater treatment plants. All wastewater treatment plants in the upper basin presently allow their treated effluent to evaporate from the treatment facilities or from fields irrigated with the treated water. In the future, municipalities may also inject or infiltrate their treated effluent into the ground to recharge the ground-water supply. Septic tank water already infiltrates but only to very shallow depths, from which evaporative pressures readily drawn it to the surface and remove it from the system. Domestic consumption rates vary from one community to another depending on such factors as the costs of delivered or pumped water, household size and income, plumbing codes, and water conservation practices.

Different kinds of mining and other industrial activities use water at different rates. Once used, the water generally flows into settling and other treatment ponds, from which some portion may infiltrate into the ground while the rest evaporates. Settling ponds for mining leachates in particular may not allow their treated water to infiltrate; all leaves through evaporation. Industrial demands for water vary with economic conditions in the basin such as the demand for sand and gravel for construction, and with the global market for nitrate products or for the metals mined in the area.

Irrigation consumes by far the greatest quantity of water in the upper basin. Water pumped from wells and diverted from the river goes to prepared fields, where it supplements the scant water provided by precipitation or available from the immediate water table. As in most of the Southwest, potential evapotranspiration in the upper basin greatly exceeds actual precipitation, making irrigation necessary for virtually all crops. Some water evaporates or infiltrates from the ditches used to bring the water to the fields. A large portion of the water finally delivered to the irrigated fields leaves through

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vegetative transpiration; the rest either evaporates directly or infiltrates back into the ground-water supply. Irrigators also must flush their fields regularly to remove salts, which exist naturally in the groundwater and become concentrated in the soil by evaporation of the irrigation water. The ratio of the water consumed by crop transpiration and soil flushing to the total amount of water sent out to fields is termed the irrigation efficiency. Irrigation demands for water vary with seasonal precipitation, air temperatures, crop types, and irrigation efficiencies.

Stockponds and reservoirs in the upper basin also consume water. These impoundments exist primarily to serve livestock. However, much of the impounded water evaporates, most of the remainder leaves as spills and infiltration, and only a very small portion actually goes into the livestock themselves (Putnam et al., 1988; ADWR, 1991).

Residents of the Upper San Pedro basin have proposed adding several other components to the basin's water budget. These include cloud seeding to increase precipitation; construction of a dam across the river or runoff impoundments in urban areas; and importation of water from nearby (or even more distant) sources. People in neighboring basins also may someday view the Upper San Pedro basin as a potential source of water to export to satisfy their own needs. The upper basin is already a net exporter of water: the City of Bisbee lies outside the ground-water divide of the upper basin but receives its domestic water supplies from well fields located inside the basin (ADWR, 1991).

Finally, the presence of the San Pedro Riparian National Conservation Area (SPRNCA) in the upper basin poses special problems. The health of the riparian and aquatic ecosystems in the upper basin depends on the presence of adequate flows in the river and adequate water tables in the floodplain aquifer, both of which must be able to fluctuate in a natural manner over the course of each year. The Bureau of Land

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Management, which manages the SPRNCA, has at least considered pumping groundwater into the river during times of abnormally low flows in order to maintain river flows.

2.1.3 Modeling the Water Budget of the Upper San Pedro Basin

WATERBUD carries out an accounting of all natural flows into and out of the two aquifers and the river. These flows depend on such factors as precipitation and evaporation rates, vegetative transpiration rates, hydraulic properties of the aquifers and the riverbed, and differences in water levels and pressures (together known as hydraulic head) among the two aquifers and the river in each sub-basin. The model includes means for examining the effects of changing climatic conditions.

The model also carries out an accounting of all known or reasonably expectable human impacts on the flow of water into and out of the two aquifers and the river. As noted above, human impacts on the upper basin's water budget depend on the interplay of many different factors. WATERBUD provides means for examining the effects of changing the strength of many of these factors. For example, the model can be used to examine the effects of increasing the delivery price of domestic water or the effects of improving irrigation efficiencies. WATERBUD also provides means for simulating other kinds of impacts such as the effects of cloud seeding or water imports.

WATERBUD thus acts as a large ledger. It tallies up the gains and losses of water for the two aquifers and the river that arise both through natural processes and human activities in the upper basin. The model carries out its accounting by separating the upper basin into two sub-basins, labeled the Sierra Vista and Benson sub-basins, as described in Chapter 1. The accounting is quite complex; even in a very simplified model, a great many factors come into play to shape the water budget in each sub-basin and for the upper basin as a whole.

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Table 2-1 summarizes the water budget for the upper basin in 1989-1990 as computed by WATERBUD. The values in Table 2-1 differ slightly from those presented by the ADWR in its Hydrographic Survey Report for the basin (1991:Table 4-12); WATERBUD uses slightly different estimates for some properties of the system than does ADWR. Notable features of the water budget shown in Table 2-1 and in the ADWR figures (1991:Table 4-12) include the large losses to domestic/municipal, irrigation, and phreatophyte consumption; and the net reduction of storage taking place from the regional aquifer in the Sierra Vista sub-basin.

Summary 1989-1990 Annual Water Budget (in acre-feet) Computed by WATERBUD
Table 2-1

	Sierra Vista	Benson
Regional Aquifer		
Underground Inflow	+2100	+410
Natural Recharge	+15440	+11620
Irrigation Depletion	0	0
Domestic/Municipal Depletion	-10637	-1457
Stockpond and Reservoir Depletion	-65	-269
Industrial Depletion	-166	-379
Underground Northward Outflow	-410	0
Discharge to Floodplain Aquifer	-21931	-10499
Floodplain Aquifer		
Underground Inflow	+900	+240
Recharge from Regional Aquifer	+21931	+10499
Irrigation Depletion	-6729	-10115
Domestic/Municipal Depletion	0	0
Industrial Depletion	0	0
Phreatophyte Consumption	-14440	-17712
Underground Northward Outflow	-240	-120
Leakage to(-)/from(+) River	-1422	+17208
Surface Water Flows		
River Inflow	+23420	+39200
Tributary Stream Inflow	+17314	+11796
Evaporation of Runoff Captured in Stockponds	-1649	-904
River Channel Evaporation	-1307	-1395
Irrigation Diversions from River	0	-5989
Leakage to(-)/from(+) Floodplain Aquifer	+1422	-17208
River Outflow	-39200	-25500
Net Changes in Storage		
Gain(+)/Loss(-) in Regional Aquifer	-15669	-574
Gain(+)/Loss(-) in Floodplain Aquifer	0	0

USF200010278

2.2 LIMITATIONS OF WATER BUDGET MODELING

Water budget modeling is a form of lumped-parameter hydrologic modeling. That is, information on hydrologic dynamics is lumped together or aggregated for large blocks of space and time. WATERBUD works with only two spatial entities, the Sierra Vista and Benson sub-basins, and works with temporal increments of a quarter-year. In contrast, a program such as MODFLOW allows the analyst to work with much smaller blocks of both space and time. The MODFLOW model refined by Vionnet (1991, 1992a) for the Sierra Vista sub-basin, for example, divides the western and central portions of the sub-basin into 630 spatial units, each of which can exhibit up to three hydrologic layers and a section of the river. The model also has the ability to work in time increments of seconds and days as well as larger units.

Figure 2-2 illustrates the spatial coarseness of a water budget model. This figure shows the kind of physical system that a water budget model actually represents for each sub-basin. The model represents each aquifer as a single container of water with a uniform water table across its entire area. Similarly, the model represents the river as an additional container, again with its own uniform water level. In the system illustrated, there is no direct connection between the river and the regional aquifer. WATERBUD represents the upper basin precisely as such a system. Flows between the three containers take place along conduits, with the rate and direction of flow depending on the resistance of the conduit to such flow and on the differences in water table elevations among the containers. Thus, the model represents the hydrologic system as a simple system of plumbing.

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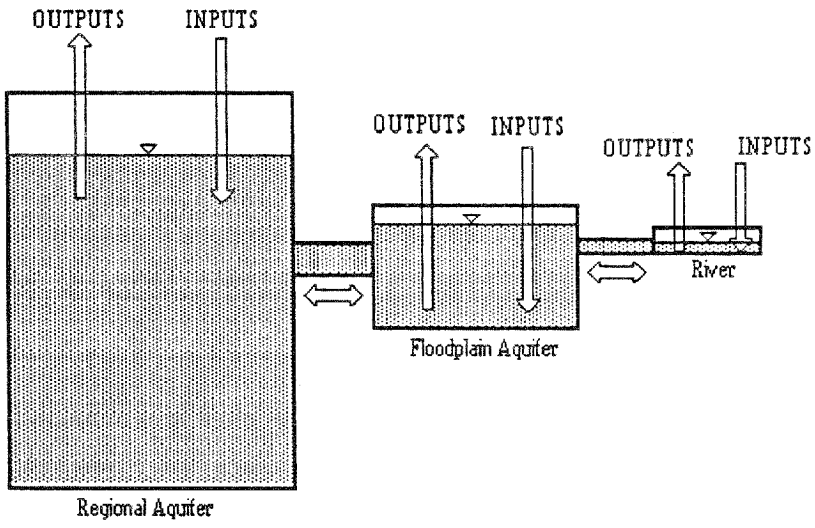
Schematic Water Budget Model for a Single Basin
Figure 2-2



Lumped-parameter modeling has several advantages. It can provide a rapid assessment of conditions in a region and it offers great flexibility for incorporating information on non-hydrologic variables such as demographic, climatic, and economic variables. However, its spatial and temporal coarseness limits its ability to provide highly precise descriptions of hydrologic dynamics. For example, pumping in the Fort Huachuca-Sierra Vista area has produced a large and growing cone of depression in hydraulic heads. A program such as MODFLOW can estimate the size, shape, and distribution of this cone of depression. A model such as WATERBUD can only estimate changes in average hydraulic head and total storage in the regional aquifer for the Sierra Vista sub-basin as a whole. Nevertheless, a properly constructed water budget model can serve as a useful planning tool, with which modelers can obtain rapid assessments of the effects of changes in the hydrologic, demographic, climatic, and economic conditions affecting the system.

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Spreadsheet programs provide a highly useful framework for developing water budget models. Developed for business accounting and forecasting, programs such as LOTUS 1-2-3®, EXCEL®, and QUATTRO-PRO® all have the capability to carry out complex sequences of linked calculations and to facilitate the analysis and presentation of calculation results. It was important that the residents of Cochise County find WATERBUD easy to use and so this author chose to explore the usefulness of spreadsheet programs rather than construct an independent computer program. However, spreadsheet programs also have disadvantages. They carry out some kinds of calculations in a fixed manner, which the user cannot change. Chapters 4 and 6 discuss ways in which fixed programming features constrained the construction of spreadsheet formulas in WATERBUD. Appendix A also points out program limitations, which may require attention during use of the model.

2.3 INPUTS AND OUTPUTS IN THE WATER BUDGET

An accurate model of the water budget for each of the two sub-basins requires dividing the lines of input to and output from the river and the two aquifers into much finer categories. In the language of systems modeling, it is necessary to describe the system as a set of nodes, each of which identifies a physical entity or process for which an account of inputs and outputs can be kept. Each node is capable of taking water from any other node; the actual lines of connection among the nodes provide a description of the system. Tables 2-2 and 2-3 list the nodes identified for each of the two sub-basins, based on a review of published descriptions of the water resources and patterns of consumption in the upper basin.

There are forty-five nodes identified between the two sub-basins with one node (number 25) common to both. These forty-five nodes can be arranged in two charts, one

USF200010281

for each sub-basin, showing which nodes are linked to each other. These charts provide a simple summary of the character of the system and identify the links, for which the model must contain equations to describe the behavior of the system. Tables 2-4 and 2-5 summarize the linkages among nodes for each of the two sub-basins. For simplicity, Tables 2-4 and 2-5 identify the nodes using the numbers in Tables 2-2 and 2-3.

Table 2-4 shows that there are 54 linkages among the 25 nodes in the Sierra Vista sub-basin. Table 2-5 shows that there are 44 linkages among the 21 nodes in the Benson sub-basin. Thus, there are 98 linkages in total requiring representation in the model. These linkages fall into seven groups defined by the kinds of equations necessary to describe their behavior:

List of Input/Output Nodes for the Sierra Vista Sub-basin
Table 2-2

01. Net Precipitation over the Sub-basin
02. Flow of Surface Waters
03. Storage in Floodplain Aquifer
04. Storage in Regional Aquifer
05. Inflow From Mexico
06. Local Inflows to Sierra Vista Sub-Basin
07. Use by City of Sierra Vista
08. Use by Sierra Vista-Southeast Suburban Area
09. Use by Fort Huachuca
10. Use by Huachuca City
11. Use by City of Tombstone
12. Use by City of Bisbee
13. Use by Town of Naco
14. Use by Rural Sierra Vista Sub-basin Water-Service Areas
15. Use by Rural Sierra Vista Sub-basin Non-Service Areas
16. Use by Irrigation
17. Use by Mining Industries
18. Use by Other Industries
19. Use and Evaporative Losses at Stockponds & Reservoirs
20. Use by Phreatophytes
21. Channel Evaporation
22. Use by SPRNCA for Stream Supplementation
23. Sub-basin Import of Water
24. Sub-basin Export of Water
25. Discharge from Sierra Vista Sub-basin to Benson Sub-basin

USF200010282

List of Input/Output Nodes for the Benson Sub-basin
Table 2-3

25. Discharge to Benson Sub-basin from Sierra Vista Sub-basin
26. Net Precipitation over the Sub-basin
27. Local Inflows to Benson Sub-Basin
28. Flow of Surface Waters
29. Storage in Floodplain Aquifer
30. Storage in Regional Aquifer
31. Use by City of Benson
32. Use by Town of St. David
33. Use by Town of Pomerene
34. Use by Rural Benson Sub-basin Water-Service Areas
35. Use by Rural Benson Sub-basin Non-Service Areas
36. Use by Irrigation
37. Use by Mining Industries
38. Use by Other Industries
39. Use by Stockponds & Reservoirs
40 Use by Phreatophytes
41. Channel Evaporation
42. Use by SPRNCA for Stream Supplementation
43. Sub-basin Import of Water
44. Sub-basin Export of Water
45. Discharge from Benson Sub-basin to Next Sub-basin

(1) Linkages involving inflows from natural sources external to the sub-basins, such as inflows from Mexico or from precipitation, require equations that include information on physical conditions alone.

(2) Linkages between the two aquifers and between the river and the floodplain aquifer require equations for hydraulic head-dependent flow.

(3) Linkages involving withdrawals by domestic, irrigation, and industrial nodes require equations that represent demands for water as functions of physical and economic variables and policy decisions.

(4) Linkages involving consumption by phreatophytes and losses to channel evaporation require representation as functions of physical variables.

(5) Linkages involving proposed imports, exports, or stream supplementation in the SPRNCA require representation as functions of specific policy decisions alone.

USF200010283

Linkages Among Nodes, Sierra Vista Sub-basin

Table 2-4

Linkages are FROM (row node) TO (column node)

	01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
01				>>		>>																			
02			>>																>>		>>				>>
03		>>		>>												>>				>>		>>		>>	>>
04			>>				>>	>>	>>	>>	>>	>>	>>	>>	>>	>>	>>	>>	>>			>>		>>	>>
05		>>	>>	>>																					
06		>>	>>	>>																					
07				>>																					
08				>>																					
09				>>																					
10				>>																					
11				>>																					
12				>>																					
13				>>																					
14				>>																					
15				>>																					
16			>>																						
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19		>>	>>	>>																					
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23			>>	>>																					
24																									
25																									

(6) Linkages involving return flows or recharges from domestic, irrigation, and industrial nodes require equations describing the physical process of capture and return of effluent water as these may be affected by policy decisions.

(7) Linkages involving changes in aquifer storage and net stream flow require equations that simply tabulate the inputs and outputs to these nodes.

USF200010284

Linkages Among Nodes, Benson Sub-basin

Table 2-5

Linkages are FROM (row node) TO (column node)

	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45
25				>>	>>	>>															
26			>>			>>															
27				>>	>>	>>															
28					>>							>>			>>		>>				>>
29				>>		>>						>>				>>		>>		>>	>>
30					>>		>>	>>	>>	>>	>>	>>	>>	>>	>>			>>		>>	>>
31						>>															
32						>>															
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41																					
42				>>																	
43					>>	>>															
44																					
45																					

2.4 INTERNAL ORGANIZATION OF THE MODEL

The WATERBUD spreadsheet contains three sections, termed the parameters, projections, and summary sections. Figure 2-3 illustrates the arrangement of these three sections within the overall spreadsheet.

The model parameters are the variables used to construct the model's equations. Their values specify the hydrologic, demographic, economic, and climatic conditions and water management policies that determine the water budget of the upper basin. Changing their values allows a user to examine the effects of different conditions or alternative policies. Chapter 3 describes each parameter and its purpose in the model, and explains the value recommended as its default setting.

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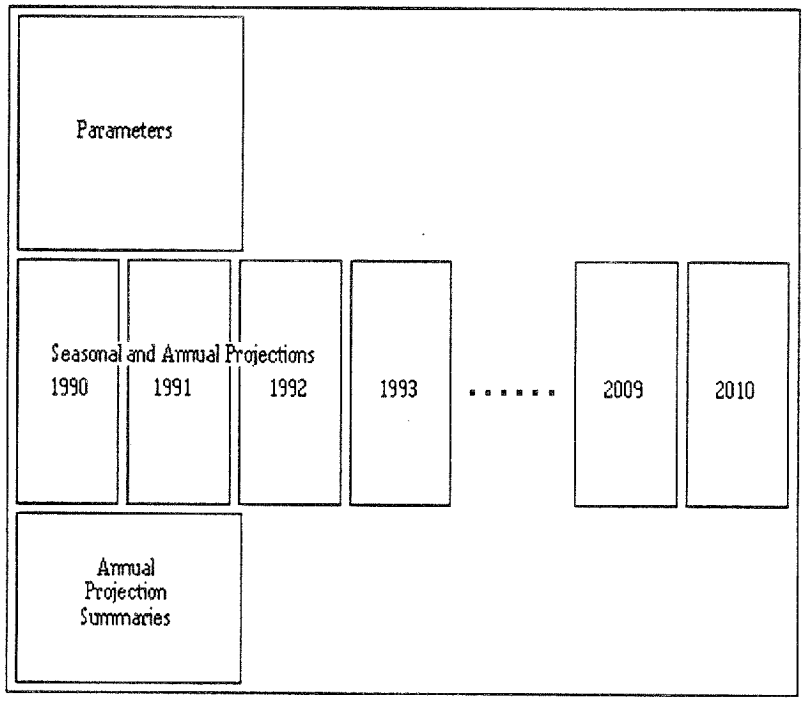
The projections section contains the equations that represent the linkages and processes described earlier in this chapter. These equations generate projections of the water budget of the upper basin for each quarter of the year over a twenty-year period. Chapter 4 explains the construction and operation of each equation and its purpose in the model. The equations are pivotal features of the model; changing their construction will change the way the model represents different linkages. For virtually all purposes, users of the model should work with alternative parameter values rather than modify the projection equations.

Finally, the summary section collects the annual results of the projection equations in one place, to simplify producing charts and graphs from the projection results. It does not contain any new equations and is provided only as an aide to using the model.

Organization of the WATERBUD Spreadsheet
Figure 2-3



USF200010286

Chapter 3
Parameters for the Model

The first section of WATERBUD, the parameters section, contains over 150 kinds of parameters, the values of which can be changed to establish different initial conditions for the simulation. The section begins with Row 1 of the spreadsheet, identified by the title, "GENERAL PARAMETERS FOR UPPER SAN PEDRO BASIN MANAGEMENT MODEL." The "initial conditions" come in two varieties: (1) parameters that help describe the characteristics of the upper basin in the years 1989-1990; and (2) parameters that help describe how these characteristics will change during the simulated twenty-year sequence from 1991 to 2010. The default settings that describe conditions in 1989-1990 are based on extensive documentation, summarized below. It is recommended that these default settings not be changed unless compelling reasons exist to do so. Some parameters serve specialized roles in the equations in the Projections section of the model. These include calibration constants and coefficients; it is recommended that the values of these parameters not be changed without understanding their roles in the equations.

This chapter describes each parameter and explains its default setting. The parameters are listed by their row numbers in the spreadsheet under eleven headings. Gaps in the row numbering sequence result from the presence of blank lines and heading lines included in the spreadsheet to make it more readable. The eleven headings are: I, Inflow from Mexico; II, Sub-Basin Natural Characteristic; III, Basin-Wide Cultural Supply and Demand; IV, Special Sierra Vista City Activities; V, Domestic Consumption; VI, Miscellaneous Domestic Consumption Parameters; VII, Agricultural Consumption;

USF200010287

VIII, Riparian Habitat and Management Status; IX, Industrial Consumption; X, Reservoirs and Stockponds; XI, Options.

3.1 INFLOW FROM MEXICO

Row 5: Inflow of Surface Water from Mexico

This parameter indicates the long-term mean annual flow of water (acre-feet) in the river at the border from Mexico, estimated at 23,420 acre-feet (ADWR, 1991:97). More precisely, this value indicates the long-term average annual flow at the U.S. Geological Survey (hereafter USGS) stream gage at Palominas, Arizona (USGS Station 094705), located approximately 4 river miles north of the border (ADWR, 1991:88).

Row 6: Inflow of Groundwater to Floodplain Aquifer from Mexico

ADWR (1991:95-96) estimates that 900 acre-feet enter the U.S. from Mexico as groundwater in the floodplain aquifer annually under 1989-90 conditions. This estimate derives from previous flow net analyses (Putnam *et al.*, 1988). Vionnet (1991:Table 9) used a slightly higher value of 910 acre-feet in her revision of previous ground-water models for the Sierra Vista sub-basin (Freethey, 1982; ADWR, 1991:Appendix E). The difference between the two estimates is slight and the 900 acre-feet value is recommended as the default simply for consistency with other ADWR estimates for the system.

Row 7: Inflow of Groundwater to Regional Aquifer from Mexico

ADWR (1991:95-96) estimates that 2100 acre-feet enter the U.S. from Mexico as groundwater in the regional aquifer annually under 1989-90 conditions. This estimate also derives from previous flow net analyses (Putnam *et al.*, 1988). Vionnet (1991:Table 9)

USF200010288

used a slightly higher value of 2810 acre-feet in her revision of previous ground-water models for the Sierra Vista sub-basin (Freethey, 1982; ADWR, 1991:Appendix E). The 710 acre-foot difference between the two estimates is small compared to other sources of uncertainty in modeling the hydrologic system and the 2100 acre-feet value is recommended as the default, again simply for consistency with other ADWR estimates for the system.

3.2 SUB-BASIN NATURAL CHARACTERISTICS

Two values are provided for each parameter in this sub-section, one for each U.S. sub-basin. The values for the Sierra Vista sub-basin appear in column B; those for the Benson sub-basin appear in column C. The spreadsheet lists the parameters under four sub-headings: Precipitation and Runoff; Aquifers; Stream-Aquifer Interactions; and Evaporation. These sub-headings are repeated in the listing below.

3.2.1 PRECIPITATION AND RUNOFF

Row 12: Watershed Area Tributary to Surface Runoff North of Border

The Sierra Vista sub-basin north of the border contains 662,863.0 acres or 1035.723 (1036) mi^2 (ADWR, 1991:A-1). However, this area includes 54 mi^2 in the U.S., runoff from which reaches the river in Mexico, i.e., south of the Palominas gage (Putnam *et al.*, 1988:3). Further, there are 56 mi^2 of watershed in Mexico, the runoff from which reaches the river north of the Palominas gage (Putnam *et al.*, 1987:3). Consequently, the watershed area tributary to the river within the Sierra Vista sub-basin north of the Palominas gage contains 1036+56-54 mi^2 = 1038 mi^2. The Benson sub-basin watershed in turn contains 485,269.4 acres or 758.2334 mi^2 (ADWR, 1991:A-1).

USF200010289

Row 13: Annual Gross Precipitation over Entire Watershed

The values for this parameter derive from the estimates of total tributary runoff in each sub-basin (ADWR, 1991:F-2,3,7,8). These estimates in turn come from an unpublished USGS report (1973) cited by ADWR (1991), which reportedly used Moosburner's (1970) equation for estimating runoff from information on average annual precipitation and watershed area. An estimate of average annual gross precipitation therefore can be derived from the watershed areas noted above and the ADWR estimates of annual runoff of 17,300 and 11,800 acre-feet for the Sierra Vista and Benson sub-basins, respectively, using the Moosburner equation. The Moosburner equation is discussed below (Rows 20-22). The derived gross annual precipitation values are 1.497 and 1.444 ft for the Sierra Vista and Benson sub-basins, respectively.

Row 14: Annual Gross Precipitation Rate over Floodplain

The values for this parameter derive from the summary data on normal annual precipitation provided by the ADWR (1991:36-37). These data indicate normal annual precipitation of 10-12 inches over the floodplain in the Sierra Vista sub-basin and roughly 11-13 inches over the floodplain in the Benson sub-basin, giving approximate averages of 0.92 and 1.0 ft, respectively

Row 15: Annual Effective Precipitation Rate over Floodplain

Effective precipitation is the precipitation that can be effectively consumed by vegetation. Row 15 specifically records effective precipitation over the floodplain and available for consumption by riparian vegetation. Its value can be estimated from the average effective precipitation rate for domestic plants cultivated on floodplain soils.

USF200010290

ADWR (1990:C10) provides values for various crop types by sub-basin. The average values are 0.43 and 0.35 ft/year for the Sierra Vista and Benson sub-basins, respectively. These averages are not weighted according to the proportion of occurrence of the different crops. ADWR (1991:B7) suggests using a uniform value of 5 inches/year (0.42 ft/year) for the entire San Pedro basin. Precipitation decreases along the floodplain from the south to the north end of the basin, however, and the alternative values recommended here should provide a more accurate model of consumption by riparian vegetation (see Rows 144-145, below).

Rows 16-19: Fraction of Annual Precipitation Falling in Seasons I-IV

The model divides the year into four seasons: January-March (I), April-June (II), July-September (III), and October-December (IV). The fractions of the average annual precipitation occurring in each season derive from the monthly precipitation data summarized by ADWR (1990: Appendixes B and C) and are estimated at 0.2143, 0.0952, 0.5952, and 0.0952, for Seasons I-IV, respectively.

Row 20: Runoff Estimator (Moosburner) Equation, Constant Term

(See explanation for Row 22).

Row 21: Runoff Estimator (Moosburner) Equation, Area Exponent

(See explanation for Row 22).

Row 22: Runoff Estimator (Moosburner) Equation, Precipitation Exponent

Moosburner (1970) developed an equation that predicts the quantity of runoff that will leave a watershed as streamflow annually using data on watershed area and annual

USF200010291

precipitation. Moosburner specifically developed and tested the equation for the Walnut Gulch area in the Upper San Pedro basin, and it has since been found to be useful for the entire southwest alluvial basins region (Anderson *et al.*, 1990). Putnam *et al.* (1987, 1988) and ADWR (1991:Appendix F) have used the Moosburner equation to estimate runoff in the Sierra Vista and Benson watersheds. The original equation estimates runoff in Q = cfs from watershed area A = mi² and average annual precipitation P = inches/year. The coefficients and constant terms have been converted to work with different units: Q = acre-feet/year, A = mi², and P = ft/year as follows:

$$Q = 16.813A^{0.77}P^{3.94}.$$

3.2.2 AQUIFERS

Row 24: Surface Area of Regional Aquifer

These values are taken from the estimates made by ADWR (1991:Table A-1). The areas are estimated at 464,554.6 and 398,416.7 acres for the Sierra Vista and Benson sub-basins, respectively.

Row 25: Steady-State Regional Aquifer Underflow

ADWR (1991: Chapter 4 and Appendix F) estimates that no water flows underground out of the regional aquifer in the Sierra Vista sub-basin to recharge the regional aquifer in the Benson sub-basin. Vionnet (1991:Table 9), however, found that an accurate model of ground-water flows in the Sierra Vista sub-basin required modeling the presence of at least some underflow discharge northward from this sub-basin (see also Freethey, 1982; ADWR, 1991:Appendix E). Vionnet (1991:Table 9) developed an

USF200010292

estimate of 410 acre-feet per year of northward underflow from the Sierra Vista sub-basin into the Benson sub-basin.

An estimate of at least some underflow in the regional aquifer from the Sierra Vista sub-basin also appears warranted on other hydrogeologic grounds. A bedrock sill extends westward into the middle of the valley from the Tombstone Hills at the north end of the sub-basin (e.g., Drewes, 1980; Halvorson, 1984). However, this sill is not present along the north end of the sub-basin for most of the western half of the sub-basin and so does not completely block all northward underflow within the basin fill deposits. Konieczki (1980) shows at least some northward flow from the western half of the sub-basin, consistent with the overall distribution of hydraulic heads. In the absence of any other estimates of underflow from the basin fill deposits of the Sierra Vista sub-basin Vionnet's estimate of 410 acre-feet per year is recommended as the default value for this parameter for the sub-basin.

A bedrock sill does cut across the entire width of the regional aquifer at the northern end of the Benson sub-basin, however, presumably blocking any significant northward underflow within the basin fill deposits (Montgomery, 1963; Worthington, 1987). ADWR (1991:Chapter 4 and Appendix F) estimates that 0.0 acre-feet per year flows leaves the regional aquifer in the Benson sub-basin as underflow to the regional aquifer in the Lower San Pedro Basin to the north. This estimate is recommended as the default value for this parameter for the Benson sub-basin.

Row 26: Average Specific Yield of Regional Aquifer

Putnam *et al.* (1988) provide an estimate of average specific yield for the regional aquifer of 0.08 based on previous studies by Harshbarger and Associates (1974) and Freethey (1982). This value is used by ADWR (1991:A-2) and in the present model. The

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regional aquifer is here treated as an unconfined aquifer, for which specific yield is the appropriate measure of storage capability.

Row 27: 1990 Total Storage in Regional Aquifer

These values are taken from ADWR (1991:Table A-2) and derive from estimates of the area, average depth of the water-bearing deposits, and specific yield of the aquifer. The resulting estimates are 31,753,242 and 27,064,683 acre-feet in the Sierra Vista and Benson sub-basins, respectively.

Row 28: Recharge to Regional Aquifer by Precipitation

Several studies provide alternative estimates of natural recharge to the regional aquifer for the two sub-basins. Recharge occurs when rainfall runoff and snowmelt from areas of exposed bedrock encounter the edges of the regional aquifer (Anderson *et al.*, 1990). Recharge from precipitation occurring directly over the regional and floodplain aquifers is negligible; any such precipitation that does not become active runoff returns rapidly to the atmosphere through evapotranspiration (Anderson *et al.*, 1990). As a result, natural recharge to the regional aquifer often is referred to as "mountain front recharge" (e.g., Anderson *et al.*, 1990).

Four estimates of mountain front recharge are available for the Sierra Vista sub-basin. ADWR (1991:250-251; F2, F8) estimates a value of 13,860 acre-feet per year; Putnam *et al.* (1987, 1988) give this same estimate. Neither study explains the methods used to derive these estimates. ADWR (1991:251, F-2, F-8) indicates only that the estimate is taken from an unpublished USGS (1973) report and an unpublished ADWR (1984) report.

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Vionnet (1991:Table 9) used an estimate of 12,555 acre-feet per year for her ground-water model of the sub-basin based on the previous modeling estimates of Freethey (1982). The modeled area does not cover the entire sub-basin, however; the estimate of 12,555 acre-feet of recharge therefore is likely to underestimate total recharge to the sub-basin.

Freethey (1982:14; see also Heindl, 1952) summarizes studies for the entire Sierra Vista sub-basin that provide estimates of recharge for each separate mountain front in the sub-basin. The total of these estimates is 15,000 acre-feet per year.

Anderson *et al.* (1990:44-47) have developed a regression equation that predicts mean annual mountain front recharge values from information on the total volume of precipitation occurring over a basin, for the Southwest Alluvial Basins region that includes the San Pedro basin. The equation is calibrated against regional water budget data and the results of twelve ground-water flow models, applies only to basins with annual gross precipitation rates greater than 8 inches per year (0.6667 ft/yr), and has a correlation coefficient of 0.95. The equation is

$$Q = 10^{-1.4} G^{0.98},$$

where Q = mean annual mountain front recharge in acre-feet and G is a function of total precipitation (in acre-feet per year) as follows:

$$G = A(P - 0.6667)$$

for A = basin total area in acres and P = the annual gross precipitation rate over the entire basin in feet per year. This equation can be used to predict the recharge for the Sierra Vista sub-basin using the same value for P as was used with the Moosburner equation to predict tributary runoff (see discussions of Rows 12, 13, and 20-22, above). The value for A must be reduced, however, to account for the presence in the sub-basin of two non-tributary ground-water basins. The Cienega Creek (33 mi²) and San Rafael

USF200010295

(56 mi^2) ground-water basins are tributary to the Santa Cruz ground-water basin while their surface runoff is tributary to the San Pedro River within the Sierra Vista sub-basin (ADWR, 1991:98-103). For purposes of estimating ground-water recharge, therefore, the effective area of the Sierra Vista sub-basin is (Row 12) - (33+56 mi^2) = 949 mi^2. These values of P and A give an estimate of 15,440 acre-feet per year for the Sierra Vista sub-basin.

The estimate for the Sierra Vista sub-basin generated by the Anderson *et al.* (1990) regression equation is higher than the other three estimates. However, it rests on the same data used to estimate tributary runoff (see above). Further, the 13,860 af/yr estimate given by ADWR for recharge is too small when combined with the 17,300 af/yr estimate for tributary runoff and the known river flow data to allow for a non-declining water table in the floodplain aquifer under pre-development conditions (see Chapter 4, below). Since pre-development conditions are assumed to have been in a steady state, this finding indicates that at least one of the components of the water budget presented by ADWR (1991:250) has been estimated incorrectly. The estimates of mountain front recharge and tributary runoff have significant effects on the estimation of the water balance for the floodplain aquifer and the river (see Chapter 4) and it is crucial that these estimates be compatible with each other. For this reason, the estimate of 15,440 acre-feet for mean annual mountain front recharge is the recommended default value for Row 28, for the Sierra Vista sub-basin.

Two estimates of mountain front recharge are available for the Benson sub-basin. ADWR (1991:250-251; F2, F8) estimates a value of 11,760 acre-feet per year. Putnam *et al.* (1987, 1988) again give this same estimate and ADWR (1991:251, F-2, F-8) again indicates only that the estimate is taken from the same unpublished USGS (1973) and ADWR (1984) reports. Using the same values for A and P as were used to in the

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Moosburner equation to predict tributary runoff (see discussions of Rows 12, 13, and 20-22, above), the Anderson *et al.* (1990) regression equation produces an estimate of 11,620 acre-feet per year. The two estimates agree closely; the regression-based estimate is recommended as the default value for the same reasons stated above for the Sierra Vista sub-basin.

Row 29: Steady-State Elevation of Regional Aquifer Water Table Above Riverbed

This parameter describes a hypothetical average elevation of the water table in the regional aquifer under pre-development conditions using a model of the water table as a level plane in each sub-basin (see Chapter 2, above). Its values are calibrated so that the projective equations for head-dependent flow between the regional and floodplain aquifers (Rows 307 and 356; see below) provide accurate results for steady-state, pre-development conditions. These equations are discussed in Chapter 4. The recommended default values are 2.4922 and 0.5634 for the Sierra Vista and Benson sub-basins, respectively.

Row 30: 1990 Estimated Elevation of Regional Aquifer Water Table Above Riverbed

This parameter is identical to Row 29, above, except that it describes a hypothetical average water table elevation for 1990 conditions rather than for pre-development conditions. The difference between the values in Rows 29 and 30 can be used to estimate the loss of water from storage that has taken place since the beginning of ground-water development in the basin. The recommended default values are 3.5052 and -6.4072 for the Sierra Vista and Benson sub-basins, respectively.

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Row 31: Surface Area of Floodplain Aquifer

These values are taken from the estimates made by ADWR (1991:Table A-1). The areas are estimated at 22,167.6 and 17170.8 acres for the Sierra Vista and Benson sub-basins, respectively.

Row 32: Steady-State Floodplain Aquifer Underflow

ADWR (1991:Chapter 4 and Appendix F) estimates that no water flows underground out of the floodplain aquifer in the Sierra Vista sub-basin to recharge the floodplain aquifer in the Benson sub-basin. Vionnet (1991:Table 9), however, found that an accurate model of ground-water flows in the Sierra Vista sub-basin required modeling the presence of at least some northward underflow from the floodplain aquifer of this sub-basin (see also Freethey, 1982; ADWR, 1991:Appendix E). Vionnet (1991:Table 9) developed an estimate of 240 acre-feet per year of northward underflow from the Sierra Vista sub-basin into the Benson sub-basin.

An estimate of at least some underflow in the floodplain aquifer from the Sierra Vista sub-basin appears warranted on other hydrogeologic grounds again. The bedrock sill that lies across portions of the north end of the sub-basin constricts the floodplain aquifer only slightly (e.g., Drewes, 1980; Halvorson, 1984). Konieczki (1980) again shows at least some northward flow along the inner valley, consistent with the overall distribution of hydraulic heads. In the absence of any other estimates of underflow from the floodplain aquifer in the Sierra Vista sub-basin, Vionnet's estimate of 240 acre-feet per year is recommended as the default value for Row 32 for the sub-basin.

ADWR (1991:Chapter 4 and Appendix F) estimates that 120 acre-feet per year discharge northward within the floodplain aquifer from the Benson sub-basin. The

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bedrock sill at the northern boundary of the Benson sub-basin also does not fully constrict the floodplain aquifer, again permitting a small underflow (Montgomery, 1963; Worthington, 1987). In the absence of other data, the estimate of 120 acre-feet per year is recommended as the default value for Row 32 for this sub-basin.

Row 33: Average Specific Yield of Floodplain Aquifer

Putnam *et al.* (1987:22-23) provide an estimate of average specific yield for the floodplain aquifer of 0.12. This value is used by ADWR (1991:A-2) and is recommended for the present model. The floodplain aquifer is an unconfined aquifer, for which specific yield is the appropriate measure of storage capability.

Row 34: 1990 Total Storage in Floodplain Aquifer

These values are taken from ADWR (1991:Table A-2) and derive from estimates of the area, average depth of the water-bearing deposits, and specific yield of the aquifer. The resulting estimates are 159,609 and 123,681 acre-feet in the Sierra Vista and Benson sub-basins, respectively.

Row 35: Pre-Development Recharge to Floodplain Aquifer by Regional Aquifer

This parameter estimates the annual steady-state, pre-development discharges from the regional to the floodplain aquifer in the two U.S. sub-basins. All groundwater recharged to the regional aquifer under pre-development conditions is assumed to have discharged either to the floodplain aquifer or (as underflow) to the regional aquifer in the next sub-basin (see Chapter 2). Evapotranspiration losses from the regional aquifer are assumed negligible, as are underflow losses to basins to the east or west. This parameter therefore is the sum of Rows 7 and 28 less the value of Row 25.

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Row 36: Inter-Aquifer Volumetric Conductance Coefficient

This is a calibration parameter for equations that project the seasonal discharge of groundwater from the regional aquifer into the floodplain aquifer for a given difference in mean water table elevation between the regional and floodplain aquifers. These projective equations occur in Rows 307 and 356 and are discussed in Chapter 4, below. The flow of water between the two aquifers is head-dependent and so the rate of flow is governed by the vertical conductance between the two hydrologic units. Numerical simulation (Chapter 4, below) indicates that the seasonal volume of discharge also varies linearly with the difference in mean water table elevation between the two aquifers. The value of this parameter for each sub-basin therefore can be calculated using information on the steady-state recharge volume and on 1990 consumption from the floodplain aquifer. The derivation of this parameter is presented in detail in Chapter 4 in the discussions of the projective equations in Rows 307 and 356. The recommended values for Row 36 are 2660.112 and 2060.496 acre-feet/foot per season (acres/season) for the Sierra Vista and Benson sub-basins, respectively.

3.2.3 STREAM-AQUIFER INTERACTIONS

Row 38: 1970-90 Average River Discharge Volume

ADWR (1991:F4-F7) has carried out statistical analyses of historic gauging data at the Tombstone and Benson (Narrows) USGS stream gages for the periods 1968-1987 and 1968-1988, respectively. These gage locations have been designated as the northern boundaries of the Sierra Vista and Benson sub-basins. The ADWR analyses indicate mean annual discharges of 39,200 and 25,500 acre-feet, respectively, for the two sub-basins.

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Row 39: Steady-State Elevation of Floodplain Water Table Above Riverbed

This parameter describes a hypothetical average elevation of the water table in the floodplain aquifer under steady-state, pre-development conditions using a model of the aquifer's water table as a level plane in each sub-basin (see Chapter 2, above). Its values are calibrated so that the projective equations for head-dependent leakage between the river and the floodplain aquifer (Rows 302-304 and 351-353) result in reasonable estimates of steady-state river discharges. These equations are discussed in Chapter 4. The recommended default values are 0.8823 and -0.8962 for the Sierra Vista and Benson sub-basins, respectively.

Row 40: 1990 Estimated Elevation of Floodplain Water Table Above Riverbed

This parameter is identical to Row 39, above, except that it describes a hypothetical average water table elevation in the floodplain aquifer for 1990 conditions rather than for pre-development conditions. The difference between the values in Rows 39 and 40 can be used to estimate the loss of water from storage in the floodplain aquifer that has taken place since the beginning of ground-water development in the basin. The recommended default values are 1.4440 and -7.7229 for the Sierra Vista and Benson sub-basins, respectively.

Row 41: Stream-Aquifer Volumetric Conductance Coefficient

This is a calibration parameter for equations that project the seasonal discharge of groundwater from the floodplain aquifer into the river or, conversely, the recharge of the floodplain aquifer by the river for a given difference in mean water table elevation between the floodplain aquifer and the river. These projective equations occur in Rows

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303 and 351 and their derivation is discussed in Chapters 4 and 5, below. The parameter is a unit-less multiplication factor; its recommended default value is 1.00 for both sub-basins.

Row 42: Effective Length of Riverbed

"Effective length" refers to the length of the riverbed along which the floodplain aquifer and the river exchange water. Putnam *et al.* (1988:27) report a total length of 62 river miles between the Mexican border and the gauge at the Narrows (USGS Benson gage). The maps in ADWR (1991) indicate that 29.7 of these miles lie in the Sierra Vista sub-basin and 32.3 miles lie in the Benson sub-basin. The final 6 miles of the Babocomari River also contribute to baseflows along the San Pedro River (Schwartzman, 1990) and so are added to the effective length value for the Sierra Vista sub-basin for a sub-basin total of 35.7 miles. The values are converted to feet.

Row 43: Average Thickness of Riverbed

The projective equations for calculating leakage between the floodplain aquifer and the river (Rows 302 and 351) require estimating the thickness of the riverbed, through which the flow takes place. The values for this parameter derive from Vionnet's (1991) finite difference model of the ground-water system in the Sierra Vista sub-basin. The recommended value is 5 ft for the Sierra Vista sub-basin and 15 ft for the Benson sub-basin.

Row 44: Discharge Exponent for Estimating Average River Stage

(See explanation for Row 45).

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Row 45: Discharge Coefficient for Estimating Average River Stage

The estimation of river stage plays a crucial part in the estimation of head-dependent flow between the floodplain aquifer and the river. BLM (1989: Appendixes I and II) has published data on width, stage, and discharges for seven cross-sections of the river within the San Pedro Riparian National Conservation Area. The locations of these seven cross-sections are shown in BLM (1987:9). These data can be fitted with equations describing the average relationship between stream stage (depth) and river discharge. Cross-sections 1-5 were used to estimate the average relationship in the Sierra Vista sub-basin. Cross-sections 6 and 7 were used to estimate the average relationship for at least the southern half of the Benson sub-basin; in the absence of other data this latter estimate had to serve for the entire Benson sub-basin. The equations have the form,

$$S = aQ^b \text{ or } \log S = \log a + b \log Q$$

where S = stage in feet, Q = discharge in acre-feet/year, a = a constant coefficient, and b = a discharge exponent. Figures 3-1 and 3-2 show the data analyzed for the two sub-basins. Least squares regression analyses of these data in logarithm form result in estimates of a = 0.4265 and 0.3446, and b = 0.010111 and 0.028046 for the Sierra Vista and Benson sub-basins, respectively.

3.2.4 EVAPORATION

Row 47: Area of Unvegetated Bare Ground on Riverbed

ADWR (1991:B11) provides estimates of the total acreage of bare (unvegetated) ground along the river course in each sub-basin exclusive of the area covered by perennial

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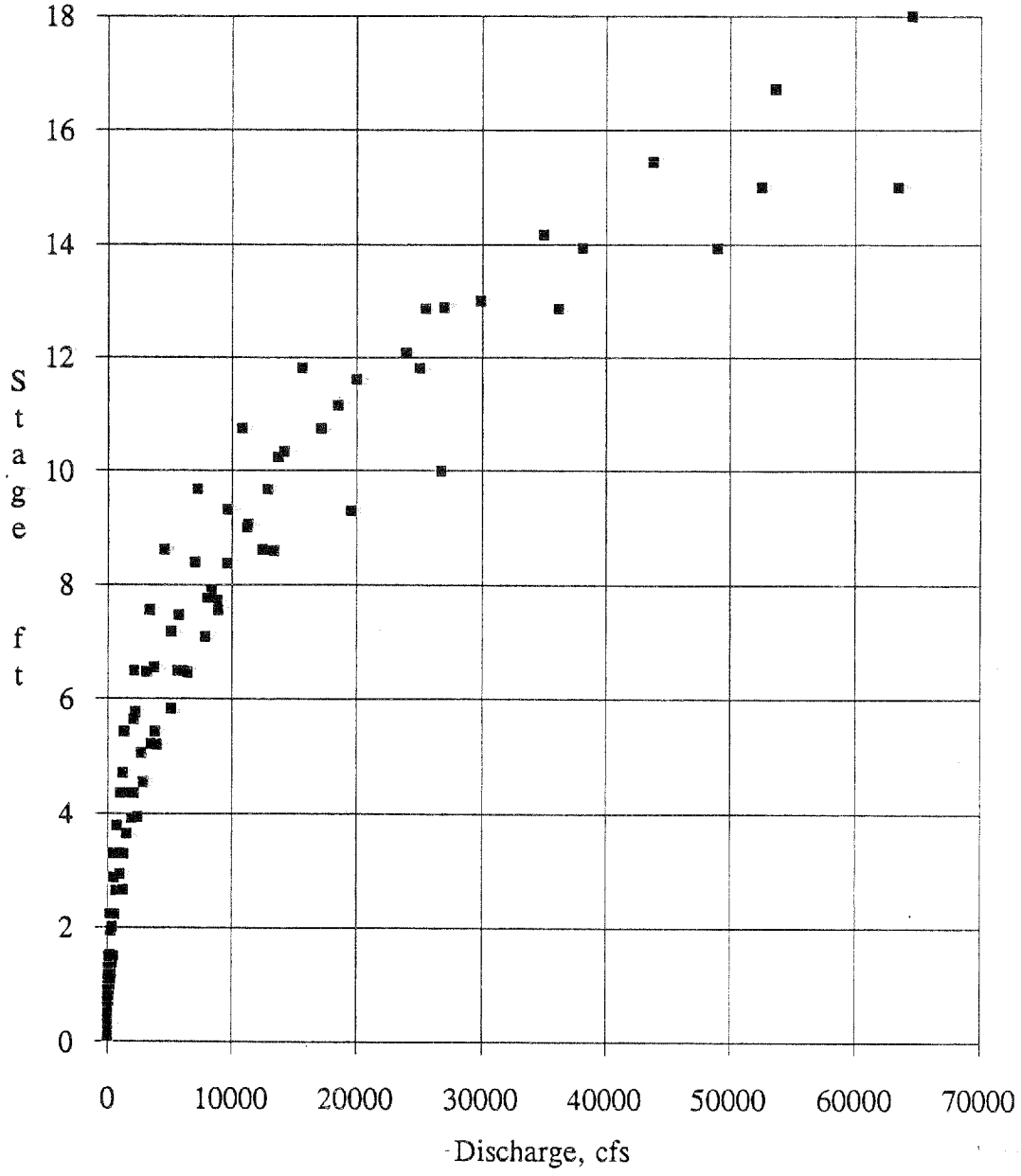
River Stage vs. Discharge
Composite of Five Synthetic Rating Curves, Sierra Vista Sub-Basin
(data from BLM, 1987: Appendixes I, II)
Figure 3-1



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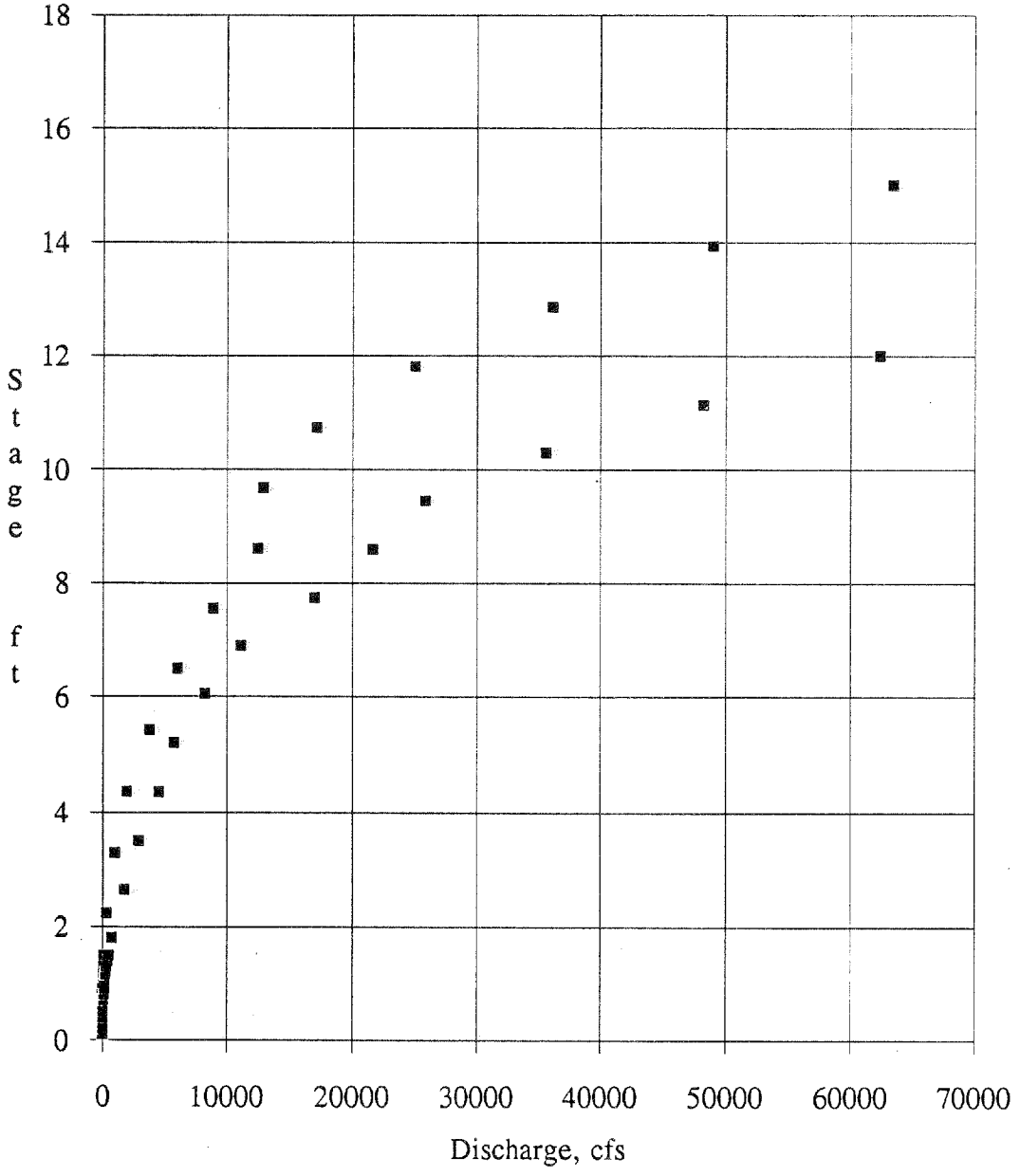
River Stage vs. Discharge
Composite of Two Synthetic Rating Curves, Benson Sub-Basin
(data from BLM, 1987:Appendixes I, II)
Figure 3-2



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river flows. The estimated areas are 956.3 and 838.1 acre-feet for the Sierra Vista and Benson sub-basins, respectively.

Row 48: Bare-Ground Consumptive Use (Evaporation) Coefficient

ADWR (1991:B11) provides data on consumptive use (surface evaporation rate) for bare ground. The ADWR figures assume a constant effective precipitation of 5 inches/year (0.417 ft) along the river course in both sub-basins. As noted above, WATERBUD contains separate estimates of effective precipitation over the floodplain aquifer. Consequently, the values for bare-ground consumptive use given in Row 48 have had the 5 inches/year rate of effective precipitation added back in, to give total use. The resulting values are 1.132 and 1.155 ft/year for the Sierra Vista and Benson sub-basins, respectively.

Row 49: Discharge Exponent for Estimating Average River Width

(See explanation for Row 50).

Row 50: Discharge Coefficient for Estimating Average River Width

The estimation of river width also plays a crucial part in the estimation of open water evaporation from the river. The BLM data (1987:Appendixes I and II) on the seven river cross-sections (see above, for Rows 44-45) also can be fitted with equations describing the average relationship between stream width and river discharge. Cross-sections 1-5 again provide the data for estimating the average relationship in the Sierra Vista sub-basin and cross-sections 6 and 7 provide at least some data for the Benson sub-basin. The equations have the form,

$$W = aQ^b \text{ or } \log W = \log a + b \log Q$$

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where W = width in feet, Q = discharge in acre-feet/year, a = a constant coefficient, and b = a discharge exponent. Figures 3-3 and 3-4 show the data analyzed for the two sub-basins. Least squares regression analyses of these data in logarithm form result in estimates of a = 0.3802 and 0.4032, and b = 0.6318 and 0.6004 for the Sierra Vista and Benson sub-basins, respectively.

Row 51: Open-Water Gross Evaporation Rate in Sub-basin

ADWR (1991:B8) provides an estimate of the open-water evaporation rate for the basin as a whole. The suggested value of 65 inches per year (5.417 ft/year) applies to both sub-basins.

Row 52: Fraction of Annual Potential Evaporation Occurring in Season I

(See explanation for row 55).

Row 53: Fraction of Annual Potential Evaporation Occurring in Season II

(See explanation for row 55).

Row 54: Fraction of Annual Potential Evaporation Occurring in Season III

(See explanation for row 55).

Row 55: Fraction of Annual Potential Evaporation Occurring in Season IV

ADWR (1991:B5) provides data on the relative intensity of potential evaporation in each month for each sub-basin. The relative intensity depends on several climatic factors, which are summarized in an F-factor based on the Blaney-Criddle method of consumptive use determination (ADWR, 1991:B4). The sum of the F-factor values for each season

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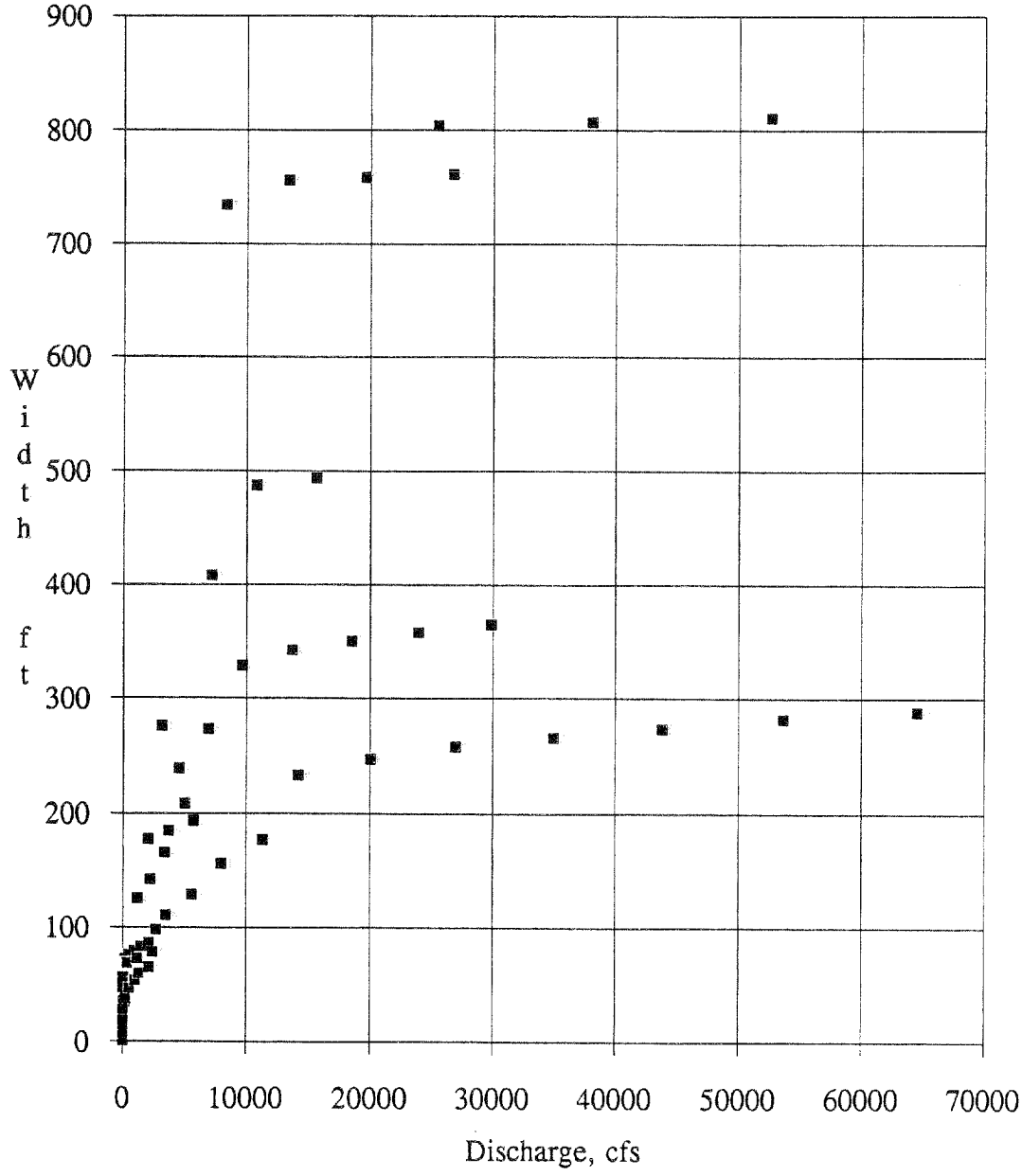
River Width vs. Discharge
Composite of Five Synthetic Rating Curves, Sierra Vista Sub-basin
(data from BLM, 1987:Appendixes I, II)
Figure 3-3



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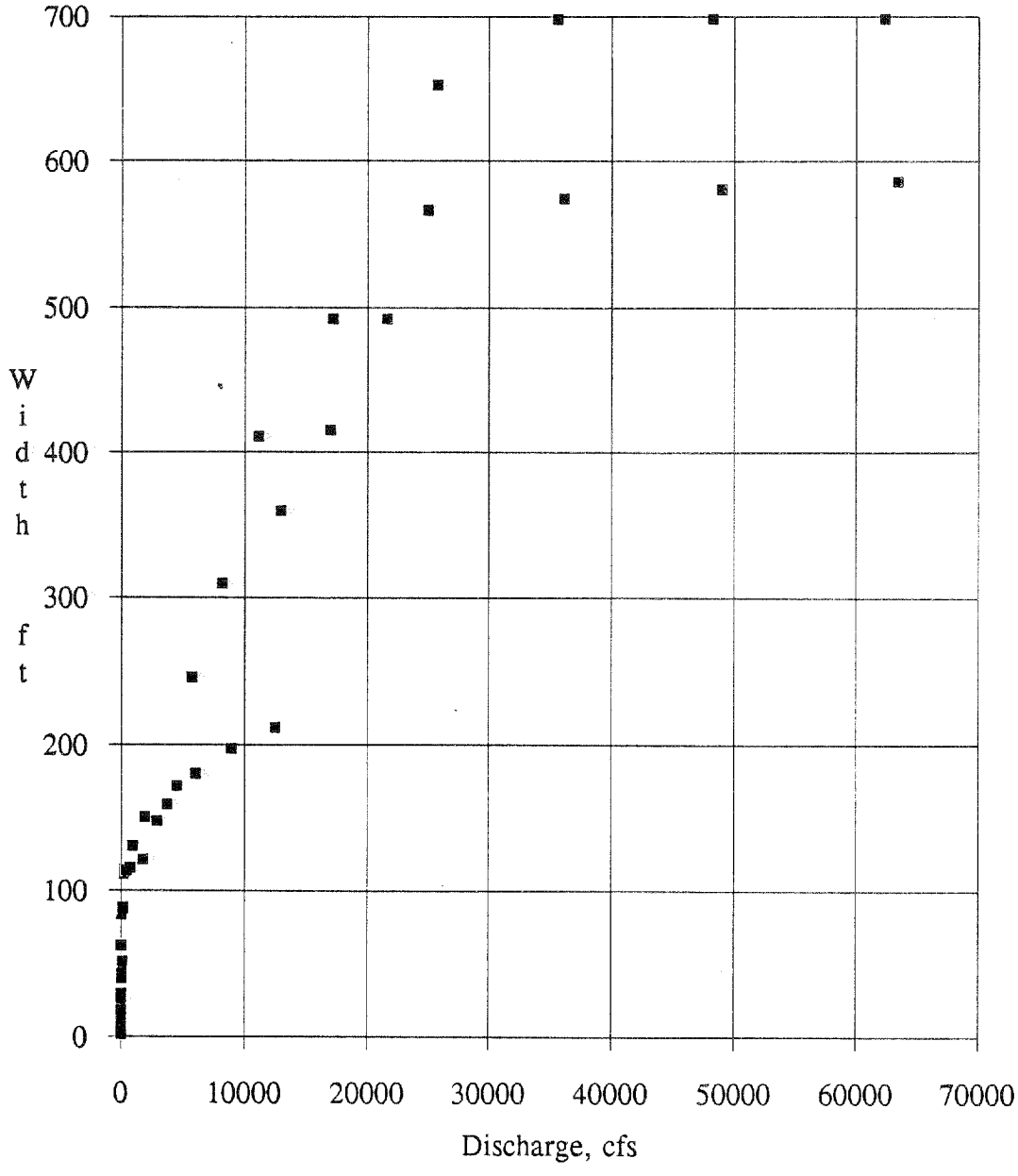
River Width vs. Discharge
Composite of Two Synthetic Rating Curves, Benson Sub-basin
(data from BLM, 1987:Appendixes I, II)
Figure 3-4



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divided by the sum of the values for the entire year yields the fraction of the potential evaporation assignable to each season. The four seasonal values for the Sierra Vista sub-basin are 0.1752, 0.2996, 0.3367, and 0.1885; for the Benson sub-basin, 0.1772, 0.2967, 0.3364, 0.1897.

3.3 BASIN-WIDE CULTURAL SUPPLY AND DEMAND

The parameters listed under this heading cover several ways by which future human activities might affect the water balance in the upper basin as a whole.

Row 58: Imported Water Recharged to Floodplain Aquifer, Sierra Vista Sub-basin

This parameter covers the possibility that parties in the upper basin will find a source of water to import into the Sierra Vista sub-basin, where it can be recharged into the floodplain aquifer. The default setting of 0 indicates that, at present, no water is imported let alone recharged.

Row 59: Imported Water Recharged to Regional Aquifer, Sierra Vista Sub-basin

This parameter covers a possibility similar to that described for Row 59 but with recharge directed into the Sierra Vista sub-basin's regional aquifer. The default setting of 0 indicates that, at present, no water is imported let alone recharged.

Row 60: Export of Water from Floodplain Aquifer, Sierra Vista Sub-basin

This parameter covers the possibility that parties in the upper basin will agree to export water from the Sierra Vista sub-basin's floodplain aquifer. The default setting of 0 indicates that, at present, no such water is exported.

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Row 61: Export of Water from Regional Aquifer, Sierra Vista Sub-basin

This parameter covers a possibility similar to that described for Row 60 but with the exported water taken from the Sierra Vista sub-basin's regional aquifer. Some water from the regional aquifer already is exported to supply the City of Bisbee (see below). Row 61 specifically concerns the export of additional water beyond what already is exported. The default setting of 0 indicates that, at present, no such additional water is exported.

Row 62: Imported Water Recharged to Floodplain Aquifer, Benson Sub-basin

This parameter covers the same possibility described for Row 58 but for the Benson sub-basin.

Row 63: Imported Water Recharged to Regional Aquifer, Benson Sub-basin

This parameter covers the same possibility described for Row 59 but for the Benson sub-basin.

Row 64: Export of Water from Floodplain Aquifer, Benson Sub-basin

This parameter covers the same possibility described for Row 60 but for the Benson sub-basin.

Row 65: Export of Water from Regional Aquifer, Benson Sub-basin

This parameter covers the same possibility described for Row 61 but for the Benson sub-basin.

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Row 66: Surface Area of River Impoundment in Sierra Vista Sub-basin

Residents of the upper basin occasionally have raised the idea of placing a dam across their river (Montgomery, 1963; BLM, 1987). The resulting impoundment, some believe, would keep runoff water in the upper basin where it could be used rather than lost downstream. In order to examine such a possibility, this parameter holds a place for information on the size of any proposed impoundment. The parameter is listed as an 'area' value because both evaporative losses and total reservoir storage will vary with reservoir area. No actual design exists for such an impoundment, however. With no reservoir storage and routing model to follow, consequently, WATERBUD presently contains no actual equations to describe the hydrologic behavior of such a reservoir and the default area value is 0.

Row 67: Fraction of Impounded River Water Recharged to Regional Aquifer

If a river impoundment is to be modeled, this parameter allows for the possibility that some of the retained water will recharge to the upper basin's groundwater. For simplicity, the recharge is assumed to go into the regional aquifer. With no actual model of a reservoir in hand, however, this parameter is set to 0. As noted above, WATERBUD presently contains no actual equations to describe the hydrologic behavior of a reservoir.

Row 68: Fraction Increase in Recharge from Cloud Seeding, Sierra Vista Sub-basin

Residents of the upper basin occasionally also have raised the idea of increasing natural recharge in the upper basin by means of cloud seeding. Essentially all natural recharge occurs along the mountain fronts and results from winter precipitation (Anderson *et al.*, 1990). Consequently, cloud seeding would have to increase winter precipitation.

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This parameter treats the effects of an increase in winter precipitation over the Sierra Vista sub-basin. Rather than model an increase in precipitation per se, the parameter allows WATERBUD simply to increase recharge directly. No cloud seeding currently is taking place and so the default setting is 0.

Row 69: Fraction Increase in Recharge from Cloud Seeding, Benson Sub-basin

This parameter covers the same possibility described for Row 68 but for the Benson sub-basin.

3.4 SPECIAL SIERRA VISTA CITY ACTIVITIES

The City of Sierra Vista presently carries out several activities and has considered carrying out several others, which distinguish its water consumption from that of other municipal areas in the upper basin. The size of the City and the volume of water consumed or potentially consumable by its activities dictate that these activities be modeled separately in WATERBUD.

Row 72: City Use of its Own Wells to Supply Municipal Facilities

The City of Sierra Vista operates several wells, from which it withdraws water to supply City parks, the community center, and the airport. Withdrawals in 1990 totaled 62,911,328 gallons, or 193 acre-feet (City of Sierra Vista, 1991, personal communication).

Row 73: Surface Area of Runoff Impoundment in Sierra Vista

The City of Sierra Vista has considered developing runoff impoundments within the city limits to capture storm runoff and retain it for recharge or direct consumption

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(City of Sierra Vista, 1985-1990). In order to examine such a possibility, this parameter holds a place for information on the aggregate size of the proposed impoundments. The parameter is listed as an 'area' value because both evaporative losses and total storage will vary with aggregate impoundment area. No actual design exists for such impoundments, however. With no storage and routing model to follow, consequently, WATERBUD presently contains no actual equations to describe the hydrologic behavior of such impoundments and the default area value is 0.

Row 74: Fraction of Captured Runoff Recharged to Regional Aquifer

If runoff impoundments are to be modeled, this parameter allows for the possibility that some of the captured water will be recharged to the upper basin's groundwater. For simplicity, the recharge is assumed to go into the regional aquifer alone. With no actual model of any impoundments in hand, however, this parameter is set to 0. As noted above, WATERBUD presently contains no actual equations to describe the hydrologic behavior of any runoff impoundments.

Row 75: Fraction of Treated Effluent Diverted to Artificial Wetland

The City of Sierra Vista presently is experimenting on a small scale with the diversion of secondary-treated waste water to an artificial wetland. This wetland is intended to provide additional biological treatment for the waste water while also providing habitat for wetland flora and fauna (City of Sierra Vista, 1985-1990). This parameter provides information on the quantity of water diverted as a fraction of the total treated waste water stream at the city's facility. Hard data on the diversions are not yet available, however, and so this parameter is assigned a default value of 0.

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Row 76: Surface Area of Artificial Wetland

This parameter provides information on the area of the city's experimental wetland. The parameter is listed as an 'area' value because evaporative losses will vary with wetland area. Hard data on the project are not yet available, however, and so this parameter is assigned a default value of 0.

Row 77: Artificial Wetland Consumptive Use (Evaporation) Coefficient

Losses will occur at the wetland as a result of both open-water evaporation and vegetative transpiration. Total losses are likely to differ from what would occur as a result of open-water evaporation alone. In the absence of data on evapotranspiration, however, the rate of loss can be estimated to approximate that of open-water evaporation. The ADWR (1991:B4) estimate of 65 inches of open-water evaporation per year (5.417 ft) for the basin is recommended as the default setting.

3.5 DOMESTIC CONSUMPTION

Most residents of the upper basin receive their household water exclusively from ground-water sources and most of this water is supplied by water delivery services regulated by the Arizona Corporation Commission. The regulated delivery services include both private and municipal water systems. The remainder of the residents either participate in unregulated, cooperative water delivery systems or operate their own private wells. Both Tombstone and Fort Huachuca derive a portion of their supplies from springs along the east slope of the Huachuca Mountains; Tombstone maintains an aqueduct to carry the spring water across the valley. Domestic use of surface waters in the upper basin otherwise is insignificant. WATERBUD includes an array of twenty numerical

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variables and two classification variables containing data on fourteen census areas in the basin. These twenty two variables, along with nine other variables in the next section (Miscellaneous Domestic Consumption Parameters; see below), provide the basis for projecting domestic consumption. Table 3-1 presents the domestic consumption data.

Row 80: Census Area Name

WATERBUD divides the upper basin into fourteen census areas based on US Census blocks and reports by the Southeast Arizona Government Organization (SEAGO) (Dorrance, 1991). These fourteen areas require some explanation. "SV CITY" includes the entire incorporated area of the city of Sierra Vista exclusive of Fort Huachuca. "SV S.E." includes an arc of residential areas lying immediately to the south and east of the incorporated area of Sierra Vista, which receive their water from regulated delivery services and send their effluent into the city's sewerage system. "Ft.HUAC" includes the population resident on the Fort Huachuca Military Reservation. "HC CITY" includes the residents of the incorporated area of Huachuca City. "TOMB." includes the residents of the incorporated area of Tombstone. "BISBEE" includes the residents of the city of Bisbee. This city lies outside of the upper basin but receives its water from wells lying within the upper basin operated by a private water company. "NACO" includes the residents of the community of Naco. There are two columns labeled "RUR.SVS," dividing the rural residents of the Sierra Vista sub-basin into two groups: those who receive their water from a regulated delivery system; and those who do not. The difference between the two is indicated in Row 81 (see below). "Rural" residents include all residents living outside of an incorporated city or town or recognized village with a dedicated water delivery system. "BENSON" includes the residents of the incorporated area of Benson. "St.DAVID" and "POME" include the residents of the villages of St.

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Recommended Default Values, Domestic Consumption Parameters (Rows 80-101)
Table 3-1

Census Area Name	SV CITY	SV S.E.	Ft.HUAC	HC CITY	TOMB.	BISBEE	NACO
Regulated Water Delivery System? (yes/no)	(yes)	(yes)	(no)	(yes)	(yes)	(yes)	(yes)
1990 Census Population	23773	1182	9210	1782	1220	6288	496
Projected Annual Per Capita Population Growth Rate	0.0422	0.0071	0	0.0071	-0.0287	-0.0128	-0.00013
1980 Median Household Income, $	16740	9769	n/a	13988	9769	10882	10882
Number of Water Service Connections, 1989	10330	446	n/a	650	550	3221	255
Acre-Feet of Delivered Water, 1989	4719.13	126.05	2712	310.07	200.16	1528.66	82.08
Target Water Consumption Rate, Gallons Per Capita Per Day	0	0	0	0	0	0	0
Fraction of Domestic Water Returned as Treatable Effluent	0.5	0.5	0.5	0.5	0.5	0	0.5
Fraction of Effluent Lost to Evaporation During Treatment	0.15	0.15	0.15	0.15	0.15	0	0.15
Fraction of Treated Effluent Recharged to Regional Aquifer	0	0	0	0	0	0	0
Fraction of Treated Effluent Used to Supplement In-Stream Flow	0	0	0	0	0	0	0
Fraction of Households in 1989 with Lowflow Fixtures	0	0	0	0	0	0	0
Fraction of Structures Annually Refitted with Low-Flow Fixtures	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
Fraction Required Conservation from 1989 Demand	0	0	0	0	0	0	0
1990 Service Price, $ per 1000 Gallons Delivered	1.27	2.41	0	1.1	0.79	2.2	1.33
Imposed Additional Water Charges, $ per 1000 Gallons	0	0	0	0	0	0	0
Seasons I-IV Indoor Use, Demand Equation Coefficient	0.5811	0.5404	n/a	0.6247	0.498	0.846	0.4933
Season I Outdoor Use, Demand Equation Coefficient	0	0	0	0	0	0	0
Season II Outdoor Use, Demand Equation Coefficient	0.5166	0.8444	n/a	0.4814	0.2851	1.2166	0.451
Season III Outdoor Use, Demand Equation Coefficient	0.4501	0.741	n/a	0.4231	0.2503	1.069	0.3963
Season IV Outdoor Use, Demand Equation Coefficient	0.2127	0.3526	n/a	0.2009	0.12	0.5079	0.1884

Census Area Name	RUR.SVS	RUR.SVS	BENSON	St.DAVID	POME.	RUR.BS	RUR.BS
Regulated Water Delivery System? (yes/no)	(yes)	(no)	(yes)	(yes)	(yes)	(yes)	(no)
1990 Census Population	294	10844	3824	1468	676	1150	1532
Projected Annual Per Capita Population Growth Rate	-0.00013	-0.00013	-0.0091	-0.00013	-0.00013	-0.00013	-0.00013
1980 Median Household Income, $	9769	9769	12831	12831	12831	9769	9769
Number of Water Service Connections, 1989	111	4337.6	1229	325	187	434	612.8
Acre-Feet of Delivered Water, 1989	29.12	1843.48	658.19	145.38	176.82	123.78	260.44
Target Water Consumption Rate, Gallons Per Capita Per Day	0	0	0	0	0	0	0
Fraction of Domestic Water Returned as Treatable Effluent	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Fraction of Effluent Lost to Evaporation During Treatment	0	0	0.15	0	0	0	0
Fraction of Treated Effluent Recharged to Regional Aquifer	0	0	0	0	0	0	0
Fraction of Treated Effluent Used to Supplement In-Stream Flow	0	0	0	0	0	0	0
Fraction of Households in 1989 with Lowflow Fixtures	0	0	0	0	0	0	0
Fraction of Structures Annually Refitted with Low-Flow Fixtures	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025
Fraction Required Conservation from 1989 Demand	0	0	0	0	0	0	0
1990 Service Price, $ per 1000 Gallons Delivered	0.33	0	0.75	0.8	0.75	1.87	0
Imposed Additional Water Charges, $ per 1000 Gallons	0	0	0	0	0	0	0
Seasons I-IV Indoor Use, Demand Equation Coefficient	0.2765	n/a	0.6471	0.5511	1.1427	0.4993	n/a
Season I Outdoor Use, Demand Equation Coefficient	0	0	0	0	0	0	0
Season II Outdoor Use, Demand Equation Coefficient	0.0721	n/a	0.3533	0.319	0.624	0.6416	n/a
Season III Outdoor Use, Demand Equation Coefficient	0.0632	n/a	0.3104	0.2802	0.548	0.5648	n/a
Season IV Outdoor Use, Demand Equation Coefficient	0.03	n/a	0.1475	0.1331	0.2605	0.2794	n/a

USF2000103 17

David and Pomerene, respectively, both of which have dedicated water delivery systems. The label, "RUR.BS," marks two columns; the distinction is the same as that between the two "RUR.SVS" columns but for the rural residents of the Benson sub-basin.

Row 81: Regulated Water Delivery System? (yes/no)

This parameter indicates whether a census area receives its water supply from a regulated water delivery system. The parameter is provided for informational purposes only and does not effect any calculations.

Row 82: 1990 Census Population

Dorrance (1991) has assembled the preliminary 1990 US census data for the upper basin using the fourteen census areas noted above. Six columns need special explanation. The 1990 preliminary census population for the "SV S.E." area totals 9237. However, Aljamal's (1991a) analysis of the Arizona Corporation Commission files for water delivery services shows that only 446 households in this area are supplied by regulated services. The preliminary US census data (Dorrance, 1991) indicate an average household size of 2.65 persons in this portion of Cochise County. Consequently, the data indicate a total of 1182 persons connected to water delivery and sewerage services in this area. The remaining 8122 censused persons are tabulated as rural residents of the sub-basin living in areas without regulated services.

The population of Fort Huachuca is tabulated from ADWR (1991). The population of "RUR.SVS" and "RUR.BS" residents living in delivery service areas is estimated from the number of rural regulated water delivery connections in each sub-basin (Aljamal, 1991a), using the estimated average household size of 2.65 persons. The population of "RUR.SVS" and "RUR.BS" residents living outside of regulated delivery

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service areas is estimated from the census data on total rural population sizes in the two sub-basins less the number of residents estimated to live inside the rural regulated delivery service areas. The estimated population of "RUR.SVS" outside of regulated delivery service areas includes the 8122 residents of the areas lying immediately south and east of the city of Sierra Vista, discussed above, who are not supplied by a regulated delivery service.

Row 83: Projected Annual Per Capita Population Growth Rate

Putnam *et al.* (1987:8) summarize the 1980 US census data for the upper basin. These data are for Sierra Vista-Fort Huachuca, Bisbee, Benson, Tombstone, Huachuca City, and all rural areas of the upper basin combined. In the absence of other data, the population of Fort Huachuca in 1980 was assumed constant at 9210 persons and was subtracted to give an estimate for the city of Sierra Vista alone.. The 1990 demographic data summarized above were recombined for these same census areas and the 1980-1990 annual per capita growth rate was estimated for each area. The estimates use the standard growth equation,

$$N_t = N_0(1+r)^t$$

where N_t = the population at end of t years, N_0 = the starting population, and r = the annual per capita growth rate. Row 83 presents the resulting estimates.

Row 84: 1980 Median Household Income, $

Aljamal (1991a) summarizes data on median household incomes in the upper basin in the areas supplied by regulated water delivery services, using information from the Arizona Department of Economic Security and the Southeastern Arizona Governments Organization. The data on income play a role in the estimation of water demand rates,

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discussed in Chapter 4. The most accurate data on household incomes available at the time of Aljamal's study derive from the 1980 census and so the 1980 median income figures are given here. Household income does not figure in the projection of water consumption at Fort Huachuca and so is omitted for this census area.

Row 85: Number of Water Service Connections, 1989

Aljamal (1991a) has assembled data from the Arizona Corporation Commission on the water deliveries and numbers of delivery connections for 1989 for all regulated water delivery services in the upper basin (see also ADWR, 1991). This information is summarized in Row 85. The number of "connections" in rural areas without delivery services is equivalent to the number of households, which is estimated from the census data using the household-size factor given in Row 112, below.

Row 86: Acre-Feet of Delivered Water, 1989

Aljamal (1991a) has assembled these data from the Arizona Corporation Commission records of the water deliveries in 1989 for all regulated water delivery services in the upper basin (see also ADWR, 1991). This information is summarized in Row 86. The volume of water supplied to households in rural areas without delivery services is estimated from the census data using the per-capita rural consumption factor given in Row 111, below.

Row 87: Target Water Consumption Rate, Gallons Per Capita Per Day

WATERBUD provides three options for modeling domestic water conservation as described for Row 176, below. One of these options is to impose a target water consumption rate in gallons per capita per day in each census area. If this options is used,

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the target consumption rate is entered in Row 87. When this option is not active, the cells in this row should be left at their default values of 0 for simplicity.

Row 88: Fraction of Domestic Water Returned to Basin as Treatable Effluent

Analyses of published data on sewerage inflows at waste water treatment plants in the upper basin (Braun, 1990) indicate that approximately half of all water delivered to domestic users returns to the sewerage system as treatable effluent. A 50% return rate is typical of domestic water systems in the arid western states (Braun, 1990). The water not returned to the system is most commonly lost to evapotranspiration during outdoor use. Rural users send their indoor waste water to septic tanks; a 50% loss may be assumed for these rural users as well. The city of Bisbee presently does not return its effluent to the basin and so must receive a default value of 0 for this parameter.

Row 89: Fraction of Effluent Lost to Evaporation During Treatment

Municipal waste water treatment facilities in the basin all use open lagoons for secondary treatment. The City of Sierra Vista (1990) has estimated that 15% of the water received at the city's main facility evaporates during the treatment cycle. No comparable data were located for other facilities in the upper basin. However, treatment methods are similar enough among all municipal systems in the upper basin that the 15% figure can be used as a reasonable default value for this parameter. Residents of census areas that do not have municipal treatment facilities all use domestic septic tanks, from which evaporative losses are negligible. Because Bisbee does not return its effluent to the upper basin, it receives a default value of 0 for this parameter.

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Row 90: Fraction of Treated Effluent Recharged to Regional Aquifer

The municipal waste water treatment systems in the upper basin presently do not recharge any of their treated effluent (Braun, 1990). If artificial recharge programs develop, it is assumed here that the recharge will be directed into the regional aquifer because of its greater volume and treatment capacity. Residents of census areas that do not have municipal treatment facilities all use domestic septic tanks. The water leaving the septic tanks is then lost to evapotranspiration due to the shallow depth of such tanks. Because Bisbee does not return its effluent to the upper basin, it again receives a default value of 0.

It should be noted that ADWR (1991:F11) uses a different method to estimate the return flow from domestic users in the San Pedro basin. ADWR simply assumes that 20% of all withdrawn water returns to the ground-water system. The method recommended here provides greater detail on return flows and so should result in more accurate water budget calculations; it also allows users of the model to examine the effects of alternative water management policies concerning the handling of effluent.

Row 91: Fraction of Treated Effluent Used to Supplement In-Stream Flow

The municipal waste water treatment systems in the upper basin presently also do not use any of their treated effluent to supplement in-stream flows (Braun, 1990). However, residents of the upper basin may want to consider a program of supplementation at some future date. This parameter holds a place for examining the effects of such a program; current conditions dictate a default setting of 0.

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Row 92: Fraction of Households in 1989 with Low-flow Fixtures

(See explanation for Row 93, below.)

Row 93: Fraction of Older Structures Annually Refitted with Low-Flow Fixtures

WATERBUD has the ability to model the effects of changes in the proportion of households equipped with low-flow plumbing fixtures. Such fixtures have been mandated for installation in all new construction and for all fixture replacements in many areas of the upper basin (Braun, 1990). The overall benefits of having water users switch to low-flow fixtures will depend on the number of older structures in the upper basin and on the rate at which these older structures are refitted with low-flow fixtures. No quantitative data exist for the first parameter, however, and default values of 0 are assigned for simplicity. Consumer Reports (1990) estimates that individual residential toilets require replacement on average once every twenty years due to deterioration. It can be assumed that the timing for replacement of any one toilet is independent of the timing for any other in a household. The average time to replace all aged toilets in a household therefore also is twenty years. Assuming that other fixtures deteriorate and are replaced no less frequently than toilets, the average replacement period for toilets can be used as an estimate of the average replacement period for all plumbing fixtures in an average residence. A twenty-year replacement cycle entails a refitting rate of 0.05 residences per year. The settings in Rows 92 and 93 have no effect on the model calculations unless Row 176, below, is assigned a value of 2, to switch on Domestic Conservation Option 2.

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Row 94: Fraction Required Conservation from 1989 Demand

As noted above, WATERBUD provides three options for modeling domestic water conservation (see Row 176, below). One of these options is to impose a target rate of conservation requiring that all users reduce their rates of consumption by a fixed fraction of their normal (current) usage. If this options is used, the target conservation rate is entered in Row 94. When this option is not active, the cells in this row should be left at their default values of 0 for clarity.

Row 95: 1989 Service Price, $ per 1000 Gallons Delivered

Aljamal (1991a) has assembled the available data from the records of the Arizona Corporation Commission on water delivery prices for regulated delivery services in the upper basin. If a delivery service handles sewerage charges for its customers as part of its billing, then these charges are included in the delivery prices listed. The average service price in each census area is the weighted arithmetic mean of the prices charged by all delivery services in that census area, weighted according to the quantities of water delivered by the individual services.

Row 96: Imposed Additional Water Charges, $ per 1000 Gallons

As noted above, WATERBUD provides three options for modeling domestic water conservation (see Row 176, below). One of these options is to impose a surcharge or tax on delivered water. The purpose of such imposed charges would be two-fold: (1) to encourage conservation but allow users to regulate their own water-consuming activities according to the consumer values of those activities; and (2) to generate revenue for the support of water-regulatory institutions. If this options is used, the target surcharge rate is

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entered in Row 96. When this option is not active, the cells in this row should be left at default values of 0 for clarity.

Row 97: Seasons I-IV Indoor Use, Demand Equation Coefficient

(See explanation for Row 101, below.)

Row 98: Season I Outdoor Use, Demand Equation Coefficient

(See explanation for Row 101, below.)

Row 99: Season II Outdoor Use, Demand Equation Coefficient

(See explanation for Row 101, below.)

Row 100: Season III Outdoor Use, Demand Equation Coefficient

(See explanation for Row 101, below.)

Row 101: Season IV Outdoor Use, Demand Equation Coefficient

The default method for projecting domestic demand for water in WATERBUD is a standard economic "demand" model. This model estimates demand, Q, as a function of five variables: (1) P, the weighted mean marginal cost of water delivered to customers in a census area (see Row 95, above); (2) b, the price elasticity of water demand; (3) Y, median household income; (4) g, the income elasticity of water demand; and (5) a, a calibration constant. The complete equation has the form,

$$Q = aP^bY^g,$$

where Q is in units of 1000's of gallons per household per season, P is in units of dollars per 1000 gallons delivered, and Y is in units of dollars.

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Aljamal (1991a) has assembled the data and carried out the analyses to construct demand equations for each census area with regulated delivery services. These equations project demand for each season (see above, Row 16). Indoor use was assumed to be constant year-round and was estimated from the Season I delivery data under an assumption that 100% of Season I consumption is for indoor use alone. Outdoor use for Season I was assumed to be constant at 0; Seasons II-IV outdoor use was computed from the actual seasonal delivery quantities by subtracting the assumed constant indoor use volumes from actual delivery quantities. The data on median household income, average delivery price, and delivered quantities of water were then used in a regression analysis to estimate b, g, and a for each census area, for each season, using the logarithmic form of the demand equation,

$$\log Q = \log a + b \log P + g \log Y.$$

Rows 97-101 present Aljamal's (1991a) estimates for a, for indoor use (Row 97) and for seasonal outdoor use (Rows 98-101). Rows 104-106, below, present Aljamal's estimates for b and g.

3.6 MISCELLANEOUS DOMESTIC CONSUMPTION PARAMETERS

Row 104: Price Elasticity, Indoor Domestic Use

(See explanation for Row 106, below.)

Row 105: Price Elasticity, Outdoor Domestic Use

(See explanation for Row 106, below.)

USF200010326

Row 106: Income Elasticity, Indoor and Outdoor Domestic Use

Aljamal (1991a) derived these estimate for b and g, the price and income elasticity exponents, based on previously published studies of the price elasticity of water demand in the arid West. The values selected by Aljamal are the average values among the studies of comparable climates and economies. The recommended value of b for indoor domestic usage is given in Row 104; b for outdoor usage in Row 105, and g for both indoor and outdoor usage in Row 106. These values are -0.3, -1.2, and 0.4, respectively.

Row 107: Number of Personnel to be Added to Fort Huachuca Staff

(See explanation for Row 108, below.)

Row 108: Year in Which Above Personnel Will be Added to Fort Staff

The military staffing of Fort Huachuca depends not on normal demographic processes but on the funding, activities, and personnel policies of the U.S. Department of Defense. WATERBUD therefore contains a separate means for modeling changes in the population of the Fort. Row 107 specifically provides a means for adding (+) or subtracting (-) military population from the base staff. Row 108 specifies the year in which the addition or subtraction of military personnel is projected to occur. WATERBUD thus can specify only a single change in overall staffing during the twenty-year period of projection. Column F for these two rows are calculated values for the number of added staff who will actually live on-base. These values are calculated based on the information in Rows 109 and 110, below, and are not entered separately. Unless

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an actual addition of military personnel is to be modeled, the values in Rows 107 and 108 must be kept at their default settings of 0.

Row 109: Average Number of Additional Family Members Arriving with New Staff

(See explanation for Row 110, below.)

Row 110: Fraction of New Personnel and Families Who Will Live Off-Base

If military personnel are added to the staff at Fort Huachuca, many of these new will arrive accompanied by additional members of their families. Some of the new military arrivals and their families will accept housing on-base while others will live off-base. Conversely, military personnel eliminated from the staff at the Fort will depart accompanied by additional family members and will depart from both on-base and off-base housing. Rows 109 and 110 provide the means for specifying how many additional family members will arrive (or depart) and how the total arriving (or departing) population of military personnel and their families will be distributed between on-base and off-base residences.

It is recommended that the value for Row 109 be calculated using an estimate of average household size and the equations,

$$T = H \times S \text{ and } F = T - S$$

where T = total arriving (+) or departing (-) population of staff and families, H = average household size, S = number of added (+) or departing (-) military personnel, and F = number of arriving (+) or departing (-) family members. The value for Row 110, in turn, will depend on the availability of on-base housing. The simulations of population scenarios presented in Chapter 5, for example, used an arbitrary value of 0.50

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for convenience. Unless an actual addition of military personnel is to be modeled, the values in Rows 109 and 110 must be kept at their default settings of 0.

Row 111: Estimated Consumption Per Person in Rural Non-Service Areas

(See explanation for Row 112, below.)

Row 112: Estimated Household Size in Rural Non-Service Areas

ADWR (1991:F11) recommends using an estimate of 0.43 acre-feet/year for household consumption in rural areas outside of regulated delivery service areas. This estimate is based on the average per-household water consumption in the upper basin exclusive of Fort Huachuca. Assuming an average rural household size of 2.5 persons for Row 112, the recommended default setting for Row 111 is 0.43/2.5 = 0.17 acre-feet/person/year.

3.7 AGRICULTURAL CONSUMPTION

Agricultural activities in the upper basin include the maintenance of pasturage and the production of crops. The watering of livestock is modeled separately under the heading of Reservoirs and Stockponds, below. Irrigation consumes surface water and groundwater from both aquifers with the surface diversions taking place solely in the Benson sub-basin. WATERBUD provides parameters for modeling demand for irrigation water based on irrigated acreage, effective precipitation, consumptive use rates, and irrigation efficiencies; and based on the price elasticity of demand for irrigation water.

Row 115: Effective Irrigated Acreage, Sierra Vista Sub-basin

(See explanation for Row 116, below.)

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Row 116: Effective Irrigated Acreage, Benson Sub-basin

ADWR (1991:C74-76) has tabulated the acres of irrigated land in active use in 1990 in the San Pedro basin by sub-basin. The data are repeated here in Table 3-2. ADWR (1991:Appendix C) explains the methods by which the acreage values were determined. The resulting values are 2597.7 and 5792.6 acres for the Sierra Vista and Benson sub-basins, respectively.

Row 117: Surface Diversion Right, St. David Irrigation District

(See explanation for Row 119, below.)

Row 118: Average Actual Surface Diversions, St. David Irrigation District

(See explanation for Row 120, below.)

Row 119: Surface Diversion Right, Pomerene Water Users Association

Two regulated irrigation districts operate in the upper basin, the St. David Irrigation District and the Pomerene Water Users Association (ADWR, 1991:319-351). The General Adjudication of the Gila River System and Source (ADWR, 1991:Chapter 1) may eventually establish new limits to the diversion rights of these two districts. If such limits are established, WATERBUD can be modified to ensure that the model also so limits the surface diversions of each district. No projective equations in the model (see below) presently consider such limits, however, and therefore Rows 117 and 119 are marked as "not applicable." The parameters are listed to hold a place for future modifications.

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Calculation of Sub-basin Weighted Average Effective Precipitation Values

Table 3-2

Crop	ET	EP	PEP	Sierra Vista ac.	Benson ac.
Alfalfa	4.11	0.69	0.09	257.4	998.6
Alfalfa, deficit irrigated	2.97	0.73	0.08	0	16.9
Corn	2.10	0.66	0.18	0	22.4
Melons	1.98	0.51	0.15	53.8	5.6
Summer pasture	2.84	0.66	0.18	162.2	434.1
Summer pasture, deficit irrigated	1.99	0.58	0.13	0	62.1
Small grains	1.23	0.27	0.43	57.0	154.7
Small grains, deficit irrigated	1.03	0.24	0.45	0	7.2
Mixed vegetables	1.76	0.53	0.21	20.8	0
Sorghum	1.58	0.38	0.16	0	29.6
Orchard without ground cover	3.69	0.61	0.13	21.4	8.0
Orchard without ground cover, deficit irrigated	2.32	0.60	0.15	41.5	0
Grapes	1.99	0.58	0.12	235.5	0.8
Grapes, deficit irrigated	1.29	0.59	0.12	6.8	0
Landscaping	1.98	0.32	0.10	16.0	11.6
Landscaping, deficit irrigated	1.80	0.58	0.10	1.0	0
Orchard with ground cover	4.24	0.59	0.13	1.2	28.3
Orchard with ground cover, deficit irrigated	3.12	0.75	0.10	0	1.9
Permanent pasture	3.95	0.78	0.01	380.3	1417.9
Permanent pasture, deficit irrigated	3.06	0.81	0.02	541.1	509.3
Pecans without ground cover	3.07	0.57	0.12	16.4	89.0
Pecans without ground cover, deficit irrigated	2.28	0.62	0.13	4.4	0.9
Pecans with ground cover	4.17	0.56	0.11	0	33.5
Pecans with ground cover, deficit irrigated	3.26	0.71	0.10	0	0.6
Pine trees	5.90	0.92	0.00	0.5	44.0
Pine trees, deficit irrigated	4.73	0.94	0.00	0.9	4.0
Turf	3.23	0.58	0.14	226.1	42.6
Turf, deficit irrigated	2.43	0.62	0.14	1.4	1.9
Winter pasture	1.00	0.21	0.33	35.1	16.0
Winter pasture, deficit irrigated	1.09	0.20	0.26	4.7	3.0
Alfalfa DC with sorghum	3.79	0.75	0.12	0	198.6
Alfalfa DC with small grains	2.39	0.21	0.16	0	278.7
Alfalfa DC with pasture	3.38	0.63	0.14	0	37.2
Fruit trees DC with vegetables	2.10	0.50	0.12	0.9	0
Small grains DC with sorghum	2.66	0.65	0.08	0	170.2
Small grains DC with corn	2.74	0.57	0.10	0	1.7
Small grains DC with summer pasture	3.80	0.85	0.13	49.3	248.0
Winter pasture DC with corn	2.81	0.69	0.08	0	5.6
Winter pasture DC with sorghum	2.69	0.65	0.08	0	136.9
Winter pasture DC with vegetables	2.60	0.61	0.06	0.9	2.2
Winter pasture DC with summer pasture	3.58	0.71	0.14	44.6	306.0
Total 1990 Active Acreage				2181.2	5329.6
Weighted Effective Precipitation Rate, ft/year				0.78	0.78

Notes: DC = double cropped
ET = crop consumptive use rate, ft/year
EP = effective precipitation in growing season, ft/year
PEP = pre-season effective precipiration, ft/year
ac. = irrigated acres

Data Sources: ADWR (1991:C50-51, C65, C74-75)

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The members of both irrigation districts also apply groundwater to their fields. Ground-water usage for irrigation in the two districts is included in the calculation of total sub-basin ground-water irrigation withdrawals (see below).

Row 120: Average Actual Surface Diversions, Pomerene Water Users Association

ADWR (1991:326-328, 342-244) has computed the average surface diversions of the Pomerene and St. David irrigation districts using the 1968-1971 period of record. This is the period of record for which the best records are available. ADWR uses the resulting averages for its analyses of surface water consumption and the values are also accepted here. The default acre-foot values are: St. David, 4425.6; Pomerene, 1563.5 .

Row 121: 1990 Average Overall Irrigation Efficiency, Sierra Vista Sub-basin

(See explanation for Row 122, below.)

Row 122: 1990 Average Overall Irrigation Efficiency, Benson Sub-basin

ADWR (1991:C73) estimates the weighted average irrigation efficiency in the Sierra Vista sub-basin at 0.55 and in the Benson sub-basin at 0.50. These values are calculated from the estimated efficiency values for each combination of crop type and irrigation method weighted according to the acreage devoted to that combination in each sub-basin.

Row 123: 1990 Weighted Average Crop Consumptive Use Requirement, Sierra Vista Sub-basin

(See explanation for Row 124, below.)

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Row 124: 1990 Weighted Average Crop Consumptive Use Requirement, Benson Sub-basin

ADWR (1991:C73) has estimated the 1990 weighted average crop consumptive use requirement for all irrigated land in the Sierra Vista sub-basin at 2.59 acre-feet/acre and in the Benson sub-basin at 2.78 acre-feet/acre. ADWR (1991:Appendix C) explains the calculation of these values. The ADWR values do not include the consumption of effective precipitation.

WATERBUD takes into account the fact that average effective precipitation varies from one year to the next depending on variation in actual precipitation. Net irrigation requirements therefore vary depending on how much of each crop's requirements must be supplied by irrigation water to compensate for what is not supplied by precipitation and near-surface groundwater. Similarly, WATERBUD takes into account that average consumptive use rates vary from one year to the next depending primarily on the effective temperature distribution and its effect on potential evapotranspiration rates (ADWR, 1991:Appendix C). Net irrigation requirements thus also vary depending on the variation effective temperatures.

The projective equations in WATERBUD take account of these several relationships. The values presented in Rows 123-124 therefore are the average <u>total</u> water requirement for irrigated crops in each sub-basin rather than the net irrigation requirement. This average total water requirement is the sum of the ADWR estimates of crop consumptive use and the estimates of average effective precipitation shown in Table 3-2 (see below for Rows 125-126). The resulting values are 2.59 + 0.78 = 3.37 acre-feet/acre for the Sierra Vista sub-basin and 2.78 + 0.78 = 3.56 acre-feet/acre for the Benson sub-basin.

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Row 125: Weighted Average Effective Precipitation for Irrigation, Sierra Vista Sub-basin

(See explanation for Row 126, below.)

Row 126: Weighted Average Effective Precipitation for Irrigation, Benson Sub-basin

ADWR (1991:C74-76) has tabulated the effective in-season (EP) and pre-season (PEP) values for all crops irrigated in 1990 in the San Pedro basin by sub-basin. The data are repeated here in Table 3-2. ADWR (1991:Appendix C) explains the methods by which the individual crop values were determined. A weighted average effective precipitation rate can be estimated by summing the estimated values for all combinations of crop type and irrigation method with each value weighted according to the acreage devoted to that combination in each sub-basin. The resulting estimates are 0.78 acre-feet/acre for both sub-basins.

Row 127: Long-Term Per-Acre Change in Irrigated Acreage, Sierra Vista Sub-basin

(See explanation for Row 128, below.)

Row 128: Long-Term Per-Acre Change in Irrigated Acreage, Benson Sub-basin

The number of acres of irrigated land in the two sub-basins will not remain static. Regional and national economic factors have constrained and will continue to constrain the viability of agricultural activities in the upper basin. It is necessary therefore to provide a means for modeling change in the total acreage devoted to irrigated agriculture in the two sub-basins. WATERBUD Rows 127 and 128 provide parameters to specify a rate of growth (or decline) of acreage for the twenty-year period of projection. The value of

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these two parameters must be given as a rate of change in acres gained (+) or lost (-) per acre of existing irrigated land per year. The simulations of scenarios of agricultural change presented in Chapter 5, for example, used a value of 0.035. This value projects a doubling of irrigated acreage over a twenty-year modeling period, the rate observed in the San Pedro basin as a whole during the 1970-1990 period of record (ADWR, 1991:122-123). Unless an actual rate of change is to be modeled, the values in Rows 127 and 128 must be kept at default settings of 0.

Row 129: Required Irrigation Efficiency, Sierra Vista Sub-basin

(See explanation for Row 130, below.)

Row 130: Required Irrigation Efficiency, Benson Sub-Basin

One of the options for water management in the San Pedro basin is to require irrigators to raise the efficiency of their irrigation methods (UAWRRC, 1991). Rows 129 and 130 provide parameters to specify a legislated efficiency level. Specifying values in these two rows has no effect on the projections unless Row 179, below, is also given the value, 1 ("yes"). The simulations of scenarios of agricultural change presented in Chapter 5, for example, used values of 0.85 for both sub-basins. This is the level of efficiency currently required for Active Management Areas in southern Arizona as authorized under the Arizona Ground Water Management Act of 1980 (UAWRRC, 1991).

Row 131: Target Weighted Average Crop Irrigation Requirement, Sierra Vista Sub-basin

(See explanation for Row 132, below.)

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Row 132: Target Weighted Average Crop Irrigation Requirement, Benson Sub-basin

Another of the options for water management in the San Pedro basin is to require irrigators to change their choices of crops to ones with lower irrigation requirements (UAWRRC, 1991). Rows 131 and 132 provide parameters to specify a target average irrigation requirement for each sub-basin. Specifying values in these two rows has no effect on the projections unless Row 178, below, is also given the value, 1 ("yes").

Row 133: Per-Acre Irrigation Demand Coefficient, Sierra Vista Sub-basin

(See explanation for Row 136, below.)

Row 134: Per-Acre Irrigation Demand Coefficient, Benson Sub-basin

(See explanation for Row 136, below.)

Row 135: Price Elasticity of Irrigation Demand, Sierra Vista Sub-basin

(See explanation for Row 136, below.)

Row 136: Price Elasticity of Irrigation Demand, Benson Sub-basin

WATERBUD provides a means for projecting demand for irrigation water using a standard economic "demand" model. This model estimates the overall quantity of demand in a sub-basin, Q, as a function of three variables: (1) P, the marginal cost of water delivered to irrigators in the sub-basin; (2) b, the price elasticity of irrigation water demand in the sub-basin; and (3) a, a calibration constant. The complete equation has the form,

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$$Q = aP^b$$

where Q is in acre-feet per sub-basin and P is in dollars of marginal cost per acre-foot.

Aljamal (1991b) has estimated demand equations for each sub-basin for increases in costs using information on the cost basis of the important irrigated crops in each sub-basin. Data on seven classes of variables were used in a linear programming analysis to establish estimates of the likely overall demand for irrigation water at several increments of increased overall water cost. Overall demand was estimated under an assumption that irrigators will vary their selection of crops and irrigation methods in order to maximize revenues. The seven classes of variables were: P_j, the net revenue in \$/acre, not accounting water cost, generated by the j th crop production activity; X_j the number of acres used for the j th production activity; C_j, the irrigation water cost, in \$/acre-foot, for the j th crop production activity; W_j, the total quantity of irrigation water needed, in acre-feet, for the j th crop production activity; a_j, the per-acre irrigation water requirement, in acre-feet/acre, for the j th crop production activity; b_j, the land availability, in acres, for the j th crop production activity; and S, an estimate of the total amount of water available for irrigation supply in the sub-basin.

The results of the linear programming analyses were passed to a regression analysis to estimate a and b for each sub-basin, using the logarithmic form of the demand equation,

$$\log Q = \log a + b \log P$$

Aljamal's (1991b) regression results have been recomputed to calibrate the a and b in two ways: (1) to ensure that the values predict the correct total crop irrigation requirement when marginal costs = \$0.00; and (2) to have the demand equations predict Q as the average crop irrigation demand rate (in acre-feet/acre) rather than as total quantity demanded. Rows 133-134 present the estimates for a: 4.68 and 5.51 acre-feet/acre for

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the Sierra Vista and Benson sub-basins, respectively. Rows 135-136 present the estimates for b: -0.3544 and -0.5624 for the Sierra Vista and Benson sub-basins, respectively.

Row 137: Imposed Irrigation Well Pumping Tax, $ Per Acre-Foot

A further option for water management in the San Pedro basin is to place a surcharge on irrigation well withdrawals, to be paid by the irrigators supplied by such wells (UAWRRC, 1991). Any such surcharge would constitute a marginal increase in the costs of obtaining irrigation water (see above). The purpose of such imposed charges would be two-fold: (1) to encourage conservation but allow irrigators to regulate their own irrigation activities according to the values of those activities; and (2) to generate revenue for the support of water-regulatory institutions. If this option is used, the target surcharge rate is entered in Row 137. When this option is not active, this row should be kept at a default value of 0 for clarity. However, specifying a value in this row has no effect on the projections unless Row 180, below, is also given the value, 1 ("yes").

3.8 RIPARIAN HABITAT AND MANAGEMENT STATUS

The Upper San Pedro Basin boasts several stretches of riparian habitat, which have remained relatively unchanged despite the development of the region. Much of this habitat is now managed by the U.S.D.I. Bureau of Land Management in the San Pedro Riparian National Conservation Area (SPRNCA). Riparian vegetation consumes significant quantities of groundwater in the basin; human activities in the basin affect the availability of groundwater to the riparian vegetation; and BLM management practices in the SPRNCA potentially can also affect ground-water balances. For these reasons, WATERBUD contains parameters for modeling water consumption by riparian vegetation and the effects of BLM management practices.

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Row 140: Area of Riparian Vegetation in 1990, Sierra Vista Sub-basin

(See explanation for Row 141, below.)

Row 141: Area of Riparian Vegetation in 1990, Benson Sub-basin

ADWR (1991:Appendix B) has mapped the distribution of riparian vegetation in the San Pedro River valley using data from previous studies and from additional field surveys and remote sensing imagery. This mapping indicates that riparian vegetation occupies approximately 5,894 acres in the Sierra Vista sub-basin, and 6,045 acres in the Benson sub-basin (ADWR, 1991:B3).

Row 142: 1990 Salvageable Riparian Acreage, Sierra Vista Sub-basin

(See explanation for Row 143, below.)

Row 143: 1990 Salvageable Riparian Acreage, Benson Sub-basin

The development of agriculture in most parts of the San Pedro Basin involved the clearing of riparian vegetation from the floodplain soils and its replacement by crops. Portions of the cleared lands have since been retired from agricultural use; however, these have not yet reverted to their pre-development conditions. As a result, riparian vegetation in the basin occupies a smaller area than would be the case without human interference. The area from which riparian vegetation has been cleared and which is likely to revert to riparian conditions if retired from agricultural use can be estimated from data on soils, geomorphology, and other conditions. The results are estimates of "salvageable riparian acreage." ADWR (1991:Appendix D) has carried out an analysis of the area of riparian vegetation displaced by agriculture in the basin. The results indicate that the Sierra Vista

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sub-basin has seen the displacement of roughly 760 acres of riparian vegetation and the Benson sub-basin has seen the displacement of 924 acres.

Row 144: Composite Consumptive Use Coefficient, Riparian Vegetation, Sierra Vista Sub-basin

(See explanation for Row 145, below.)

Row 145: Composite Consumptive Use Coefficient, Riparian Vegetation, Benson Sub-basin

Consumptive use is the use of groundwater rather than moisture provided by precipitation. ADWR (1991:Appendix B) has estimated the consumptive use rates for different kinds of riparian vegetative associations in the San Pedro Basin. The findings can be combined with data on the areas occupied by these different associations to yield estimates of the weighted average consumptive use rate for all riparian vegetation in each sub-basin. The coefficient values in Rows 144 and 145 combine the weighted average consumptive use rates and the average effective precipitation rates (Row 15, above) over the floodplain in the two sub-basins. The resulting values are 2.88 and 3.28 acre-feet per acre for the Sierra Vista and Benson sub-basins respectively.

Row 146: Riparian Corridor Width Equation, First Coefficient

(See explanation for Row 147, below.)

Row 147: Riparian Corridor Width Equation, Second Coefficient

Accurate modeling of the water budget of the upper basin requires modeling how riparian vegetation densities might change as a result of a change in the availability of

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water to this vegetation. Dorrance (1991) conducted a literature review of research on the effects of hydrologic changes on riparian density and area of cover in the arid Southwest. Four studies suggested four different modeling approaches (Groeneveld and Griepentrog, 1985; Leighton *et al.*, 1989; McNeish, 1989; and Taylor, 1982). Of these four approaches, only one (Taylor, 1982) uses parameters that could be practicably incorporated into WATERBUD. Taylor examined variation in riparian corridor width along lower-elevation streams on the eastern flanks of the Sierra Nevada Range within the Inyo National Forest, California. Taylor found that corridor width was predictable from the mean annual flow rate of the adjacent stream by the regression equation,

$$W = 4.95F - 0.034F^2,$$

where W = corridor width in meters and F = mean annual stream flow rate in cfs. When rewritten for W in feet and F in acre-feet per year, the equation becomes

$$W = 0.02243F - 0.2128F^2.$$

Taylor's equation is based on a different mixture of riparian vegetative associations than occurs in the San Pedro Valley. Nevertheless, the equation provides at least an initial method for estimating how riparian vegetation might change in response to changes in mean annual stream flow. More powerful but more complex models are possible, incorporating information on depths to the floodplain water table, frequency of flood events, extent of seasonal fluctuations in stream flow and water table depths, and other factors. However, no tested model that incorporated such additional factors was located.

The Taylor equation was adapted to the San Pedro case for use in WATERBUD by converting it into an equation predicting the relative change in riparian corridor width for a given relative change in stream flow rate. The Taylor equation was used to estimate corridor width values for flow rates varying from 1 to 100 cfs; the results are shown in Figure 3-5. The results were used to compute the percent increase in corridor width

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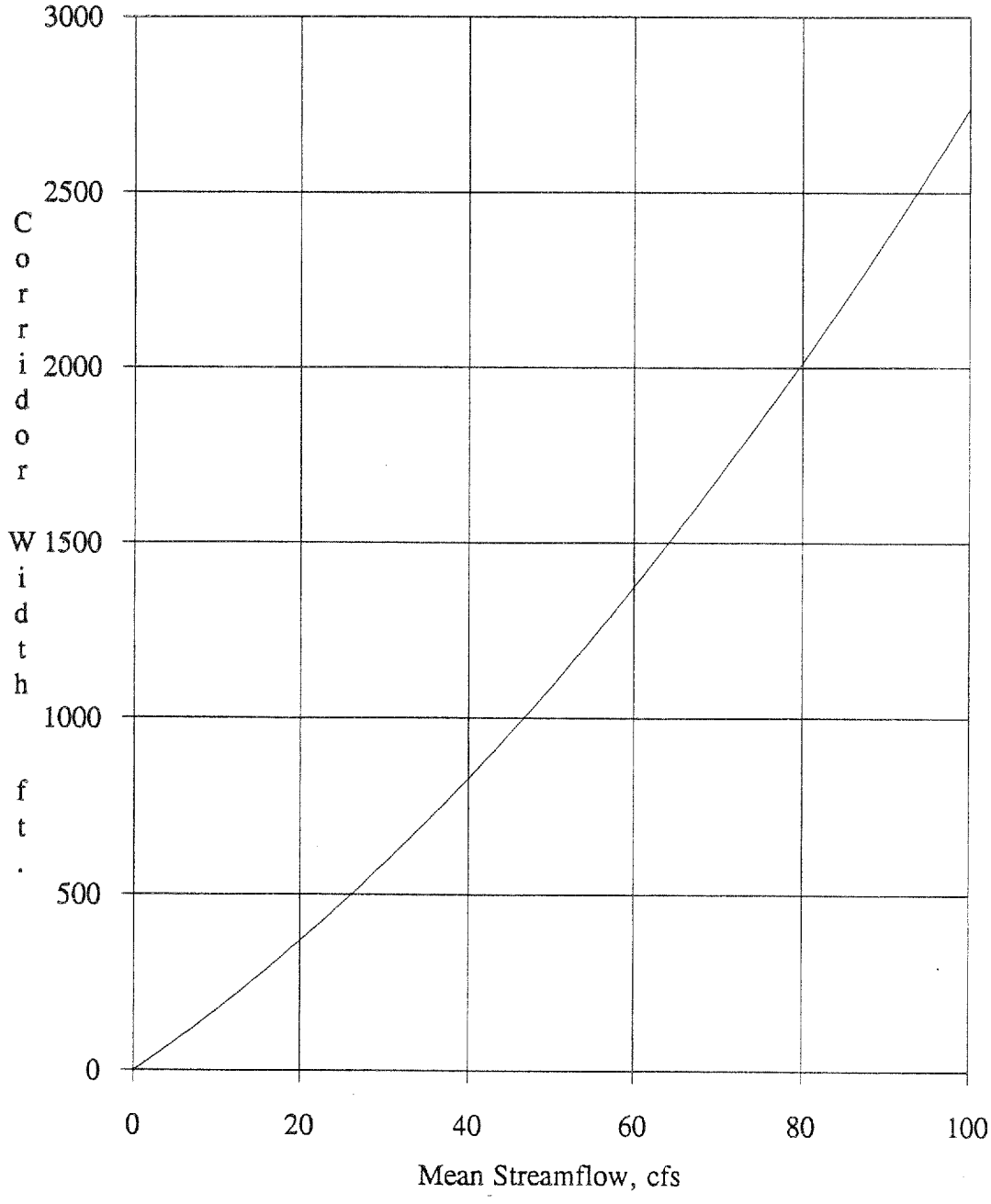
Riparian Corridor Width vs. Streamflow as Predicted by Taylor Equation
Figure 3-5



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($\Delta\%W$) predicted for an increase of 1 cfs in stream flow, expressed as a percent increase in stream flow, $\Delta\%F$, at each value of the stream flow rate variable. The relationship between ($\Delta\%W$) and $\Delta\%F$ is shown in Figure 3-6. For the ratio,

$$E = \Delta\%W \div \Delta\%F,$$

the relationship was found by regression to fit a linear equation of the form,

$$\log E = a\sqrt{F} + b \text{ or } E = 10^{a\sqrt{F}}10^{b},$$

where a = 0.018144 and 10^{b} = 0.932133. This final equation is used in Rows 261-262, to project changes in riparian corridor area (see below). The values for a and 10^{b} are stored as model parameters in Rows 146 and 147, respectively.

Row 148: SPRNCA Withdrawals from Floodplain Aquifer, Sierra Vista Sub-basin

(See explanation for Row 151, below.)

Row 149: SPRNCA Withdrawals from Regional Aquifer, Sierra Vista Sub-basin

(See explanation for Row 151, below.)

Row 150: SPRNCA Withdrawals from Floodplain Aquifer, Benson Sub-basin

(See explanation for Row 151, below.)

Row 151: SPRNCA Withdrawals from Regional Aquifer, Benson Sub-basin

It is the responsibility of the BLM to protect the flow of water in the San Pedro River through the San Pedro Riparian National Conservation Area. Drought and human interference can interfere with this flow. One option available to the BLM is to withdraw groundwater from the floodplain and/or the regional aquifer and divert the withdrawn waters into the river channel to supplement the surface flow. Rows 148-151 provide

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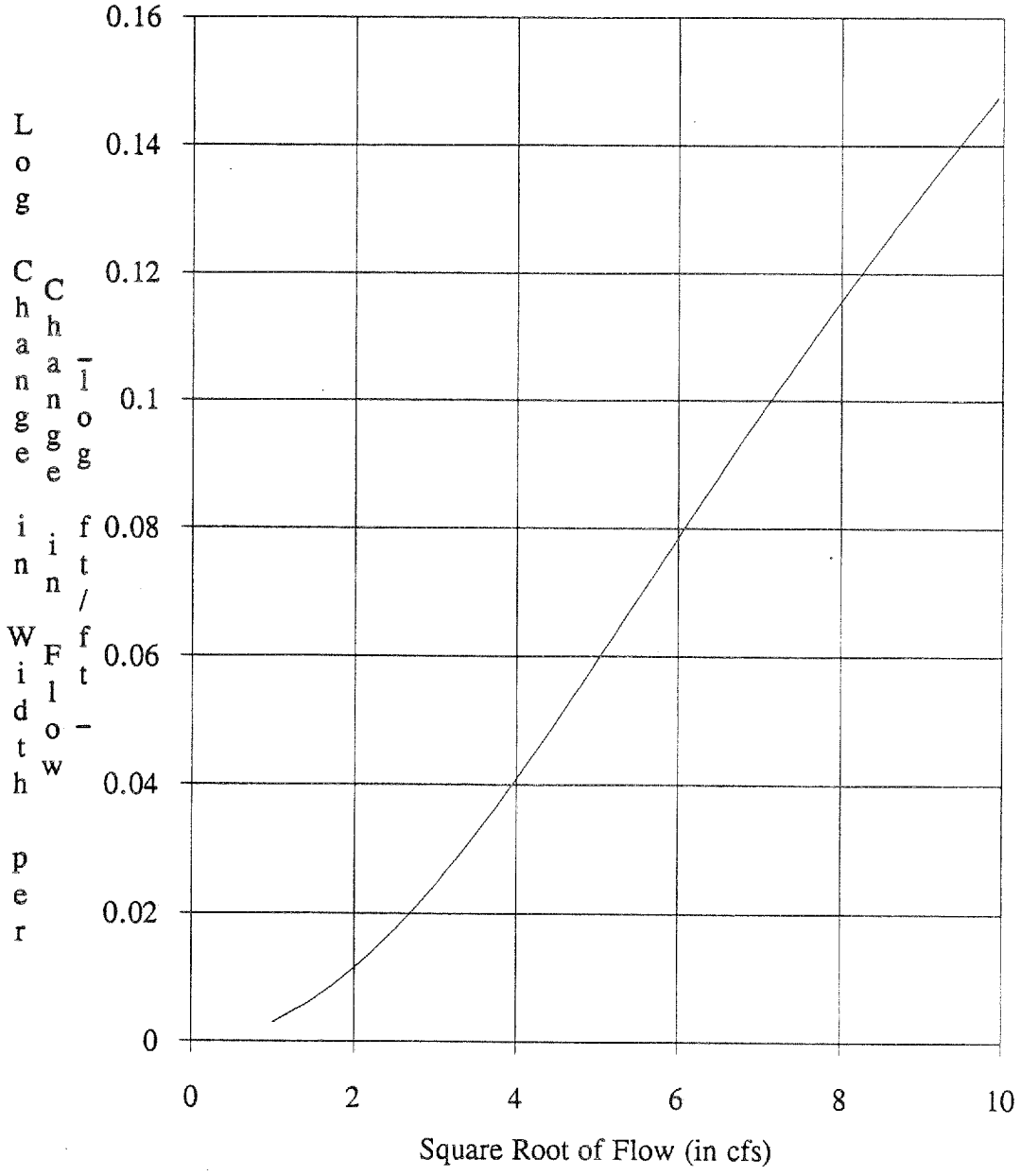
Log Change in Riparian Corridor Width for a Unit Change in Stream Flow
vs. Square Root of Stream Flow
Figure 3-6



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places, in which to specify the quantities (acre-feet) to be withdrawn from the two aquifers in the two sub-basins and used to supplement the surface flow. If withdrawals are not anticipated, the parameters must be kept at their default values of 0 acre-feet.

3.9 INDUSTRIAL CONSUMPTION

Few industrial activities consume significant quantities of water in the Upper San Pedro Basin (ADWR, 1991; Bazlen, 1989). These activities include mining, sand and gravel processing, and the manufacture of chemical products at the Apache Nitrogen Products plant directly across the river from the town of St. David. Mine-related activities in the upper basin at present are minimal but have the potential to increase significantly and so increase their water consumption significantly in this metal-rich region. Because of this potential for significant changes in industrial water use, WATERBUD models the consumption of water by mining activities separately from consumption by other industries. All of the modeled industrial activities are supplied with water from the regional aquifer.

Row 154: 1989 Mining Withdrawals from Regional Aquifer, Sierra Vista Sub-basin

(See explanation for Row 158, below.)

Row 155: 1989 Other Industrial Use of Regional Aquifer, Sierra Vista Sub-basin

(See explanation for Row 159, below.)

Row 156: Fraction of Mining Usage Recharged to Regional Aquifer, Sierra Vista Sub-basin

(See explanation for Row 160, below.)

USF200010345

Row 157: Fraction of Other Industrial Usage Recharged to Regional Aquifer, Sierra Vista Sub-basin

(See explanation for Row 161, below.)

Row 158: 1989 Mining Withdrawals from Regional Aquifer, Benson Sub-basin

ADWR (1991:352-374) has summarized the consumption of water at mining facilities in the basin during 1989. At present, only two facilities are operating, both in the Sierra Vista sub-basin and both only at minimal maintenance levels: the ALANCO, Ltd., AR-MEX Custom Mill; and the RAMCO, Inc., PBR Minerals plant at the Contention Mine, both located near the City of Tombstone. ADWR (1991:353) estimates that these two facilities together presently consume approximately 2 acre-feet per year. The recommended default (1990) values for Rows 154 and 158 are thus 2.0 and 0.0 acre-feet, respectively.

Row 159: 1989 Other Industrial Use of Regional Aquifer, Benson Sub-basin

ADWR (1991:352-374) also has summarized the consumption of water at other industrial facilities in the basin during 1989. At present, four facilities are operating in the Sierra Vista sub-basin and one in the Benson sub-basin. The facilities in the Sierra Vista sub-basin and their estimated water consumption are: Babocomari Ranch Co.-Huachuca Concrete Co., 71.8 acre-feet; Desert Concrete Co., 11.1 acre-feet; Sierra Ready Mix, 63.2 acre-feet; and Young Concrete and Rock, 58.6 acre-feet. The total for the four facilities is 204.7 acre-feet, the recommended default value for Row 155. The single facility in the Benson sub-basin is the Apache Nitrogen Products, Inc. plant, consuming 542.0 acre-feet, the recommended default setting for Row 159.

USF200010346

Row 160: Fraction of Mining Usage Recharged to Regional Aquifer, Benson Sub-basin

Some recharge of water may result from mining related activities. At present, mining discharges are highly regulated and restricted due to the potential for the release of sediments and hazardous substances. Waste waters generally are trapped in protected ponds, from which little or no recharge occurs. The recommended default rate for the recharge of waters at mining facilities therefore is set to 0.00 for both sub-basins.

Row 161: Fraction of Other Industrial Usage Recharged to Regional Aquifer, Benson Sub-basin

ADWR (1991:F15) has assumed that 80% of the water used in sand and gravel processing is returned to surface and ground-water flows after use. However, the specific information collected by ADWR (1991:352-374) indicates that only the Babocomari Ranch/Huachuca Concrete facility discharges its used water. This facility releases as much as 50% of its used water into a tributary of the Babocomari River. The other sand and gravel facilities place their used water in unlined settling ponds and recirculate the settled water. It therefore seems likely that out of the 204.7 acre-feet consumed in 1989 by non-mining industries in the Sierra Vista sub-basin, recharges add up to only approximately 36 acre-feet plus unmeasured infiltration from the unlined settling ponds. The recommended range for non-mining recharge in the Sierra Vista sub-basin (which contains all of the sand and gravel facilities) therefore is 17% to 50% (0.17 to 0.50). Assuming that infiltration from the settling ponds is low and losses during water use and settling are high, WATERBUD uses a default value of 0.20. The location of the sand and gravel facilities in the Sierra Vista sub-basin results in all recharge going into the regional aquifer.

USF200010347

Recharges from non-mining industries in the Benson sub-basin take place only at Apache Nitrogen Products. Investigations at this federal "Superfund" site suggest that the plant recharge penetrates upper deposits of the regional aquifer (ADWR, 1991:354-356; Hargis+Associates, 1991). These deposits are perched on a relatively impermeable clay formation (Gray, 1965). The perched groundwater flows primarily eastward and eventually discharges into adjacent portions of the floodplain aquifer (Hargis+Associates, 1991). However, initial recharge is into the regional aquifer and is so modeled in WATERBUD. ADWR (1991:F15) estimates that roughly 30% (0.30) of the water used at the facility eventually recharges; this estimate is the recommended default value for non-mining industrial recharge in the Benson sub-basin.

Row 162: Projected Annual Rate of Growth of Mining Consumption

(See explanation for Row 163, below.)

Row 163: Projected Annual Rate of Growth of Other Industrial Consumption

The consumption of water by mining and other industries in the upper basin will change if these industries experience either growth or decline during the twenty-year period of projection. Rows 162 and 163 provide parameters for specifying a projected rate of growth (+) or decline (-) for the two classes of industry. The values for these parameters are held constant for the entire period of projection and are applied to both sub-basins. In the absence of a major change in the economy of the upper basin, the recommended default values for these parameters are both set to 0.00.

USF200010348

3.10 RESERVOIRS AND STOCKPONDS

The Upper San Pedro Basin presently contains numerous water impoundments, mostly stockponds for livestock. The impoundments are supplied by runoff or groundwater. Rows 166-171 provide parameters for modeling the consumption of water at these impoundments. Direct consumption by livestock is minimal (ADWR, 1991:C90; Putnam *et al.*, 1987:69); consumption results entirely from evaporation. Rows 166-171 concern impoundments other than the one proposed for the San Pedro River itself, discussed for Row 66, above.

Row 166: 1990 Surface Area of Runoff-Supplied Impoundments in Sierra Vista Sub-basin

(See explanation for Row 167, below.)

Row 167: 1990 Surface Area of Runoff-Supplied Impoundments in Benson Sub-basin

(See explanation for Row 169, below.)

Row 168: 1990 Surface Area of Groundwater-Supplied Impoundments in Sierra Vista Sub-basin

(See explanation for Row 169, below.)

Row 169: 1990 Surface Area of Groundwater-Supplied Impoundments in Benson Sub-basin

ADWR (1991:F12-F14) provides data on the surface areas of impoundments in the upper basin and on the source (surface or groundwater) of the supply to these structures.

USF200010349

These data indicate a total of 611.2 acres of impoundments supplied by surface water and 25.9 acres supplied by groundwater in the Sierra Vista sub-basin; 341.0 acres supplied by surface water and 108.8 acres supplied by groundwater in the Benson sub-basin. These estimates provide the recommended default values for Rows 166-169 in WATERBUD.

Row 170: Water Retention Rate for Runoff-Supplied Impoundments

(See explanation for Row 171, below.)

Row 171: Water Retention Rate for Groundwater-Supplied Impoundments

ADWR (1991:F12-F14) recommends using a "retention factor" to estimate the percentage of water retained in impoundments and subject to evaporation. Impoundments are assumed to be filled to capacity only rarely and to lose water to both seepage and evaporation. Water seeping out of the impoundments is assumed to return to the groundwater system. Stockponds make up the majority of impoundments supplied by surface water and ADWR (1991:F12) suggests using a retention factor of 0.6 for such impoundments. Most reservoirs are supplied by groundwater although in the Sierra Vista sub-basin more are supplied by surface water than by groundwater. ADWR (1991:F14) suggests using a retention factor of 0.56 for reservoirs in general. WATERBUD uses a retention factor value of 0.6 as the default for impoundments supplied by surface water and a value of 0.56 as the default for those supplied by groundwater.

3.11 OPTIONS

WATERBUD provides several "switches," each activating a specific option for modeling the hydrologic system. These options cover alternative possibilities for the

USF200010350

system that cannot be handled simply by assigning alternative parameter values. Most of these options concern the effects of alternative management policies.

Row 174: Include Riparian Salvage Acres in Total Initial Riparian Acreage?

Many acres of land were cleared of riparian vegetation for the development of agriculture in the upper basin, as discussed above. Two circumstances exist, in which it is useful to model the total system by subtracting this acreage from the total for agricultural lands and adding it back into the total for riparian vegetation. First, it is useful to model the system as it would behave in the absence of human activities (see Row 175, below). Second, it is useful to consider how the system would behave if all salvageable acres were restored to riparian conditions. This option and all other options involving a "yes" or "no" answer use the code, 1, for "yes" and the code, 0, for "no."

Row 175: Model System Without Human Depletions?

It is useful to be able to model the hydrologic system of the upper basin as it would behave in the absence of human activities, as noted above. Simulations of the pre-development system can be compared to other estimates of pre-development conditions (e.g., ADWR, 1991:259-261; Vionnet, 1991). Activating this option "turns off" all human depletions in the calculation of the sub-basin water budgets. The option is coded yes/no.

Row 176: Impose Domestic Conservation? (Choose Option 0, 1, 2, or 3)

The parameters in WATERBUD allow for the modeling of four domestic conservation policies (see above). Option 0 specifies that no conservation measures will be encouraged or enforced. Option 1 models the effects of reducing domestic

USF200010351

consumption by a fixed percent of current rates. Option 2 models the effects of the installation of low-flow plumbing fixtures. Option 3 models the effects of imposing a fixed limit on the rate of consumption in gallons per capita per day (gpcd). Each option is activated by specifying its designated number code. Note that the effects of a surcharge on delivered water (Row 96) are not activated by this option. They are activated solely by specifying values in Row 96 other than 0.

Row 177: Include Fort Huachuca in Conservation Efforts?

The Fort Huachuca Military Reservation presently is not participating in the public discourse within the upper basin over ways to manage the region's water resources. Yet it is conceivable that the Fort may eventually choose to participate in the management of these resources. Row 177 provides a means for modeling the effects to the hydrologic system that would arise if the Fort implemented the same water conservation policies that can be modeled for the rest of the upper basin, as specified in Row 176, above. The option is coded yes/no.

Row 178: Impose Target Crop Irrigation Requirements?

Conservation in the agricultural sector can be achieved by requiring irrigators to shift to crops with lower irrigation requirements. Row 178 provides the means for modeling the effects of a policy that imposes upper limits on crop irrigation requirements. The option is coded yes/no and can be activated at the same time as Row 179, below.

Row 179: Impose Target Irrigation Efficiencies?

Conservation in the agricultural sector also can be achieved by requiring irrigators to shift to irrigation practices with higher average efficiencies. Row 180 provides the

USF200010352

means for modeling a policy that imposes upper limits on irrigation efficiency. The option is coded yes/no and can be active at the same time as Row 178, above.

Row 180: Impose Pumping Tax on Irrigation Use of Groundwater?

Finally, conservation in the agricultural sector can be achieved by imposing a surcharge on the pumping of groundwater, as discussed above. Row 180 provides the means for modeling the effects on irrigated agriculture of a policy that imposes a fixed surcharge on groundwater withdrawals across the entire upper basin. The option is coded yes/no. If it is activated at the same time as Rows 178 or 179, above, the projective equations give precedence to the value of Row 180 for setting irrigation consumption rates (see Chapter 4).

USF200010353

Chapter 4
Projection Equations for the Model

The second section of WATERBUD, the projections section, contains over 160 equations, beginning in Row 200 of the spreadsheet with the title, TWENTY-YEAR PROJECTION OF WATER BALANCE AND SOCIOECONOMIC CONDITIONS. The equations continue through Row 386. They are used first to develop a detailed description of conditions in 1990, referred to as the "initialization year." The equations are then used to project conditions in twenty succeeding years, labeled as "projection years" 1991-2010. There are ten sets of equations, generating projections for the following groups of variables: I, Socioeconomic Conditions; II, Gross Hydrological and Ecological Status Indicators; III, Inflows to the Sierra Vista Sub-basin; IV, Sierra Vista Sub-basin Losses to Storage; V, Sierra Vista Sub-basin Recharge and Returns to Storage; VI, Inflows to Benson Sub-basin; VII, Benson Sub-basin Losses to Storage; VIII, Benson Sub-basin Recharge and Returns to Storage; IX, Seasonal and Annual Hydrological Changes; and X, Net Socioeconomic Changes.

This chapter describes and explains the construction of each projection equation, by row number. Appendix C contains a full listing of the worksheet equations for the initialization year and the first projection year. For each row in the spreadsheet, Column A provides the equation title and Column B lists the unit of measurement for the equation result. Column C summarizes the starting value for each row at the beginning of 1990, labeled for convenience as its "1989 end-of-year" value. The values in Column C simply summarize information from the Parameters section of the spreadsheet. Column D and every sixth column thereafter is left blank to separate each set of annual projections. Each

USF200010355

set of annual projections consists of five columns. The pattern begins with Columns E-I, covering the projections for 1990: The first four columns (Columns E-H, for example, for 1990) present the projections for each of the four seasons of the year. The fifth column (Column I, for 1990) summarizes the conditions projected for the end of that year.

Rows 400-575 repeat the results of the annual projections without the seasonal projections under the heading, ANNUAL SUMMARY OF TWENTY-YEAR PROJECTION OF WATER BALANCE AND SOCIOECONOMIC CONDITIONS. These rows are provided simply as a convenience, to simplify the process of producing graphical output from the spreadsheet results. Users of the model who do not need separate annual summaries of the results can delete these rows from the spreadsheet without affecting any of the calculations.

4.1 SOCIOECONOMIC CONDITIONS

This subsection contains only five equations, but these five are repeated for each of the census areas. The five equations provide projections of population size, median household income, change in household consumer surplus and a related factor labeled "Net Difference in Demand," and the fraction of households equipped with low-flow plumbing. The results of these equations are tabulated on an annual basis only; no seasonal values are given. The "Net Difference in Demand" equation merely provides an intermediate calculation necessary for the projection of household consumer surplus loss and median household income, and so is not given its own rows in the spreadsheet; it appears in the third column of each set of annual projections.

USF200010356

Rows 204-217: Population Projections

Rows 204-217 project the populations for each of the fourteen census areas listed in the Parameters section of the model, under the labels: Population of City of Sierra Vista; Population of Sierra Vista-Southeast Suburban Area; Population of Fort Huachuca; Population of Huachuca City; Population of City of Tombstone; Population of City of Bisbee; Population of Town of Naco; Population of Water Service Areas of Rural Sierra Vista Sub-basin; Population of Non-Service Areas of Rural Sierra Vista Sub-basin; Population of City of Benson; Population of Town of St. David; Population of Town of Pomerene; Population of Water Service Areas of Rural Benson Sub-basin; and Population of Non-Water Service Areas of Rural Benson Sub-basin.

The annual projections for each of these census areas except Fort Huachuca are carried out using the standard demographic equation:

$$N_t = N_{t-1}(1 + r)$$

Where N_t = the population at the end of year t, N_{t-1} = the population at the end of the preceding year, and r = the annual per capita rate of population change. The populations at the start of the simulation are taken from Row 82; the annual per capita rates of population change are taken from Row 83.

Population change at Fort Huachuca is handled as described in Chapter 3 (see Rows 107-110). The model allows the simulation of a single episode of expansion or reduction of staffing at the Fort. The residential population of the City of Sierra Vista is affected by any such change in staffing at the Fort, as described in Chapter 3. The normal demographic equation is not applied to that portion of the population of the City of Sierra Vista that may "arrive" with any increase in staffing at the Fort.

USF200010357

Rows 218-231: Median Household Income Projections

Rows 218-231 project the median household incomes for each of the fourteen census areas in the model, under the following labels: Median Household Income, City of Sierra Vista; Median Household Income, Sierra Vista-Southeast Suburban Area; Median Household Income, Fort Huachuca; Median Household Income, Huachuca City; Median Household Income, City of Tombstone; Median Household Income, City of Bisbee; Median Household Income, Town of Naco; Median Household Income, Rural Water Service Areas, Sierra Vista Sub-basin; Median Household Income, Rural Non-Service Areas Sierra Vista Sub-basin; Median Household Income, City of Benson; Median Household Income, Town of St. David; Median Household Income, Town of Pomerene; Median Household Income, Rural Water Service Areas, Benson Sub-basin; and Median Household Income, Rural Non-Service Areas, Benson Sub-basin.

The estimates of median household income appear in the model for two reasons. First, changes in their values provide insight into projected economic conditions in the basin, as these may be affected by water management policies. Second, the estimates are necessary in order to generate projections of municipal water demand, as this demand is affected by changes in water pricing.

U.S. census estimates of median household income for 1990 were not available at the time this model was developed. Aljamal (1991a) used estimates from the 1980 U.S. census reported by the Arizona Department of Economic Security to develop price-demand equations for municipal water demand (see below). These 1980 figures are used to initialize Rows 218-231, in Columns C and I.

USF200010358

The model estimates median household income for the end of each year by adding the household consumer surplus loss estimated for that year (Rows 232-242) to the median household income estimated for the end of the preceding year. Thus,

$$M_t = M_{t-1} + S_{c,t}$$

where M_t = median household income at the end of year t, M_{t-1} = median household income at the end of the preceding year $t-1$, and $S_{c,t}$ = household consumer surplus loss for the year t. The spreadsheet equations also contain an IF statement, that sets the estimated value to 0 when Row 175=1, i.e., when the hydrologic system is to be modeled without human depletion.

Fort Huachuca water usage is not affected by household incomes among the Fort's residents, and household incomes at the Fort are affected more by national Department of Defense policies than by local economic conditions. For these reasons, median household income for residents of the Fort is listed simply as "not applicable" (N/A) in the model.

Rows 232-242: Household Consumer Surplus Loss Projections

Rows 232-242 project the household consumer surplus loss for the ten census areas in the model, within which demand for water is affected by a delivery price, under the following labels: Household Consumer Surplus Loss, City of Sierra Vista; Household Consumer Surplus Loss, Sierra Vista-Southeast Suburban Area; Household Consumer Surplus Loss, Huachuca City; Household Consumer Surplus Loss, City of Tombstone; Household Consumer Surplus Loss, City of Bisbee; Household Consumer Surplus Loss, Town of Naco; Household Consumer Surplus Loss, Rural Water Service Areas, Sierra Vista Sub-basin; Household Consumer Surplus Loss, City of Benson; Household Consumer Surplus Loss, Town of St. David; Household Consumer Surplus Loss, Town of

USF200010359

Pomerene; and Household Consumer Surplus Loss, Rural Water Service Areas, Benson Sub-basin.

"Consumer surplus loss" is the added cost expended by consumers as a result of their being required to pay a higher price for a consumer good than they would ordinarily be willing to pay (Shaffer, 1976). For example, if a surcharge were added to the price per 1000 gallons of delivered water, consumers would use less water in response to the higher price and also pay slightly more for their monthly water usage. The total loss to income summed over each unit of water foregone in response to the raised cost is expressed as a consumer surplus loss by the equation (Shaffer, 1976:67):

$$L_c = \int_{q=q_o}^{q_n} (a^{\frac{1}{e}} \times q^{\frac{-1}{e}} - p_n) dq$$

where q = quantity of water demanded, q_n = the quantity of water that would have been demanded (potential demand) at the original price p_n, q_o = the quantity of water demanded at the higher price p_o, a = the calibration constant in the price-demand equation (see explanation for Row 101, Chapter 3, above), and e = the absolute value of the price elasticity of demand (see Row 101, Chapter 3, above).

The solution to this integral equation for cases with $e \neq 1$ is (Shaffer, 1976:68):

$$L_c = p_n q_n \left\{ \frac{e}{e-1} \left(1 - (1-x)^{\frac{e-1}{e}} \right) - x \right\}$$

where x is the difference between potential and actual demand expressed as a fraction of potential demand,

$$x = \frac{q_n - q_o}{q_n}$$

and all other variables are as stated above.

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The model computes x separately under the label, Net Difference in Demand, as follows: q_n is computed with the price-demand equation described in Chapter 3 (Row 101), using the price that consumers would be charged in the absence of any surcharge on delivered water (Row 95). q_o also is computed with the price-demand equation described in Chapter 3 (Row 101), but using a price that includes any surcharge on delivered water specified by Row 96. The method of calculation for the price-demand equation is described further, for Rows 280-288 and Rows 331-335, below. The model computes x for each year, t, using the equivalent expression,

$$x_t = 1 - \frac{q_{o,t}}{q_{n,t}}.$$

The value of L_c is then computed using the result for x_t. The equations for L_c again include an IF statement, that sets the estimated value to 0 when Row 175 = 1.

Rows 243-254: Projected Fractions of Households with Low-Flow Plumbing

Rows 243-254 project the fraction of households equipped with low-flow plumbing fixtures in the fourteen census areas of the model, but combining all rural households in each sub-basin into a single category. The resulting twelve equations are: Fraction of Households with Low-Flow Plumbing, City of Sierra Vista; Fraction of Households with Low-Flow Plumbing, Sierra Vista-Southeast Suburban Area; Fraction of Households with Low-Flow Plumbing, Fort Huachuca; Fraction of Households with Low-Flow Plumbing, Huachuca City; Fraction of Households with Low-Flow Plumbing, City of Tombstone; Fraction of Households with Low-Flow Plumbing, City of Bisbee; Fraction of Households with Low-Flow Plumbing, Town of Naco; Fraction of Households with Low-Flow Plumbing, Rural Sierra Vista Sub-basin; Fraction of Households with Low-Flow Plumbing, City of Benson; Fraction of Households with Low-Flow Plumbing, Town of

USF200010361

St. David; Fraction of Households with Low-Flow Plumbing, Town of Pomerene; and Fraction of Households with Low-Flow Plumbing, Rural Benson Sub-basin.

The fraction of households equipped with low-flow plumbing fixtures is estimated by the equation,

$$F_t = \frac{F_{t-1}H_{t-1} + E_n + E_r}{H_t}$$

where F_{t-1} and F_t = fraction of households in a census area equipped with low-flow fixtures at the end of years $t-1$ and t, respectively; H_{t-1} and H_t = number of households present in the census area at the end of years $t-1$ and t, respectively; E_n = the number of new households added to the census area during year t, assuming that all new construction is equipped with low-flow plumbing; and E_r = the number of older households refitted with flow-flow plumbing during year t, that were not refitted in any previous year.

The values for H_{t-1}, H_t, E_n, and E_r in practice are computed by dividing a population figure by a ratio, (Row 85/Row 82), that gives the average number of persons per household for each census area. However, this ratio appears in all terms of both the numerator and the denominator of the equation for F_t, and so cancels out. The actual equation used therefore is,

$$F_t = \frac{F_{t-1}N_{t-1} + P_n + P_r}{N_t}$$

where N_{t-1} and N_t = number of people present in the census area at the end of years $t-1$ and t, respectively; P_n = the number of new people added to the census area during year t, assuming that all occupy new construction and that the new construction is equipped with low-flow plumbing; and P_r = the number of people living in older households that become refitted with low-flow plumbing during year t, that were not refitted in any

USF200010362

previous year. The value of P_n is computed as the difference between N_{t-1} and N_t. The value of P_r is computed using the equation,

$$P_r = (1 - F_{t-1}) R_r N_{t-1}$$

where R_r = the annual refitting rate for older structures given in Row 93 (Chapter 3).

The equations in Rows 243-254 contain two additional elements. First, the equations again contain an IF statement that sets the estimated value to 0 when Row 175=1. Second, the equations contain an IF statement to handle circumstances, in which population growth in a census area is negative (declining) and in which the rate of population decline is greater than the annual refitting rate for older structures. Under these circumstances, the value of F_t could become negative, creating computational problems within the spreadsheet. The second IF statement simply specifies that, when the rate of population growth is negative, the value of P_n is set to 0 and therefore is not included in the calculations.

4.2 GROSS HYDROLOGICAL AND ECOLOGICAL STATUS INDICATORS

The equations in this section calculate a series of gross indicators of hydrologic and ecological conditions in the basin for each projected season and each projection year.

Row 257. Storage in Floodplain Aquifer, Sierra Vista Sub-basin

The total storage of water in the floodplain aquifer is computed in acre-feet as the storage at the start of a period plus all inflows minus all outflows during the current period, as follows,

$$V_{257,t} = V_{257,t-1} + V_{274,t} + V_{276,t} + V_{307,t} + V_{317,t} + V_{321,t} - V_{289,t} - V_{294,t} - V_{296,t} - V_{298,t} - V_{300,t} - V_{303,t}$$

where $V_{257,t}$ = total storage at the end of the current season, t ; $V_{257,t-1}$ = total storage at the end of the immediately preceding season, $t-1$; $V_{274,t}$ = underflow from the floodplain

USF200010363

aquifer in Mexico (Row 274) during the current season; $V_{276,t}$ = any artificial recharge of imported water (Row 276) during the current season; $V_{307,t}$ = natural recharge from the regional aquifer (Row 307) during the current season; $V_{317,t}$ = recharge of irrigation return flows (Row 317) during the current season; $V_{321,t}$ = recharge from any on-river impoundments (Row 321) during the current season; $V_{289,t}$ = withdrawals for irrigation (Row 289) during the current season; $V_{294,t}$ = consumption by phreatophytes (Row 294) during the current season; $V_{296,t}$ = any withdrawals by the BLM from its wells within the SPRNCA to supplement in-stream flows (Row 296) during the current season; $V_{298,t}$ = any withdrawals for export from the aquifer (Row 298) during the current season; $V_{300,t}$ = underflow to the floodplain aquifer in the next down-gradient sub-basin (Row 300) during the current season; and $V_{303,t}$ = discharge from the aquifer to the river (Row 303) during the current season. All units are in acre-feet.

The formulas for Row 257 also include an "error trapping" function, that prevents the values in this row from varying too widely during the course of iterative calculations by the program. Because of the manner by which spreadsheet programs carry out iterative calculations, small adjustments for an early projected year in WATERBUD can result immediately in large changes in the values of cells for the latest projected years. These effects are gradually eliminated as the program carries out its iterative calculations, so that even the values in the latest years converge on correct projections. However, during the internal process of iteration, the cumulative fluctuations can be quite large. Several equations in WATERBUD do not operate correctly, when provided with extremely large or small or even negative values as input, during the process of iteration. As a result, it is necessary to provide some equations with functions that prevent its values from going too far outside of the appropriate range for calculation. The estimates of storage in the floodplain aquifer (Rows 257 and 259) proved extremely sensitive to fluctuations during

USF200010364

the process of iteration. Both therefore were provided with functions, that prevent them from fluctuating over a range greater than $\pm 5\%$ of the value estimated for the immediately preceding year. This inclusion prevents most errors that might arise due to iterative fluctuations, and also speeds up the process of iteration (see also Appendix A).

The value of 5% was selected based on an analysis of an initial simulation of Scenario D under Policy 1 (see Chapters 1 and 5). Among all simulations carried out during the research reported here, this combination of a scenario and a policy produced the greatest year-to-year changes in storage in the floodplain aquifer. The largest year-to-year changes observed were 0.4% for the Sierra Vista sub-basin and 3.2% for the Benson sub-basin. These changes took place between the initialization year and the first year of projection, and represent simply the initial equilibration of the model to the simulated drought conditions. Year-to-year changes in the Sierra Vista sub-basin thereafter ranged between 0.0 and 0.1%, and in the Benson sub-basin between 0.2 and 0.6%. The value of 5% was selected to allow for a much greater range of variation than observed in either sub-basin while still having the desired error trapping effect.

Row 258: Storage in Regional Aquifer, Sierra Vista Sub-basin

The total storage of water in the regional aquifer also is computed in acre-feet as the storage at the start of a period plus all inflows minus all outflows during the current period, as follows,

$$V_{258,t} = V_{258,t-1} + V_{275,t} + V_{277,t} + V_{(308:316),t} + V_{318,t} + V_{319,t} - V_{(280:288),t} - V_{290,t} - V_{291,t} - V_{293,t} - V_{297,t} - V_{299,t} - V_{301,t} - V_{307,t}$$

where $V_{258,t}$ = total storage at the end of the current season, t ; $V_{258,t-1}$ = total storage at the end of the immediately preceding season, $t-1$; $V_{275,t}$ = sum of mountain front recharge and underflow from the regional aquifer in Mexico (Row 275) during the current season; $V_{277,t}$ = artificial recharge of imported water (Row 277) during the current season;

USF200010365

$V_{(308:316),t}$ = recharges of treated effluent from municipal and domestic activities in the nine census areas within the sub-basin (Rows 308-316) during the current season; $V_{318,t}$ = recharge of return flows from mining industries (Row 318) during the current season; $V_{319,t}$ = recharge of return flows from other industries (Row 319) during the current season; $V_{(280:288),t}$ = withdrawals for municipal and domestic activities in the nine census areas within the sub-basin (Rows 280-288) during the current season; $V_{290,t}$ = withdrawals for mining uses (Row 290) during the current season; $V_{291,t}$ = withdrawals for other industrial uses (Row 291) during the current season; $V_{293,t}$ = losses due to evaporation from groundwater-supplied stockponds and reservoirs (Row 293) during the current season; $V_{297,t}$ = any withdrawals by the BLM from its wells within the SPRNCA to supplement in-stream flows (Row 297) during the current season; $V_{299,t}$ = any withdrawals for export from the aquifer (Row 299) during the current season; $V_{301,t}$ = underflow to the regional aquifer in the next down-gradient sub-basin (Row 301) during the current season; and $V_{307,t}$ = discharge from the regional aquifer to the floodplain aquifer (Row 307) during the current season.

Row 259: Storage in Floodplain Aquifer, Benson Sub-basin

The equations in this row are analogous to those in Row 257, but for the Benson sub-basin. The equations have the form,

$$V_{259,t} = V_{259,t-1} + V_{325,t} + V_{327,t} + V_{356,t} + V_{362,t} - V_{338,t} - V_{343,t} - V_{345,t} - V_{347,t} - V_{349,t} - V_{352,t}$$

where $V_{259,t}$ = total storage at the end of the current season, t ; $V_{259,t-1}$ = total storage at the end of the immediately preceding season, $t-1$; $V_{325,t}$ = underflow from the floodplain aquifer in the Sierra Vista sub-basin (Row 325) during the current season; $V_{327,t}$ = any artificial recharge of imported water (Row 327) during the current season; $V_{356,t}$ = natural recharge from the regional aquifer (Row 356) during the current season; $V_{362,t}$ = recharge

USF200010366

of irrigation return flows (Row 362) during the current season; $V_{338,t}$ = withdrawals for irrigation (Row 338) during the current season; $V_{343,t}$ = consumption by phreatophytes (Row 343) during the current season; $V_{345,t}$ = any withdrawals by the BLM from its wells within the SPRNCA to supplement in-stream flows (Row 345) during the current season; $V_{347,t}$ = any withdrawals for export from the aquifer (Row 347) during the current season; $V_{349,t}$ = underflow to the floodplain aquifer in the next down-gradient sub-basin (Row 349) during the current season; and $V_{352,t}$ = discharge from the aquifer to the river (Row 352) during the current season. The equations in this row use the same error trapping function described above for Row 257.

Row 260: Storage in Regional Aquifer, Benson Sub-basin

The equations in this row are analogous to those in Row 258, but for the Benson sub-basin. The equations have the form,

$$V_{260,t} = V_{260,t-1} + V_{326,t} + V_{328,t} + V_{(357:361),t} + V_{363,t} + V_{364,t} - V_{(331:335),t} - V_{339,t} - V_{340,t} - V_{342,t} - V_{346,t} - V_{348,t} - V_{350,t} - V_{356,t}$$

where $V_{260,t}$ = total storage at the end of the current season, t ; $V_{260,t-1}$ = total storage at the end of the immediately preceding season, $t-1$; $V_{326,t}$ = sum of mountain front recharge and underflow from the regional aquifer in the Sierra Vista sub-basin (Row 326) during the current season; $V_{328,t}$ = artificial recharge of imported water (Row 328) during the current season; $V_{(357:361),t}$ = recharges of treated effluent from municipal and domestic activities in the five census areas within the sub-basin (Rows 357-361) during the current season; $V_{363,t}$ = recharge of return flows from mining industries (Row 363) during the current season; $V_{364,t}$ = recharge of return flows from other industries (Row 364) during the current season; $V_{(331:335),t}$ = withdrawals for municipal and domestic activities in the five census areas within the sub-basin (Rows 331-335) during the current season; $V_{339,t}$ = withdrawals for mining uses (Row 339) during the current season; $V_{340,t}$ = withdrawals

USF200010367

for other industrial uses (Row 340) during the current season; $V_{342,t}$ = losses due to evaporation from groundwater-supplied stockponds and reservoirs (Row 342) during the current season; $V_{346,t}$ = any withdrawals by the BLM from its wells within the SPRNCA to supplement in-stream flows (Row 346) during the current season; $V_{348,t}$ = any withdrawals for export from the aquifer (Row 348) during the current season; $V_{350,t}$ = underflow to the regional aquifer in the next down-gradient sub-basin (Row 350) during the current season; and $V_{356,t}$ = discharge from the regional aquifer to the floodplain aquifer (Row 356) during the current season.

Rows 261-262: Potential Areas of Riparian Vegetation in the Sierra Vista and Benson Sub-basins

The equations in these two rows provide estimates of the area likely to be occupied by riparian vegetation in each sub-basin. The results are tabulated on an annual basis only; no seasonal values are given.

The viability of riparian vegetation depends on the availability of water both to sustain the vegetation during the growing season and to disperse and encourage the germination of seeds. As discussed for Rows 146-147 in Chapter 3, the annual discharge of the stream through a riparian corridor provides one indicator of the likely viability of the riparian corridor itself. WATERBUD is written to use estimates of stream discharge as a basis for modeling the area likely to be occupied by riparian vegetation in each sub-basin. As also discussed for Rows 146-147, above, the model actually uses an equation that predicts the relative change in riparian corridor width likely to occur for a given relative change in stream discharge. The model takes the conditions recorded for 1990 (ADWR, 1991) and estimates the changes likely to take place from this starting point.

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The equations in Rows 261-262 also take two additional factors into account, in estimating the area likely to be occupied by riparian vegetation in each sub-basin. First, human activities may either destroy riparian vegetation or prevent it from expanding into new areas, and so prevent it from occupying all of the area for which it is potentially suited under a given set of hydrologic conditions. Rows 142-143 (see above, Chapter 3) record the areas in each sub-basin, from which riparian vegetation had either been removed or suppressed as of 1990. Second, it can take many years for riparian vegetation to expand and mature over its expanded acreage, in response to a given improvement in hydrologic conditions. Similarly, it can take many years for a riparian corridor to lose acreage, in response to a given deterioration in hydrologic conditions. The equations used here take this lagged behavior into account, by assuming that it takes 25 years for riparian acreage to respond completely to a given one-year change in stream discharge. The number, 25, was chosen as a simple expedient based on descriptions (e.g., BLM, 1987; Hereford, 1991) of how riparian vegetation in the upper San Pedro basin has responded to previous changes in stream flow.

It should also be noted that bedrock outcrops and arroyo bluffs may act as barriers to the expansion of riparian vegetation, preventing it from occupying all of the area for which it is potentially suited under a given set of hydrologic conditions. However, there are very few sections of the San Pedro or Babocomari Rivers, along which bedrock outcrops might act as barriers to the spread of riparian vegetation. The model could recognize the limitations posed by the presence of arroyo bluffs, by acknowledging that riparian acreage cannot exceed the total acreage of the floodplain aquifer in each sub-basin. However, the estimates of the acreage likely to be occupied by riparian vegetation in each sub-basin consistently fall far below the known areas of the floodplain in the sub-

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basins. Hence, it was not necessary to specify a maximum acreage limitation in the equations in Rows 261-262.

The equations in Rows 261-262 thus have the form,

$$A_{r,t} = A_{r,t-1}\left(1 + \frac{E_t(\Delta\%F)}{25}\right) + \sum_{i=1}^{t-1}(A_{r,i} - A_{r,i-1}),$$

for $E_t = 10^{(a\sqrt{0.0013813 \times F_{t-1}})} \times 10^b$, $\Delta\%F = \frac{F_t - F_{t-1}}{F_{t-1}}$, and $F = \frac{F_{\text{upstream}} + F_{\text{downstream}}}{2}$

where $A_{r,t}$ = the area in acres likely to be occupied by riparian vegetation at the end year t; $A_{r,t-1}$ = the area in acres likely to be occupied by riparian vegetation at the end year $t-1$; E_t = the percent change in riparian corridor area likely to occur in response to a change of 1 cfs in stream flow, starting from a given specific value of stream flow, with the change in stream flow expressed as a percent change, $\Delta\%F$; a and b = a regression coefficient and constant, respectively, as discussed for Rows 146-147 in Chapter 3, above; F_t and F_{t-1} are the mean stream flow rates (average of the flow rates at the upstream and downstream ends of the river in each sub-basin) in acre-feet/year at the end of years t and $t-1$, respectively; the number 0.0013813 is a conversion factor to change stream flow rates in acre-feet/year to cfs; and the expression,

$$\sum_{i=1}^{t-1}(A_{r,i} - A_{r,i-1})$$

accumulates the annual lagged changes in riparian corridor area resulting from changes in stream flow in previous years.

It should be noted that the period of projection for the model extends for only twenty years while it is assumed to take twenty-five years for riparian acreage to respond completely to a given one-year change in stream discharge. Thus, the model assumes that, over the course of the twenty-year period of projection, the riparian ecosystem in the

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upper basin will not reach equilibrium with any changes in stream discharge that may occur during this period.

Rows 263-264: Average River Stages in Sierra Vista and Benson Sub-basins

The estimates of river stage computed in Rows 263 and 264 play a crucial role in the estimation of the discharge of water from the floodplain aquifer into the river, and hence in the estimation of the river discharge from each sub-basin. The rate and direction of flow of water between the floodplain aquifer and the river depends on the difference in hydraulic head between the aquifer and the river. Further, the hydraulic head in the river depends on the average discharge rate of the river, which in turn depends on the rate and direction of flow of water between the floodplain aquifer and the river. The model therefore must adjust its estimates of river discharge, floodplain aquifer discharge, and river stage by iteration, in order to converge simultaneously on accurate estimates for all three. The iterative adjustment of circular references among equations in spreadsheet programs such as EXCEL® and LOTUS 1-2-3® is made possible by an "Iteration" option in the "Calculation" mode setting.

The model computes the average hydraulic head in the aquifer and the river as elevations relative to the average bottom elevation of the riverbed in each sub-basin. As a result, the computed hydraulic head for the river is equivalent the river stage plus the riverbed thickness, while the computed hydraulic head in the floodplain aquifer (see Rows 267 and 269, below) is equivalent to the difference in elevation between the water table and the bottom of the riverbed. Rows 263 and 264 compute river stage using the equations described for Rows 44-45 in Chapter 3,

$$S_{r,t} = aF_t^b$$

where $S_{r,t}$ = the average river stage at the end of time period t ; F_t = the average of the

USF200010371

flow rates in acre-feet/year at the upstream and downstream ends of the river in each sub-basin at the end of year t (see discussion for Rows 261-262, above); and a and b are constants as described for Rows 44 and 45, above.

The equations in Rows 263-264 also include an IF statement, made necessary by the way in which spreadsheets carry out iterative calculations. It is physically impossible for a river to have a negative discharge rate. However, during the calculation of the rate of flow of water between the floodplain aquifer and the river, it is mathematically possible for the spreadsheet program temporarily to register a negative value for the river discharge rate. When this happens, several equations can become mathematically undefined (e.g., they may require division by 0 or the raising of a negative number to some exponent). The IF statement in Rows 263-264 prevents such an occurrence by specifying that, if the spreadsheet program temporarily registers a negative value for river discharge, the estimate of stage is temporarily assigned a value of 10^{-15}. This expedient allows the program to continue iterating, to arrive at a final estimate of the average stage.

Rows 265-266: Average River-Aquifer Head Differences, Sierra Vista and Benson Sub-basins

The rate and direction of flow between the floodplain aquifer and the river depends on the difference in hydraulic head between the aquifer and the river, as stated above. Because of their pivotal role in describing the behavior of the hydrologic system, the equations for computing the difference in hydraulic head between the floodplain aquifer and the river are presented separately in the model, in Rows 265-266.

The modeling of flow between the floodplain aquifer and the river follows the same approach used by Prudic (1989) to simulate stream-aquifer interactions with MODFLOW, the U.S.G.S. finite-difference ground-water flow model (McDonald and

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Harbaugh, 1988). In this approach, a stream is modeled as occupying a channel that is separated from the underlying alluvial aquifer by a riverbed of known area, thickness, and hydraulic conductivity. Four variables are then needed, to describe the difference in hydraulic head between the stream and the aquifer. These four variables and their relationships to each other are illustrated in Figure 4.1; they consist of the elevation of the stream stage, h_{riv}; the elevation of the top of the riverbed, R_{top}; the elevation of the bottom of the riverbed, R_{bot}; and the elevation of the aquifer water table, h_{aq}. Note that stream stage $= h_{riv} - R_{top}$. When $h_{riv} = R_{top}$, no water is present in the stream; h_{riv} cannot be less than R_{top}.

If $h_{riv} > R_{top}$ and $h_{aq} > h_{riv}$, water will discharge from the aquifer into the stream, at a rate determined by the difference between h_{aq} and h_{riv}. If $h_{riv} = R_{top}$ and $h_{aq} > R_{top}$, water will also discharge from the aquifer into the stream channel, at a rate determined by the difference between h_{aq} and R_{top}. If $h_{riv} > R_{top}$ and $R_{bot} < h_{aq} < h_{riv}$, water will discharge from the river into the aquifer, at a rate determined by the difference between h_{riv} and h_{aq}. If $h_{riv} > R_{top}$ but $h_{aq} < R_{bot}$, water will discharge from the river into the aquifer but at a rate determined only by the difference between h_{riv} and R_{bot}. Finally, if $h_{riv} = R_{top}$ and $h_{aq} < R_{bot}$, or if $h_{riv} = h_{aq}$, no water will flow in either direction.

The head difference between the river and the aquifer, ΔH, therefore can be defined as follows. If $h_{riv} > R_{top}$ and $h_{aq} > R_{bot}$, then $\Delta H = h_{riv} - h_{aq}$. If $h_{riv} > R_{top}$ and $h_{aq} \leq R_{bot}$, then $\Delta H = h_{riv} - R_{bot}$. If $h_{riv} = R_{top}$ and $h_{aq} > R_{top}$, then $\Delta H = R_{top} - h_{aq}$. If $h_{riv} = R_{top}$ and $h_{aq} \leq R_{top}$, then $\Delta H = 0$. As noted above, the model actually computes the hydraulic heads in the aquifer and the river as elevations relative to the bottom elevation of the riverbed in each sub-basin. As a result, R_{top} is equivalent to the riverbed thickness and the above expressions reduce to the following: If $h_{riv} > R_{top}$ and $h_{aq} > 0$, then $\Delta H = h_{riv} - h_{aq}$. If $h_{riv} > R_{top}$ and $h_{aq} \leq 0$, then $\Delta H = h_{riv}$. If $h_{riv} = R_{top}$ and $h_{aq} > R_{top}$, then

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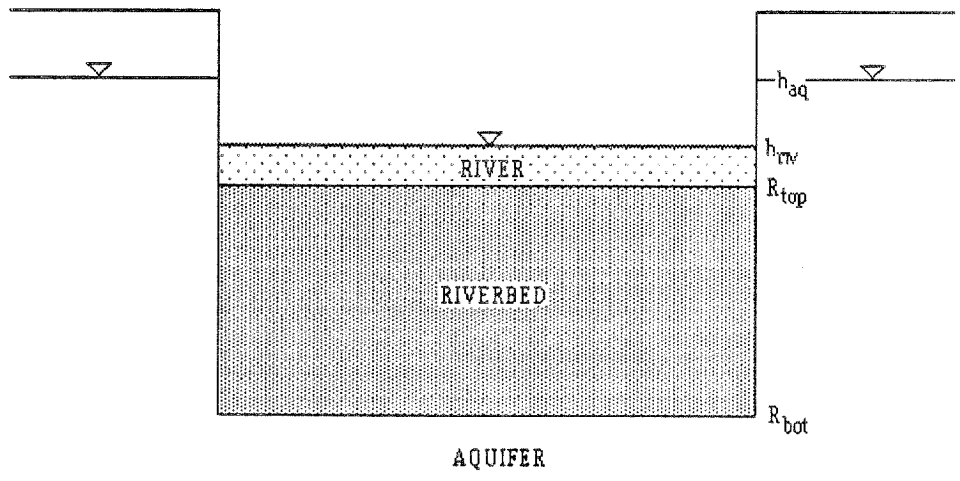
$\Delta H = R_{top} - h_{aq}$. If $h_{riv} = R_{top}$ and $h_{aq} \leq R_{top}$, then $\Delta H = 0$. Note that if $\Delta H > 0$, flow is from the stream to the aquifer; if $\Delta H < 0$, flow is from the aquifer to the stream; and if $\Delta H = 0$, no flow takes place.

Schematic Diagram of River-Riverbed-Aquifer Head Relationships
Figure 4-1



Rows 265-266 express this set of conditions in a single IF/THEN/ELSE statement for each sub-basin. The value of h_{riv} is represented by the river stage (Rows 263 and 264) for the current season minus the thickness of the riverbed (Row 43). The value of h_{aq} is represented by the sum of three elements: (1) the elevation of the aquifer water table relative to the top of the riverbed in the preceding season (Rows 267 and 269); (2) the thickness of the riverbed (Row 43); and (3) the change in elevation of the aquifer water table between the preceding and current seasons (Rows 372 and 374). The value of R_{top} is represented by the thickness of the riverbed (Row 43) and R_{bot} has the constant value, 0.

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Row 267: Period-End Elevation of Floodplain Aquifer Water Table Above Riverbed, Sierra Vista Sub-basin

The estimate of the elevation of the floodplain aquifer water table computed in Row 267 (see also Row 269, below) also plays a crucial role in the estimation of the discharge of water from the floodplain aquifer into the river, and hence in the estimation of the river discharge from each sub-basin. As noted above for Rows 263 and 264, the rate and direction of flow of water between the floodplain aquifer and the river depends on the difference in hydraulic head between the aquifer and the river. The model adjusts its estimates of river stage, river discharge, floodplain aquifer head, and floodplain aquifer discharge by iteration, in order to converge simultaneously on accurate estimates for all four. Row 267 stores the results of the iterative estimation of hydraulic head in the floodplain aquifer.

The model computes the average hydraulic head in the aquifer as an elevation relative to the average bottom elevation of the riverbed in each sub-basin, as noted above. As a result, the computed hydraulic head in the floodplain aquifer is equivalent to the difference in elevation between the water table and the bottom of the riverbed. The hydraulic head at the end of each projected season as

$$H_t = H_{t-1} + \Delta H_t,$$

where H_t and H_{t-1} are the water table elevation values at the end of seasons t and $t-1$, respectively, and ΔH_t is the change in water table elevation estimated to take place during season t. ΔH_t is computed elsewhere in the model, in Rows 372 and 374 for the two sub-basins, respectively (see below).

The values of H_t under pre-development conditions and at the start of 1990, used to initialize the model's calculations for pre-development conditions and future

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projections, are stored in Rows 39 and 40. As noted in Chapter 3, the values stored in Rows 39 and 40 are generated during calibration of the model. Calibration of these values for predevelopment conditions specifically involves their manual adjustment until the model calculations of river discharge match some independent estimate of pre-development discharges. In turn, calibration of these values for 1990 conditions involves their manual adjustment until the model calculations of river discharge match the reference values given in Row 38 (see above, Chapter 3). The process of model calibration is discussed further in Chapter 5, below.

Row 268: Period-End Elevation of Regional Aquifer Water Table Boundary Above Riverbed, Sierra Vista Sub-basin

Estimates of the elevation of the water table in the regional aquifer along its boundary with the floodplain aquifer (Rows 268 and 270) play a crucial role in the estimation of the discharge of water from the regional aquifer to the floodplain aquifer. The rate and direction of flow of water between the two aquifers depends on the difference in hydraulic head between them. The model therefore also adjusts by iteration its estimates of water table elevations in the floodplain aquifer and along the boundary between the two aquifers, and its estimates of the rate and direction of flow of water between the two aquifers, in order to converge simultaneously on accurate estimates for all three phenomena. Rows 268 and 270 store the results of the iterative estimation of the water table elevation along the boundary between the two aquifers.

Rows 268 and 270 only store their results annually under an assumption that the seasonal changes in water tables in the regional aquifer are too small to affect the overall behavior of the system. The annual equations for these rows have the form,

$$H_t = H_{t-1} + \Delta H_t / 100,$$

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where H_t and H_{t-1} are the water table elevations at the boundary between the two aquifers at the end of years t and $t-1$, respectively, and ΔH_t is the change in average water table elevation for the regional aquifer as a whole estimated to take place during year t. ΔH_t is computed elsewhere in the model, in Rows 373 and 375 for the two sub-basins, respectively (see below).

The values of ΔH_t are actually calculated from the values in Rows 380 and 381. These two rows take into account that a change in the average water table elevation in the regional aquifer in a given year will not result in a change in an identical change in water table elevations along the edges of the aquifer. Pumping in the two sub-basins is not distributed evenly across their entire areas, but is concentrated in a few areas of urban settlement and agricultural development. As discussed by Freethey (1982), Kraeger-Rovey (1987), Vionnet (1991), and ADWR (1991), it can take many decades for the effects of pumping from the regional aquifer in these areas of concentrated activity to result in changes in hydraulic head gradients along the boundary between the regional and floodplain aquifers. In contrast, the floodplain aquifer responds quickly and widely to localized withdrawals; its hydraulic conductivities are one to two orders of magnitude greater than those in the regional aquifer.

The values tabulated in Rows 380 and 381, simulate a 100-year lag period, over which a change in the average water table elevation in the regional aquifer for any single year will cumulatively affect water table elevations along the edges of the aquifer. That is, the model assumes that it will take 100 years for the full effects of any single year of withdrawals from the regional aquifer to reach the boundary between the regional and floodplain aquifers in each sub-basin. The model assumes that the effects accumulate linearly, with 1/100 of each year's effects reaching the boundary in any single subsequent year until the full 100 years has elapsed. The value of 100 years was selected, based on

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more detailed studies of the ground-water flow systems in the basin (Freethey, 1982; Kraeger-Rovey, 1987; Vionnet, 1991; Vionnet and Maddock, 1992; ADWR, 1991). These studies indicate that it can take over 50 years for pumping at wells ten or more miles from the aquifer-aquifer boundary even to begin to affect hydraulic gradients along this boundary. This 50-year figure was arbitrarily doubled for the model, in the absence of any better means for estimating average system lags .

Rows 269 and 270: Period-End Elevations of Floodplain and Regional Aquifer Water Tables Above Riverbed, Benson Sub-basin

(See explanations for Rows 267 and 268, above).

4.3 INFLOWS TO SIERRA VISTA SUB-BASIN

The five rows in this section of the model tabulate the volumes of water flowing into the river and the two aquifers in the Sierra Vista sub-basin from sources outside of the sub-basin. All five rows tabulate their volumes seasonally as well as annually.

Row 273: Natural Inputs to Surface Waters in the Sierra Vista Sub-basin

The natural inputs to surface water in the Sierra Vista sub-basin consist of the river discharge from Mexico plus tributary runoff from precipitation over the sub-basin. The surface flows from Mexico and the tributary runoff are assumed to vary seasonally as simple functions of the amount of precipitation falling in each season. Total seasonal inflow volume, $V_{273,t}$, is then estimated according to the equation,

$$V_{273,t} = f_{p,t}(M + T),$$

where $f_{p,t}$ is the fraction of annual precipitation occurring during season t as specified in Rows 16-19; M is the annual inflow volume from Mexico as specified in Row 5; and T is

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the estimate of annual tributary inflow volume calculated using the Moosburner equation specified by Rows 13 and 20-22.

Row 274: Natural Inputs to the Floodplain Aquifer in the Sierra Vista Sub-basin

The natural inputs to the floodplain aquifer in the Sierra Vista sub-basin consist exclusively of underflow within the floodplain aquifer from the Mexican portions of the aquifer. The model assumes that the rate of underflow does not vary across the four seasons, and so computes the seasonal underflow volume, $V_{274,t}$, for season t, as,

$$V_{274,t} = \tfrac{1}{4} V_6,$$

where V_6 is the total annual volume of underflow specified in Row 6.

Row 275: Natural Inputs to the Regional Aquifer in the Sierra Vista Sub-basin

The natural inputs to the regional aquifer in the Sierra Vista sub-basin consist of underflow within the aquifer from Mexico and mountain front recharge within the sub-basin. The model assumes that the rate of underflow does not vary across the four seasons. The rate of mountain front recharge does vary across the seasons. However, the effects of this seasonal cycle diffuse only very slowly across the entire aquifer, and so the effects of mountain front recharge on the aquifer as a whole can be assumed to be essentially constant across the four seasons. The model therefore computes the seasonal volume coming into the regional aquifer, $V_{275,t}$, for season t, as,

$$V_{275,t} = \tfrac{1}{4}\left(V_7 + R_{28}(1+c)\right),$$

where V_7 is the annual volume of underflow specified in Row 7; R_{28} is the annual volume of natural mountain front recharge specified in Row 28; and c is the fractional increase in mountain front recharge achieved by cloud seeding specified in Row 68. The effects of cloud seeding can be examined only if Row 175 is set to 0 (see above, Chapter 3).

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Row 276: Imported Water Stored in the Floodplain Aquifer in the Sierra Vista Sub-basin

The model is able to examine the effects of the importation of water from outside of the sub-basin. Row 276 provides the necessary calculation for the seasonal inflow of imported water to the floodplain aquifer, $V_{276,t}$, for season t assuming that the imported water arrives at a constant rate across the four seasons, as,

$$V_{276,t} = \tfrac{1}{4} V_{58},$$

where V_{58} is the annual volume of water recharged to the floodplain aquifer from Row 58.

Row 277: Imported Water Stored in the Regional Aquifer in the Sierra Vista Sub-basin

Row 277 provides the necessary calculation for the seasonal recharge of imported water to the regional aquifer, $V_{277,t}$, for season t assuming that the imported water arrives at a constant rate across the four seasons, as,

$$V_{277,t} = \tfrac{1}{4} V_{59},$$

where V_{59} is the annual volume of water recharged to the regional aquifer, from Row 59.

4.4 SIERRA VISTA SUB-BASIN LOSSES TO STORAGE

The fifteen rows in this section of the model tabulate the withdrawal of water from the two aquifers and the river by natural processes and human activities in the sub-basin. All fifteen rows tabulate their results by season as well as by year.

Row 280: City of Sierra Vista Use of Regional Aquifer

The residents and facilities of the City of Sierra Vista consume water pumped exclusively from the regional aquifer (ADWR, 1991). The model allows for the estimation of gross seasonal demand in four ways, as described for Row 176 in Chapter 3.

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The model also allows for the simulation of the hydrologic system in the absence of all human activities including consumption in the City of Sierra Vista, through the activation of Row 175. The equations for Row 280 thus have five parts; only one of these five is active for any single simulation, depending on the settings in Rows 175 and 176. The equations calculate the seasonal volume of demand, $V_{x,t}$, for season t, as follows:

If Row 175 = 1, then $V_{x,t} = 0$.

If Row 175 = 0 and Row 176 = 0, then

$$V_{x,t} = \tfrac{1}{4} V_{72} + 0.0030688 N_{x,t} \frac{C_x}{N_{x,0}} M_{x,t}^{g} \left(a_{o,x} (P_x + \Delta P_x)^{b_o} + a_{i,t,x} (P_x + \Delta P_x)^{b_i} \right)$$

where V_{72} is the annual volume withdrawn by the City of Sierra Vista from its own municipal wells as specified in Row 72, assumed to be withdrawn at a constant rate across the four seasons; 0.0030688 is a constant to convert measurement units from 1000s of gallons to acre-feet; $N_{x,t}$ is the population of census area x during season t (x = City of Sierra Vista, in this instance); the ratio, $\frac{C_x}{N_{x,0}}$ is the ratio of the number of water consumer connections to the total population in census area x, fixed at its 1990 (t =0) value; $M_{x,t}^{g}$ is the median household income estimated for census area x during season t raised to the income elasticity exponent specified in Row 106; $(P_x + \Delta P_x)$ is the sum of the initial service price per 1000 gallons of delivered water as specified in Row 95 and any imposed charges per 1000 gallons as specified in Row 96, in census area x; $a_{o,x}$ and $a_{i,t,x}$ are, respectively, the outdoor demand equation coefficient specified in Row 97 and the indoor demand equation coefficient for season t specified in Row 98, for census area x; and b_o and $b_{i,t}$ are, respectively, the outdoor price elasticity exponent specified in Row 105 and the indoor price elasticity exponent specified in Row 104. The discussion of Row 101 in Chapter 3 explains the structure of this equation further.

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If Row 175 = 0 and Row 176 = 1, then all terms in the RHS of the equation above (for Row 175 = 0 and Row 176 = 0) except the V_{72} term are multiplied by a factor, $(1-\Delta V_x)$, where ΔV_x is the fraction of required conservation for census area x specified in Row 94. The model thus assumes that the pumping carried out by the city from its own municipal wells will not be affected by the conservation efforts.

If Row 175 = 0 and Row 176 = 2, then all terms in the RHS of the equation above (for Row 175 = 0 and Row 176 = 0) except the V_{72} term are multiplied by a factor, $(1-0.125F_{x,t})$, where $F_{x,t}$ is the fraction of households equipped with low-flow plumbing in census area x during season t, as estimated in Row 243-254 as appropriate. The coefficient, 0.125, is used to correct for two additional conditions: (1) the installation of low-flow plumbing affects indoor but not outdoor patterns of water consumption, with indoor consumption constituting 50% of total use; and (2) the maximum reduction in indoor water consumption achievable through the installation of low-flow plumbing is on the order of 25% (Braun, 1990). The value of 0.125 (0.5×0.25) thus expresses an estimate of the extent to which the installation of low-flow plumbing fixtures will reduce overall water consumption.

Finally, if Row 175 = 0 and Row 176 = 3, then $V_{x,t} = \frac{1}{4}V_{72} + 0.00112N_{x,t}G_x f_t$, where G_x is the target water consumption rate in gallons per capita per day for census area x specified in Row 87; 0.00112 is a constant to convert measurement units from gallons per capita per day to acre-feet per year; and f_t is the fraction of domestic and municipal water consumption that takes place in season t. Aljamal (1991a) has estimated the values of f_t to be 0.18, 0.30, 0.29, and 0.23 for Seasons I-IV, respectively.

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Row 281: Sierra Vista-Southeast Suburban Area Use of Regional Aquifer

The residents of the Sierra Vista-Southeast Suburban area also consume water pumped exclusively from the regional aquifer (ADWR, 1991). The model computes the seasonal volumes of withdrawals from the aquifer using the same equations described above for Row 280, except that the V_{72} term is not present.

Row 282: Fort Huachuca Use of Regional Aquifer

The residents and facilities of Fort Huachuca consume water exclusively from the regional aquifer (ADWR, 1991). As noted in Chapter 3, further, the Fort is not required to participate in any efforts at water management developed by the other residents of the basin. However, it is possible that the Fort may choose to participate in these efforts, as specified in Row 177, above. It should be noted also, that residents of the Fort are not charged for the delivery of their water, and so the model does not include any equations for projecting demand at the Fort as a function of water pricing and household income. The model equations for Row 282 thus have five parts, with only one of these five is active for any single simulation depending on the settings in Rows 175, 176, and 177.

If Row 175 = 1, then $V_{x,t} = 0$.

If Row 175 = 0 and Row 177 = 0, then $V_{x,t} = f_t N_{x,t}\left(D_{x,0}/N_{x,0}\right)$,

where $\left(D_{x,0}/N_{x,0}\right)$ is the per capita rate of water demand at the Fort in the absence of water conservation, estimated from the ratio of total annual demand to total Fort population in 1990; and all other variables are as described above for Row 280.

USF200010383

If Row 175 = 0, Row 177 = 1, and Row 176 = 1, then the equation above (for Row 175=0 and Row 177=0) is multiplied by a factor, $(1-\Delta V_x)$, where ΔV_x is the fraction of required conservation specified in Row 94.

If Row 175 = 0, Row 177 = 1, and Row 176 = 2, then the equation above (for Row 175=0 and Row 177=0) is multiplied by the factor, $(1-0.125F_{x,t})$, where $F_{x,t}$ is the fraction of households at the Fort equipped with low-flow plumbing during season t as estimated in Row 245.

Finally, if Row 175=0, Row 177=1, and Row 176=3, then

$$V_{x,t} = 0.00112 N_{x,t} G_x f_t,$$

where G_x is the target water consumption rate in gallons per capita per day for census area x specified in Row 87; 0.00112 is a constant to convert measurement units from gallons per capita per day to acre-feet per year; and f_t is the fraction of domestic and municipal water consumption that takes place in season t.

Rows 283-287: Use of Regional Aquifer by Huachuca City, City of Tombstone, City of Bisbee, Town of Naco, and Rural Sierra Vista Sub-basin Water Service Areas

The residents of these five census areas all consume water pumped exclusively from the regional aquifer (ADWR, 1991), and all are charged for the delivery of their water. The model therefore computes the seasonal volumes of withdrawals from the regional aquifer in these census areas using the same equations described above for Row 280, except again that the V_{72} term is not present.

Row 288: Rural Sierra Vista Sub-basin Non-Service Area, Use of Regional Aquifer

The residents of this census area also consume water pumped exclusively from the regional aquifer (ADWR, 1991), but they are not charged for the delivery of their water

USF200010384

by any regulated water service company. The model therefore estimates their seasonal volumes of withdrawals in a manner similar to that used for Row 282, as follows:

If Row 175 = 1 then $V_{x,t} = 0$.

If Row 175 = 0 and Row 176 = 0, then $V_{x,t} = f_t N_{x,t} R_x$,

where R_x is the estimated annual consumption rate per person in acre-feet in rural non-service areas specified in Row 111; and all other variables are as described for Row 280.

If Row 175 = 0 and Row 176 = 1, then the equation above (for Row 175=0 and Row 176=0) is multiplied by the factor, $(1 - \Delta V_x)$, where ΔV_x is the fraction of required conservation specified in Row 94.

If Row 175 = 0 and Row 176 = 2, then the equation above (for Row 175=0 and Row 176=0) is multiplied by the factor, $(1 - 0.125 F_{x,t})$, where $F_{x,t}$ is the fraction of rural households equipped with low-flow plumbing during season t as estimated in Row 250.

Finally, if Row 175 = 0 and Row 176 = 3, then

$V_{x,t} = 0.00112 N_{x,t} G_x f_t$, as described above for Row 280.

Row 289: Irrigation Use of Groundwater in the Sierra Vista Sub-basin

Irrigation use of groundwater in the Sierra Vista sub-basin includes withdrawals from both the floodplain and regional aquifers (ADWR, 1991), but with most of the pumping taking place in the floodplain aquifer alone (Vionnet, 1991; Vionnet and Maddock, 1992). The irrigation withdrawals in the sub-basin therefore are tabulated as withdrawals from the floodplain aquifer alone, as noted for Row 257, above.

The model represents irrigation demand for water in the sub-basin as a function of four variables: (1) the area irrigated; (2) the average crop consumptive use requirement; (3) the average irrigation efficiency; and (4) the costs of pumping the water. The area irrigated can vary over time, for example as a result of the discontinuation of irrigation on

USF200010385

a portion of the available acreage, or as a result of the intentional restoration of some areas to riparian conditions. The average crop consumptive use requirement, the average irrigation efficiency, and the costs of pumping the water all may vary as a result of changes in economic conditions and irrigation practices, which in turn may result from the adoption of specific water management policies. The model allows for the imposition of changes in average crop consumptive use requirement, the average irrigation efficiency, and the costs of pumping the water, through the options provided in Rows 178-180.

The equations used in Row 289 for the seasonal volume of withdrawals for irrigation, $V_{289,t}$, in season t, thus is,

$$V_{289,t} = AD_t,$$

where A is the total acreage of actively irrigated lands in the sub-basin as estimated in Row 383, below; and D_t is the projected irrigation demand per acre (acre-feet per acre). The value of D_t, in turn, varies depending on the values of the options set in Rows 178-180, as follows:

If Row 180 = 1, then <u>regardless</u> of the settings in Rows 178 and 179, $D_t = f_t a P^b$, where a is the annual per-acre irrigation demand equation coefficient for the sub-basin specified in Row 133; P = the annual value of any irrigation well pumping tax specified in Row 137; b = the annual price elasticity of irrigation demand specified in Row 135; and f_t is the fraction of the annual irrigation demand assignable to season t. The values of f_t derive from the summary of monthly consumptive use requirements in ADWR (1991:Appendix B), and are 0.1715, o.3346, 0.2851, and 0.2088 for Seasons I-IV, respectively.

If Row 180 = 0 then $D_t = \dfrac{f_{e,t}(C_{123}, C_{131})_{178} - f_{p,t} P_e}{(C_{121}, C_{129})_{179}}$,

USF200010386

where $f_{e,t}$ and $f_{p,t}$ are the fractions of annual potential evaporation and annual precipitation taking place in season t as specified in Rows 55 and 19, respectively; P_e is the weighted average effective precipitation for irrigation in the sub-basin specified in Row 125; $(C_{123}, C_{131})_{178}$ represents the value of the annual weighted average crop consumptive use requirement to be used depending on the setting of Row 178; and $(C_{121}, C_{129})_{179}$ represents the value of the average overall irrigation efficiency to be used depending on the setting of Row 179. If Row 178 = 0, then $(C_{123}, C_{131})_{178}$ takes the value of Row 123, the default annual weighted average crop consumptive use requirement, otherwise it takes the value of Row 131, a target weighted average crop consumptive use requirement. If Row 179 = 0, then $(C_{121}, C_{129})_{179}$ takes the value of Row 121, the default average overall irrigation efficiency, otherwise it takes the value of Row 129, the required irrigation efficiency.

Row 290: Mining Industrial Use of the Regional Aquifer in the Sierra Vista Sub-basin

Mining activities in the Sierra Vista sub-basin use water exclusively from the regional aquifer, as discussed in Chapter 3. Withdrawals by the mining industry in season t of year y are estimated by the equation,

$$V_{t,y} = \tfrac{1}{4}(1 + r_m) V_{y-1},$$

where r_m is the annual rate of growth estimated for the mining industry in the sub-basin as specified in Row 162; and V_{y-1} is the total withdrawal by the mining industry in the sub-basin estimated for the immediately preceding year. $V_{t,y}$ for 1990 takes the value of Row 154 if Row 175 = 0, and takes the value of 0 if Row 175 = 1.

USF200010387

Row 291: Other Industrial Use of the Regional Aquifer in the Sierra Vista Sub-basin

All other industrial activities in the Sierra Vista sub-basin also use water exclusively from the regional aquifer, as discussed in Chapter 3. Withdrawals by these other industries in season t of year y are estimated by the equation,

$$V_{t,y} = \tfrac{1}{4}(1 + r_o)V_{y-1},$$

where r_o is the annual rate of growth estimated for these other industries in the sub-basin as specified in Row 163; and V_{y-1} is the total withdrawal by these other industries in the sub-basin estimated for the immediately preceding year. V_y for 1990 takes the value of Row 155 if Row 175 = 0, and takes the value of 0 if Row 175 = 1.

Row 292: Evaporation from Runoff-Supplied Stockponds and Reservoirs, Sierra Vista Sub-basin

The model computes only the net losses from runoff-supplied stockponds and reservoirs. Water not lost to evaporation is assumed to infiltrate and become part of the natural processes affecting infiltrated runoff waters in the hydrologic system. The model uses the method recommended by ADWR (see Row 170-171 discussion in Chapter 3) for estimating the net losses, all of which are attributed to evaporation. Losses due to livestock consumption comprise a negligible fraction of the losses from stockponds and reservoirs, and so are not estimated in the model.

The model first computes the annual loss from runoff-supplied stockponds and reservoirs and stores this value in Column C. The model does not vary the retention factor or the area of these impoundments over the period of projection, and so this annual value also does not change over the period. The annual loss is computed as,

USF200010388

$$V_{292} = A_r R_r (E - P_f),$$

where A_r is the area of runoff-supplied stockponds and reservoirs specified in Row 166; R_r is the water retention rate for runoff-supplied stockponds and reservoirs specified in Row 170; E is the open-water gross evaporation rate specified in Row 51; and P_f is the annual effective precipitation rate over the floodplain. Most runoff-supplied stockponds and reservoirs occur at lower elevations where runoff can provide adequate supplies for the impoundments, and so the effective precipitation rate over the floodplain provides the more accurate estimate of effective precipitation for purposes of computing evaporative losses. The expression, $(E - P_f)$, represents the net evaporative loss rate in acre-feet per acre for the impoundments. The equations in Row 292 also include a condition that if Row 175 = 1, the annual loss rate = 0.

The seasonal loss, $V_{292,t}$, is computed for each season t, as a fraction of the annual loss, V_{292}, where this fraction is a function of the seasonal open-water gross evaporation rate and the seasonal effective precipitation rate over the floodplain, as follows,

$$V_{292,t} = V_{292} \frac{(E f_{E,t}) - (P_f f_{P,t})}{(E - P_f)},$$

where $f_{E,t}$ is the fraction of evaporation and $f_{P,t}$ is the fraction of effective precipitation taking place in season t as specified in Rows 52-55 and 16-19, respectively; and all other variables are the same as in the equation for the annual loss.

Row 293: Evaporation from Groundwater-Supplied Stockponds and Reservoirs, Sierra Vista Sub-basin

The losses from groundwater-supplied stockponds and reservoirs are estimated in the same manner as the losses from runoff-supplied impoundments described for Row 292. The equations for the two rows differ only in that A_r is replaced by A_g, the area of

USF200010389

groundwater-supplied impoundments specified in Row 168, and R_r is replaced by R_g, the water retention rate for groundwater-supplied impoundments specified in Row 171.

Row 294: Phreatophyte Consumption from the Floodplain Aquifer in the Sierra Vista Sub-basin

All phreatophyte consumption takes place from the floodplain aquifer. The seasonal volume consumed, $V_{294,t}$, in season t is estimated as,

$$V_{294,t} = A_p(C_p f_{E,t} - P_e f_{P,t}),$$

where A_p is the area of riparian vegetation at the end of the preceding year estimated in Row 261; C_p is the composite annual consumptive use coefficient for riparian vegetation specified in Row 144; $f_{E,t}$ is the fraction of annual potential evaporation taking place in season t specified in Rows 52-55; P_e is the annual effective precipitation rate over the floodplain specified in Row 15; and $f_{P,t}$ is the fraction of annual precipitation falling in season t specified in Rows 16-19.

Row 295: Channel Evaporation from the Riverbed in the Sierra Vista Sub-basin

Evaporative losses along the riverbed arise from two sources, evaporation from open water surfaces and evaporation from bare, unvegetated ground exposed along the water course. Evaporation from the bare ground is assumed to take place from surfaces wetted by runoff events. As a result, both components of channel evaporation constitute losses from surface water flows. The equation for the total channel evaporation loss, $V_{295,t}$, in season t is thus,

$$V_{295,t} = \left(A_b(C_b f_{E,t} - P_e f_{P,t})\right) + \left(\frac{a(4Q_{R,t})^b L\left(Ef_{E,t} - P_g f_{P,t}\right)}{43560}\right).$$

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The first part of the RHS estimates the bare-ground losses using five variables: A_b is the area of unvegetated bare ground along the riverbed specified in Row 47; C_b is the bare-ground consumptive use coefficient specified in Row 48; $f_{E,t}$ is the fraction of annual potential evaporation taking place in season t specified in Rows 52-55; P_e is the annual effective precipitation rate over the floodplain specified in Row 15; and $f_{P,t}$ is the fraction of annual precipitation taking place in season t specified in Rows 16-19.

The second expression in the RHS, in turn, estimates the losses from open waters along the river course and contains these terms: a and b are the discharge coefficient and exponent, respectively, for estimating average river width (ft) from average annual river discharge, as discussed for Rows 49 and 50 in Chapter 3; $4Q_{R,t}$ is the average river discharge in season t estimated in Row 304, below, multiplied by 4 to normalize its value to an annual basis for use in the equation for estimating average river width; L is the effective length of the riverbed (ft) specified in Row 42; E is the annual open water gross evaporation rate (ft) specified in Row 51; P_g is the annual gross precipitation rate (ft) over the floodplain specified in Row 14; and $f_{E,t}$ and $f_{P,t}$ are as specified above for the first expression in the RHS. The constant, 43560, converts the calculated volume in cubic feet to acre-feet.

Rows 296 and 297: SPRNCA Withdrawals from the Floodplain and Regional Aquifers in the Sierra Vista Sub-basin

Rows 148 and 149 (see Chapter 3, above) discuss the provisions in the model for examining the effects of ground-water withdrawals by the BLM, to supplement surface flows in the river. The model assumes that any such withdrawals would take place only during Season II, April to June. This is the time of year when precipitation is lowest and consequently when stream flows are most vulnerable and potentially would benefit most

USF200010391

from supplementation. Rows 296 and 297 thus merely assign the entire annual withdrawal from each aquifer to Season II, and register the withdrawals as part of the annual water budgets of the two aquifers. The equations in both rows also include an IF/THEN condition, to ensure that the row values are set to 0 when Row 175 = 1.

Rows 298 and 299: Exports from the Floodplain and Regional Aquifers in the Sierra Vista Sub-basin

Rows 60 and 61 (see Chapter 3, above) discuss the possibility that parties in the sub-basin will withdraw and export water from the two aquifers, beyond what is already exported from the regional aquifer to supply the City of Bisbee. The model assumes that the withdrawals would take place during Seasons I and IV rather than year-round in order to avoid interfering with other uses of the aquifers. These other demands on the aquifers are lowest during these two seasons. Rows 298 and 299 thus merely assign half of the entire annual withdrawal for export from each aquifer to Season I and half to Season IV and register the withdrawals as part of the annual water budgets of the two aquifers. The equations in both rows also include an IF/THEN condition to ensure that the row values are set to 0 when Row 175 = 1.

Rows 300 and 301: Underflows from the Floodplain and Regional Aquifers in the Sierra Vista Sub-basin

Rows 25 and 32 (see Chapter 3, above) discuss the estimates of annual underflow leaving the two aquifers in the Sierra Vista sub-basin. The model assumes that the underflows take place at constant rates rather than varying in their rates depending on other hydrologic conditions. Rows 300 and 301 thus merely assign one quarter of the

USF200010392

entire annual underflow from each aquifer to each season and register the losses as parts of the annual water budgets of the two aquifers.

Row 302: Potential Discharge from the Floodplain Aquifer to the River in the Sierra Vista Sub-basin

The flow of water between the floodplain aquifer and the river is an important component in the overall water budget of each sub-basin. Both the magnitude and direction of this flow depend on the difference in hydraulic head between the aquifer and the river, as also discussed above (Rows 263-270). The classic Darcian equation for describing this flow along a specific reach of a river (Prudic, 1989) is,

$$Q_{aq} = K_{riv} \frac{L_{riv} w_{riv}}{T_{riv}} (h_{riv} - h_{aq}),$$

where Q_{aq} is the instantaneous rate of flow (volume/time); K_{riv} and T_{riv} are the hydraulic conductivity and thickness of the riverbed sediments; L_{riv} and w_{riv} are the length and width of the river reach under consideration; and h_{aq} and h_{riv} are the hydraulic heads in the aquifer and the river, respectively.

Unfortunately, this equation describes only the instantaneous rate of flow as a function of h_{aq} and h_{riv} at a single point in time. Any discharge from the aquifer to the river will simultaneously decrease h_{aq} and increase h_{riv} and so result in a change in the instantaneous rate of flow, which will change the values of h_{aq} and h_{riv} and so forth. Similarly, any discharge from the river to the aquifer will simultaneously increase h_{aq} and decrease h_{riv} and so forth. A model of the volumetric water budge must somehow translate this understanding of the process of interaction into a description of the volume of water that will flow between the floodplain aquifer and the river over long periods of time such as entire seasons or years.

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This task of translation is made more complicated by the fact that h_{aq} and h_{riv} both affect and are affected by other processes in the hydrologic system such as the rate of channel evaporation losses (see above, Row 295) and the rate of flow between the regional and floodplain aquifers (see below, Row 307). A model of the volumetric water budget therefore must be able to adjust its estimates of the volume of water flowing between the floodplain aquifer and the river by iteration to arrive at an estimate that takes into account all constraints on h_{aq} and h_{riv} during each period of estimation.

Finally, any estimate of the volume of water flowing between the floodplain aquifer and the river must take into account two special conditions that hold when h_{riv} is both greater than 0 and greater than h_{aq}. Under these conditions, first, the river cannot discharge to the aquifer any more water than enters the river reach as surface flow from upstream regardless of the magnitude of the difference between the two heads. Second, as discussed for Rows 265-266 above, when h_{aq} additionally lies below the bottom of the riverbed sediments, the flow of water from the river into the aquifer takes place at what is most easily described as a constant rate regardless of the magnitude of h_{riv} (Prudic, 1989).

The model handles these complexities of estimating the volume of water flowing between the floodplain aquifer and the river during each season in two steps. First, the model estimates the volume of water that would flow between the aquifer and the river during the season of estimation given the magnitudes of h_{aq} and $h_{riv} - h_{aq}$. This is the calculation carried out in Row 302 for the Sierra Vista sub-basin. The estimate generated in Row 302 is adjusted iteratively with other equations, the results of which also affect the estimation of river discharge and hydraulic head in the floodplain aquifer. Second, the model adjusts the estimate of the volume of water that would flow between the aquifer and the river as necessary to ensure that the river does not discharge to the aquifer any more

USF200010394

water than could actually be present in the river during the season of estimation. This second calculation is carried out in Row 303, below.

The relationship between (1) the volume of water flowing between the floodplain aquifer and the river during a season and (2) the magnitudes of h_{aq} and $h_{riv} - h_{aq}$ at the start of that season was examined in a series of numerical simulations. Each simulation produced an estimate of the direction and volume of flow between the floodplain aquifer and the river during a single season (91.5 days) for a given set of initial values of h_{aq} and $h_{riv} - h_{aq}$. The simulation results were then tabulated for a wide range of initial values of h_{aq} and $h_{riv} - h_{aq}$ to examine how the system behaved overall. This examination led to the construction of an equation, which summarizes the results of the simulations. This equation estimates the magnitude and direction of seasonal flow between the floodplain aquifer and the river as a function of the values of h_{aq} and $h_{riv} - h_{aq}$ existing at the beginning of each season.

It also would have been possible, alternatively, to include the numerical simulation of stream-aquifer interactions directly into the capabilities of the overall model. However, doing so would have increased greatly the computation times required for running the overall model and the time required to calibrate the model whenever recalibration became necessary. For these reasons, only the summary equation was used.

The numerical simulations provided an evaluation of the expression,

$$V_{302,t} = \sum_{\tau=1}^{183} Q_{aq}(\tau)\Delta\tau,$$

where $V_{302,t}$ is the volume of flow between the river and the floodplain aquifer during season t ; τ is the simulation timestep marker for the 183 half-day time steps in a single season; $\Delta\tau$ is the timestep size, 0.5 days; and $Q_{aq}(\tau)$ is the rate of flow in acre-feet per half-day estimated for timestep τ. $V_{302,t}$ is a measure of flow relative to the river; a (+)

USF200010395

value indicates flow from the aquifer to the river and a (-) value indicates flow in the opposite direction.

$Q_{aq}(\tau)$, in turn, is estimated as a function of the width of the river's in-stream flow and the difference in hydraulic head between the aquifer and the river as

$$Q_{aq}(\tau) = \frac{K_{riv} L_{riv}}{T_{riv}} w_{riv}(\tau) \Delta H(\tau),$$

where K_{riv}, L_{riv}, and T_{riv} are constants for the hydraulic conductivity, length, and thickness of the riverbed in acre-feet/day, feet, and feet, respectively; $w_{riv}(\tau)$ is the width of the actively flowing river in feet; and $\Delta H(\tau)$ is the difference in hydraulic head between the river and the aquifer in feet, $h_{riv} - h_{aq}$, during timestep. The value of K_{riv} in the simulations was set at 0.734 ft/d (6.149E-3 acre-feet/yr) based on estimates of riverbed conductivity developed by Vionnet (1991) during the course of her modeling of ground-water flows in the upper San Pedro basin. L_{riv} and T_{riv} took the values of Rows 42 and 43 of the main model, respectively. $Q_{aq}(\tau)$ also is limited in the simulation runs such that flow from the river into the aquifer ($h_{aq} < h_{riv}$) cannot exceed the amount of water entering the river reach from upstream ($Q_{riv}(\tau)$, see below) during the same time step.

In turn, $w_{riv}(\tau)$ is estimated as a function of the rate of flow in the river using the equation discussed for Rows 49-50 in Chapter 3, as follows,

$$w_{riv}(\tau) = a_w \left[Q_{riv}(\tau) \times 2 \times 365 \right]^{b_w},$$

where a_w and b_w are the width-discharge equation coefficient and exponent values given in Rows 50 and 49, respectively; and $Q_{riv}(\tau)$ is the estimated flow rate of the river during timestep τ in acre-feet per half-day. The value of $Q_{riv}(\tau)$ is multiplied by 2×365 to convert its units from acre-feet per half-day to acre-feet per year, the units in which the equation described for Rows 49-50 correctly works. And $\Delta H(\tau)$ is computed using the value of T_{riv} and the values of h_{aq} and h_{riv} estimated for the end of the immediately

USF200010396

preceding timestep, $\tau - 1$, according to the set of conditional expressions described above for Rows 265-266. The values of $h_{aq}(\tau = 0)$ and $h_{riv}(\tau = 0)$ used to initiate each simulation were changed from one simulation to the next to cover a wide range of possible values for both h_{aq} and $h_{riv} - h_{aq}$.

Finally, $(Q_{riv}(\tau)$ was estimated using the value of $h_{riv}(\tau - 1)$ by inverting the stage-discharge equation described above for Rows 44-45 in Chapter 3. This equation can be inverted to the form,

$$Q_{riv}(\tau) = \frac{\left(\frac{h_{riv}(\tau - 1)}{a_s}\right)^{\frac{1}{b_s}}}{2 \times 365},$$

where a_s and b_s and the stage-discharge equation coefficient and exponent values given in Rows 45 and 44, respectively. The RHS is divided by 2×365 to convert its units from acre-feet per half-day to acre-feet per year, the units in which the equation described for Rows 44-45 correctly works.

These equations allowed for the accumulation of values of $Q_{aq}(\tau)\Delta\tau$ for successive time steps. At the end of each time step, new values of $h_{aq}(\tau)$ and $h_{riv}(\tau)$, as follows:

$$h_{aq}(\tau) = h_{aq}(\tau - 1) + \Delta h_{aq}(\tau) \text{ for } \Delta h_{aq}(\tau) = \frac{Q_{aq}(\tau)\Delta\tau\Theta_{aq}}{A_{aq}}$$

where $\Delta h_{aq}(\tau)$ is the change in hydraulic head in the aquifer during timestep τ; and A_{aq} and Θ_{aq} are the area and specific yield of the floodplain aquifer in acres and fractions specified in Rows 31 and 33, respectively. And,

$$h_{riv}(\tau) = a_s\left[\frac{Q_{riv}(\tau) + \left(Q_{riv}(\tau) + Q_{aq}(\tau)\Delta\tau\right)}{2} \times 2 \times 365\right]^{b_s}.$$

In this last expression, the term,

USF200010397

$$\left[\frac{Q_{riv}(\tau)+\left(Q_{riv}(\tau)+Q_{aq}(\tau)\Delta\tau\right)}{2}\right]$$

gives the average flow in the river during a single time step, assuming that the discharge from the aquifer to the river takes place at a uniform rate over the entire length of a time step rather than abruptly at the end of the time step. This term is multiplied by 2×365 to convert its units from acre-feet per half-day to acre-feet per year, the units in which the equation described for Rows 44-45 correctly works.

Figures 4-2 to 4-4 summarize the results of the simulations for conditions in which $h_{aq} > h_{riv}$ and $h_{aq} < h_{riv}$. The left half of Figure 4-2 shows the relationship between $V_{302,t}$ and $h_{riv} - h_{aq}$ for $h_{aq} > h_{riv}$. The data on this side of Figure 4-2 reveal that $V_{302,t}$ varies approximately linearly with $h_{riv} - h_{aq}$ overall, with all lines passing through the point, $V_{302,t} = 0$, $h_{riv} - h_{aq} = 0$. However, the slope of this linear relationship varies as a function of h_{riv}. Figure 4-3 shows the relationship between the ratio of $V_{302,t}$ to $h_{riv} - h_{aq}$ and the value of h_{riv}. For $h_{riv} < 0.035$ feet, the ratio is essentially constant at approximately -275 feet per foot of difference in hydraulic head. For $h_{riv} > 50$ feet, the ratio is essentially constant at -2660 feet per foot of difference in hydraulic head. This limiting ratio is identical to the product of the specific yield and area of the floodplain aquifer in the sub-basin, and represents the maximum volume of water that can enter or leave the floodplain aquifer for a one-foot change in aquifer hydraulic head.

The average h_{riv} for a season is not likely ever to exceed 2 feet; a river stage of this magnitude would correspond to an average flow rate of more than 250,000 acre-feet per year or 62,500 acre-feet per season. Therefore, it is safe to develop an expression that summarizes the results for $h_{aq} > h_{riv}$ only for $2 > h_{riv} > 0$ feet. Regression analysis of the results for $h_{aq} > h_{riv}$ and $2 > h_{riv} > 0.035$ feet produces the following summary equation:

$$V_{302,t} = -\Delta H\left[764.806h_{riv} + 248.815\right], \text{ in acre-feet for a single season.}$$

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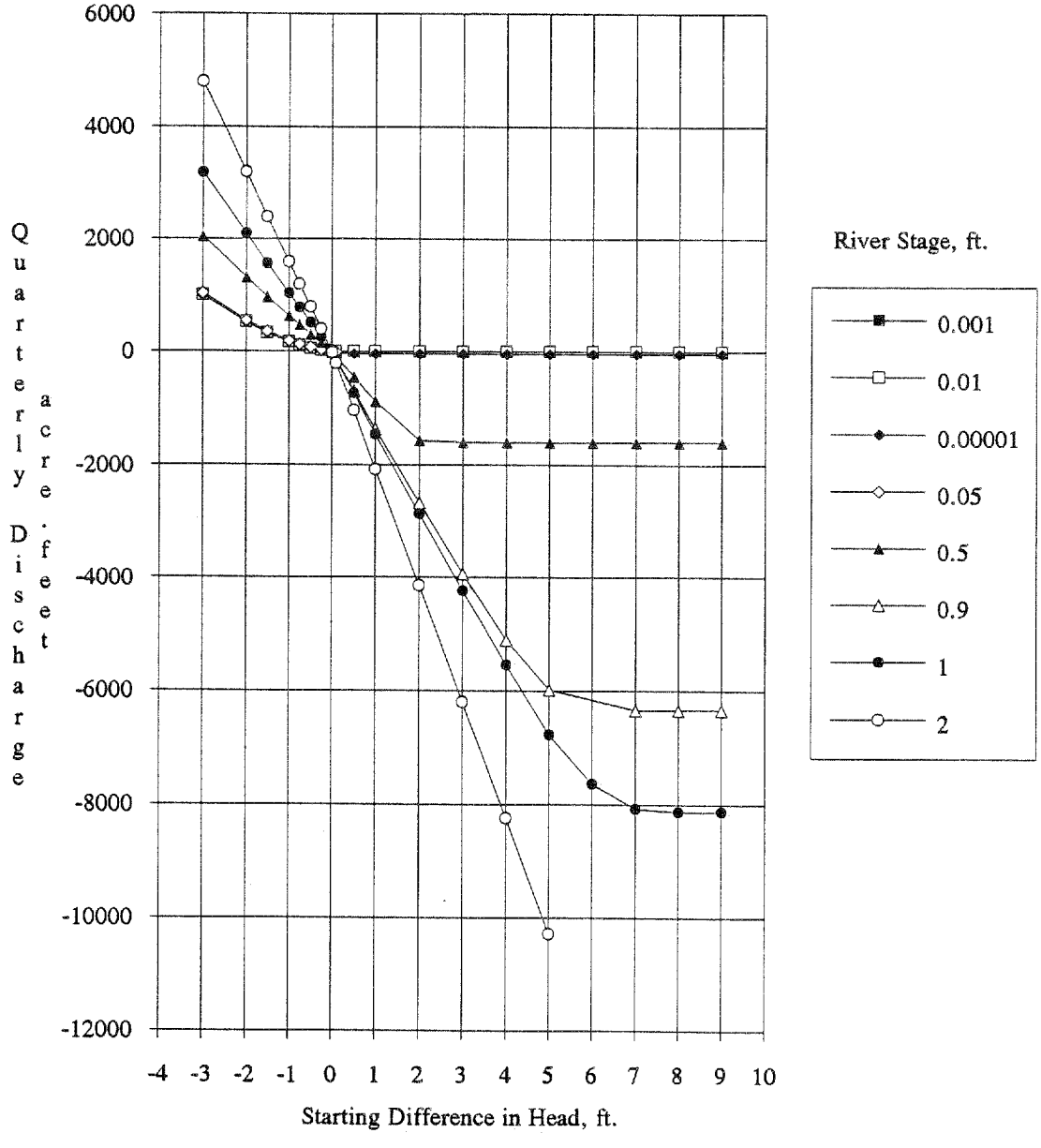
Quarterly Discharge from Aquifer to River
vs. Start-of-Quarter Difference in Head (River-Aquifer)
for Different Values of Start-of-Quarter River Stage,
Simulated Sierra Vista Sub-basin
Figure 4-2



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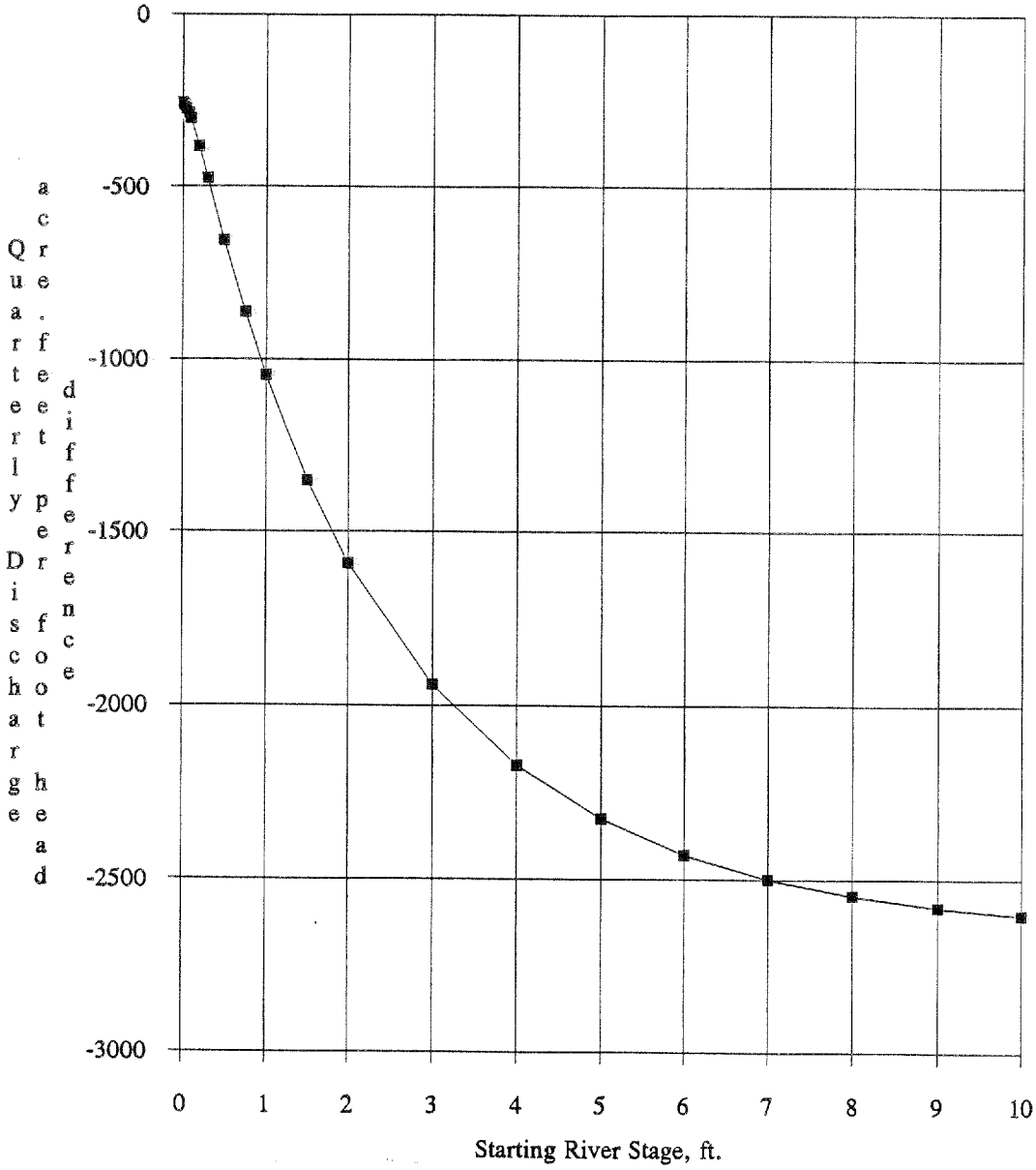
Quarterly Discharge from Aquifer to River
per Unit Start-of-Quarter Head Difference (River-Aquifer)
vs. Start-of-Quarter River Stage,
Simulated Sierra Vista Sub-basin
Figure 4-3



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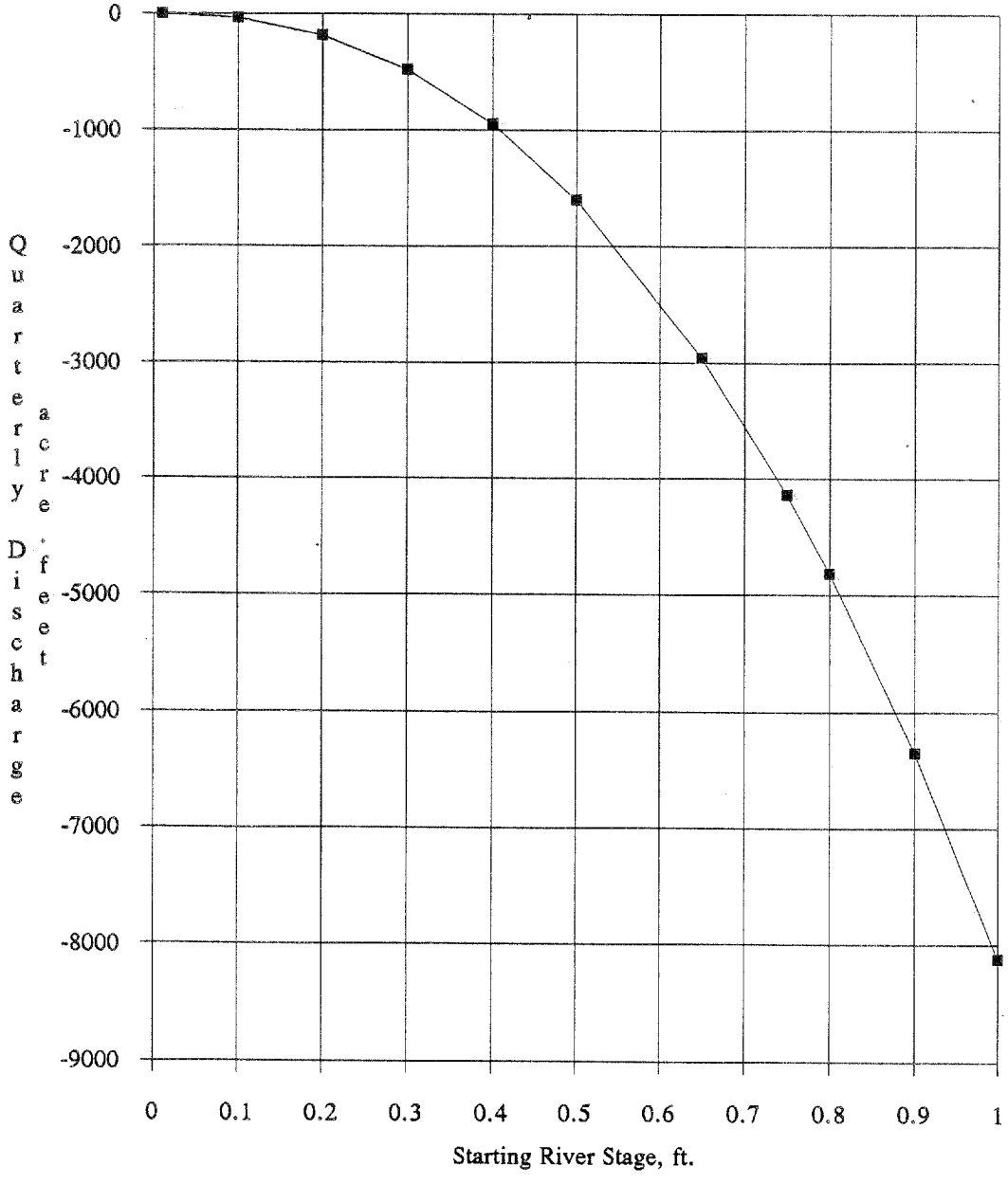
Quarterly Discharge from Aquifer to River,
"Leveling-Off" Discharge vs. Start-of-Quarter River Stage,
Simulated Sierra Vista Sub-basin
Figure 4-4



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And for $h_{aq} > h_{riv}$ and $h_{riv} \leq 0.035$ feet, $V_{302,t}$ is calculated as,

$V_{302,t} = -275\Delta H$, in acre-feet for a single season.

The right side of Figure 4-2 shows the relationship between $V_{302,t}$ and $h_{riv} - h_{aq}$ for $h_{aq} < h_{riv}$. The data for this part of Figure 4-2 reveal that $V_{302,t}$ again varies as a linear function of $h_{riv} - h_{aq}$ overall with all lines passing through the point, $V_{302,t} = 0$, $h_{riv} - h_{aq} = 0$ but with a special additional feature. For almost all values of h_{riv}, $V_{302,t}$ eventually reaches a fixed, constant value as $h_{riv} - h_{aq}$ increases. This leveling-off reflects the fact that, for most values of h_{riv}, as h_{aq} falls further below h_{riv}, eventually h_{aq} will fall below the bottom of the riverbed and the rate of flow from the river into the aquifer will become constant.

Thus, for $h_{aq} < h_{riv}$, both the slope of the linear relationship between $V_{302,t}$ and $h_{riv} - h_{aq}$ and the leveling-off value for $V_{302,t}$ vary as functions of h_{riv}. Analyses were carried out on the relationship between the ratio of $V_{302,t}$ to $h_{riv} - h_{aq}$ and the value of h_{riv}, for values of $V_{302,t}$ less than the leveling-off value for a given h_{riv}, for $h_{aq} < h_{riv}$. Experimentation showed that this relationship was essentially the same as that found for $h_{aq} > h_{riv}$, described above.

Figure 4-4 in turn shows the relationship between the leveling-off value for $V_{302,t}$ and the value of h_{riv} for $h_{aq} < h_{riv}$. Experimentation with various transformations of the data again coupled with regression analysis produced the following summary equation for the behavior of the data in Figure 4-4:

$V_{302,t} = -8122.7h_{riv}^{2.3447}$, in acre-feet for a single season.

The actual value of $V_{302,t}$ for $h_{aq} < h_{riv}$ can then be computed as the greater (least negative) of the values predicted by the linear equation or the leveling-off equation.

The equation in Row 302 simply combines the summary equations for $h_{aq} > h_{riv}$ and $h_{aq} < h_{riv}$ into a single set of conditional expressions. In practice, it is not neccary to

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include the equation that specifies the leveling-off condition. Row 265 includes information on the relationship between h_{aq} and R_{bot} that already takes the thickness of the riverbed into account in calculating $h_{riv} - h_{aq}$. Thus, it is not necessary to have the equation in Row 302 also keep track of this relationship. The equations in Row 302 also should be used with a caveat: The relationship between $V_{302,t}$ and $h_{riv} - h_{aq}$ is only approximately linear. The departure from non-linearity is slight but is most pronounced for small values of h_{riv}. As a result, the equation for $h_{aq} > h_{riv}$ slightly overestimates the value of $V_{302,t}$ for small values of $h_{riv} - h_{aq}$. The overestimation is greatest for values of $h_{riv} - h_{aq}$ between -0.7 and -0.9 feet and again for +0.7 to +0.9 feet, for which the overestimations fall in the range of 90 to 100 acre-feet per season. This is not considered a significant overestimation.

Finally, the equation in Row 302 includes one additional term, the stream-aquifer volumetric conductance coefficient specified in Row 41. This coefficient appears as a factor by which the entire remainder of the equation is multiplied. The coefficient is used to correct the results of the equation for the fact that K_{riv} had to be set at a single, fixed value in order to carry out the simulations described above. The selected value of K_{riv} is a reasonable estimate for a single, short reach of the river. However, users of WATERBUD may wish to examine the effects of modeling a higher or lower value for this variable. Because of its role in the simulation equations, the estimation of $V_{302,t}$ may be expected to vary essentially linearly with the estimate of K_{riv}. The volumetric conductance coefficient therefore is included as a calibration parameter, the value of which is adjusted during calibration of the model in order to produce correct results. The process of calibration is described in Chapter 5, below.

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Row 303: Available Discharge from the Floodplain Aquifer to the River in the Sierra Vista Sub-basin

The discussion of Row 302, above, noted that the seasonal volume of flow of water from the river into the floodplain aquifer cannot be allowed to exceed the seasonal volume of water flowing in the river itself for any one season. The equation in Row 302 has the capability to limit discharge from the river to the aquifer in this way. However, the process of iteration used by the model nevertheless can result in a temporary overallocaction of water from the river to the aquifer and hence in an estimation of negative flow in the river during an individual cycle of iteration. As a result, it was found necessary to include an equation in Row 303 that would prevent any such temporary over allocation of water even during an individual cycle of iteration.

The equation in Row 303 consists of an IF/THEN/ELSE expression that detects two conditions:

(1) $\Delta H > 0$, (that is, $h_{riv} > h_{aq}$), and

(2) $V_{302,t} < -(V_{273,t} - V_{292,t} - V_{295,t} + V_{320,t})$,

where the terms in the RHS of the second statement are the inflow of surface waters to the river in the sub-basin (from Row 273, above), the loss of surface runoff intercepted by stockponds and reservoirs (from Row 292, above), the loss of surface water to channel evaporation (from Row 295, above), and supplementation of in-stream flows in the SPRNCA by the BLM from groundwater (from Row 320, below), respectively, for season t. These four terms in the RHS of the second statement together constitute the flow of water in the river that is potentially available for discharge to the floodplain aquifer. The equation in Row 303 simply specifies that, if both of the above conditions are true, then the available discharge of water from the river to the aquifer is equal to the

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value of the RHS of the second statement; otherwise, the discharge is equal to the potential discharge estimated in Row 302, above.

Row 304: River Discharge from the Sierra Vista Sub-basin

The equation in Row 304 tabulates the inputs and losses to river flow in the Sierra Vista sub-basin by season. The sum of these inputs and losses necessarily leaves the sub-basin as river discharge. The equation has the form,

$$V_{304,t} = V_{273,t} - V_{292,t} - V_{295,t} + V_{303,t} + V_{320,t},$$

where $V_{303,t}$ is the result of the equation in Row 303 for season t, and all other terms are as stated above in the description of Row 303.

4.5 SIERRA VISTA SUB-BASIN RECHARGE AND RETURNS TO STORAGE

This section of the model tabulates the return flows and recharges to the floodplain and regional aquifers that result from or potentially are affected by human activities in the sub-basin.

Row 307: Recharge from the Regional to the Floodplain Aquifer in the Sierra Vista Sub-basin

The regional aquifer is a major source of recharge to the floodplain aquifer. The regional aquifer, in turn, discharges almost exclusively to the floodplain aquifer, with only a small volume leaving as underflow to the regional aquifer in the next sub-basin. Thus, under predevelopment conditions, with storage in equilibrium in both aquifers, the volume flowing from the regional aquifer into the floodplain aquifer would have only slightly less than the total volume flowing into the regional aquifer itself. However, this property of

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the hydrologic system does not imply that the flow between the two aquifers was unaffected by any other factors.

The rate of discharge from the regional aquifer to the floodplain aquifer, in fact, necessarily depends on the difference in hydraulic head between the two along their shared boundaries. This feature of the system carries an important for modeling the discharge under modern, developed conditions. Depletions to storage in either aquifer have the potential to change their hydraulic heads along their shared boundaries, and so change the rate at which water moves from the regional to the floodplain aquifer. Such effects are clearly evident in the results obtained by Vionnet (1991; Vionnet and Maddock, 1992), in her detailed modeling of ground-water dynamics in the sub-basin under both steady-state (pre-development) and transient (development) conditions.

Instantaneous flow across the interface between the two can be described by a classic Darcian equation,

$$Q_{aq\text{-}aq} = C_{aq\text{-}aq}\Delta H_{aq\text{-}aq}.$$

$Q_{aq\text{-}aq}$ is the instantaneous rate of discharge from one aquifer to the other; $C_{aq\text{-}aq}$ is the conductance across the interface between the two aquifers, a product of the hydraulic conductivity and geographic dimensions of the interface; and $\Delta H_{aq\text{-}aq}$ is the difference in average hydraulic head, $h_{ra} - h_{fa}$, between the regional aquifer, h_{ra}, and the floodplain aquifer, h_{fa}, along their interface. Unfortunately, such an equation can not provide information on how the two aquifers behaved overall in relation to each other, nor on the volume that would flow between the two aquifers over large periods of time.

Modeling the discharge from the regional aquifer to the floodplain aquifer therefore poses problems similar to those involved in modeling the flow between the floodplain aquifer and the river, above. Flow from the regional aquifer to the floodplain aquifer during a single increment of time will both decrease the average hydraulic head in

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the regional aquifer, h_{ra}, and increase the average hydraulic head in the floodplain aquifer, h_{fa}. This will change $\Delta H_{aq\text{-}aq}$, which will change the rate of flow in the next time increment, and so forth. Modeling the process of discharge over an entire season thus requires modeling the process of interaction between $Q_{aq\text{-}aq}$ and $\Delta H_{aq\text{-}aq}$, rather than the behavior of $Q_{aq\text{-}aq}$ alone.

Separate simulations were carried out, to examine how the cumulative volume of discharge for a single season varies as a function of $C_{aq\text{-}aq}$ and the value of $\Delta H_{aq\text{-}aq}$ at the start of the season. These results (not shown due to their simplicity) revealed that, for any given value of $C_{aq\text{-}aq}$, seasonal discharge varies linearly as a function of the starting value of $\Delta H_{aq\text{-}aq}$. This linearity results from the fact that single-season discharges from the regional aquifer have essentially no effect on the average hydraulic head in that aquifer; the magnitude of these discharges is simply too small to have any significant effect. There is thus no interaction between h_{ra} and h_{fa} over the course of an individual season, that could result in any non-linear behavior in the system.

Modeling the seasonal volume of flow between the two aquifers therefore requires an equation with three variables, $C_{aq\text{-}aq}$, and the values of h_{ra}, and h_{fa} at the start of a modeling period. However, a starting value of h_{fa}, the average hydraulic head in the floodplain aquifer, is already provided in the larger water budget model (see above), for purposes of estimating the flow between the floodplain aquifer and the river. Thus, only two variables require estimation, to model the interaction between the two aquifers alone.

These two variables can be estimated based on two facts and one assumption:

(1) The average seasonal volume of discharge from the regional aquifer to the floodplain aquifer under pre-development conditions is known, consisting of 25% of the annual natural recharge to the regional aquifer in the sub-basin minus 25% of the annual

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underflow to the next sub-basin. That is, under predevelopment conditions, the recharges to and discharges from the regional aquifer are considered to be in balance.

(2) The seasonal volume of "potential" depletions to the floodplain aquifer under 1990 conditions is known. This quantity consists of (a), 25% of the annual withdrawals and discharges from the aquifer, including 25% of the annual discharges to the river; minus (b), 25% of the annual recharges and return flows, including 25% of the pre-development annual recharge from the regional aquifer to the floodplain aquifer. This quantity is termed the "potential" depletions, because it constitutes the volume of depletion to storage in the floodplain aquifer that would occur, if the regional aquifer were only to discharge water at its pre-development rate.

(3) The rate of discharge of the regional aquifer to the floodplain aquifer under 1990 conditions necessarily exceeds the rate of discharge under pre-development conditions, by a quantity sufficient to balance some proportion of the "potential" depletions taking place in the floodplain aquifer. We can therefore pose the question, How large is this proportion? Water tables in the floodplain aquifer are known to have declined over recent decades (Roeske and Werrell, 1973; Konieczki, 1980; Putnam *et al.*, 1988; BLM, 1987; ADWR, 1991; Vionnet, 1991; Vionnet and Maddock, 1992). These declines are largely the result of agricultural withdrawals. However, these withdrawals have declined greatly in the past decade, as a result of the discontinuation of pumping within the boundaries of the SPRNCA and reductions in agricultural activity in the Palominas-Hereford area (ADWR, 1991; Vionnet, 1991; Vionnet and Maddock, 1992). As a result, it cannot be demonstrated that the discharges from the regional aquifer to the floodplain aquifer in 1990 were <u>not</u> sufficient to balance the "potential" depletions taking place in the floodplain aquifer. Consequently, it can be assumed that, at least in 1990, the

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rate of discharge from the regional aquifer to the floodplain aquifer was sufficient to balance 100% of the "potential" depletions taking place in the floodplain aquifer.

These two facts and one assumption permit the estimation of $C_{aq\text{-}aq}$, and the value of $\Delta H_{aq\text{-}aq,t}$ at the start of the twenty-year modeling period (i.e., at $t = 0$), in the equation,

$$V_{aq\text{-}aq,t} = C_{aq\text{-}aq}\Delta H_{aq\text{-}aq,t},$$

where $V_{aq\text{-}aq,t}$ is the seasonal volume of flow between the two aquifers. This equation also expresses a crucial additional fact: when $\Delta H_{aq\text{-}aq,t} = 0$, it should also be the case that $V_{aq\text{-}aq,t} = 0$ as well. The estimation involves four steps:

(1) Pre-development discharge is described by the expression,

$$V_{aq\text{-}aq,t}(\text{PreD}) = C_{aq\text{-}aq}X;$$

1990 conditions are described by the expression,

$$V_{aq\text{-}aq,t}(1990) = C_{aq\text{-}aq}(X + Y);$$

and a further condition is given by the expression,

$$V_{aq\text{-}aq,t} = 0 \text{ when } \Delta H_{aq\text{-}aq,t} = 0.$$

The variables, X and Y represent the value of $\Delta H_{aq\text{-}aq,t}$ under pre-development conditions, and the change in $\Delta H_{aq\text{-}aq,t}$ that would result, if the 1990 "potential" depletions in the floodplain aquifer took place without any balancing increase in discharge from the regional aquifer.

The value of $V_{aq\text{-}aq,t}(\text{PreD})$ is calculated as 25% of the sum of Row 28 and Row 7 minus Row 25. The value of $V_{aq\text{-}aq,t}(1990)$ is calculated as 25% of the annual sum, $(-V_{274} - V_{276} - V_{317} - V_{321} + V_{289} + V_{294} + V_{296} + V_{298} + V_{300} + V_{303})$ for 1990, the initialization year for the model. Note that the calculation of $V_{aq\text{-}aq,t}(1990)$ requires the prior estimation of V_{303}, the annual discharge from the floodplain aquifer to the river. Thus, the model must first be calibrated for its representation of the discharge from the floodplain aquifer to the river before it can be calibrated for its representation of the discharge from the

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regional to the floodplain aquifer. The calibration process is described in Chapter 5. The calculations for 1990 in the model are carried out, so that the value of $V_{aq\text{-}aq,f}(1990)$ is given in Column I for Row 307, while $V_{aq\text{-}aq,f}(\text{PreD})$ is given in Column C.

It should also be noted that a user of the model can choose to assume that the rate of discharge from the regional aquifer to the floodplain aquifer in 1990 was not sufficient to balance 100% of the "potential" depletions taking place in the floodplain aquifer. That is, a user may decide that the rate of discharge from the regional aquifer to the floodplain aquifer in 1990 was sufficient to balance only (for example) 90% of the "potential" depletions taking place in the floodplain aquifer, and carry out the remaining calculations with an accordingly reduced estimate of $V_{aq\text{-}aq,f}(1990)$.

The three expressions, $V_{aq\text{-}aq,f}(\text{PreD}) = C_{aq\text{-}aq}X$, $V_{aq\text{-}aq,f}(1990) = C_{aq\text{-}aq}(X+Y)$, and ($V_{aq\text{-}aq,f}=0$ when $\Delta H_{aq\text{-}aq,f}=0$), are rearranged as,

$$\frac{V_{aq\text{-}aq,f}(\text{PreD})}{X} = \frac{V_{aq\text{-}aq,f}(1990)}{X+Y}, \text{ and solved for } Y\text{:}$$

$$Y = X\left(\frac{V_{aq\text{-}aq,f}(1990) - V_{aq\text{-}aq,f}(\text{PreD})}{V_{aq\text{-}aq,f}(\text{PreD})}\right).$$

(2) The value of Y is next calculated separately. Knowing the area and specific yield of the floodplain aquifer allows calculation of the change in water table elevation that would result from the removal of a volume of water from storage, by the equation,

$$Y = \frac{\left(V_{aq\text{-}aq,f}(1990) - V_{aq\text{-}aq,f}(\text{PreD})\right)}{SA},$$

where S and A are the specific yield and area of the floodplain aquifer, from Rows 33 and 31, respectively.

(3) The results of the first two steps are then combined and solved for X by the equation,

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$$X = \frac{V_{aq\text{-}aq,t}(\text{PreD})}{SA}.$$

The value of $\Delta H_{aq\text{-}aq,t}$ in 1990 is then known: $\Delta H_{aq\text{-}aq,t}(1990) = X + Y$. This value is stored implicitly in Row 30, which consists of the sum of Row 40 and $\Delta H_{aq\text{-}aq,t}(1990)$. In turn, Row 29 stores the sum of Row 39 and X.

(4) Finally, the results of the first and third steps are used to solve for $C_{aq\text{-}aq}$ by the equation,

$$C_{aq\text{-}aq} = \frac{V_{aq\text{-}aq,t}(\text{PreD})}{X}.$$

Combining the third and fourth equations, however, reveals that $C_{aq\text{-}aq}$ is nothing more than the product of the specific yield and area of the floodplain aquifer. That is, $C_{aq\text{-}aq}$ expresses the volume of water that can be stored in or removed from a 1-foot thickness of the floodplain aquifer. The value of $C_{aq\text{-}aq}$ is stored in Row 36.

The actual equation in Row 307 varies. For the 1990 initialization year, the value in Row 307 for each season, t ,consists of the larger of two expressions: (1) 0, or (2) $V_{275,t} - V_{301,t}$ minus 25% of the 1990 annual sum, $(V_{274} + V_{275} + V_{276} + V_{317} + V_{321} - V_{289} - V_{294} - V_{296} - V_{298} - V_{300} - V_{301} - V_{303})$. For all other years, Row 307 uses the seasonal expression,

$$V_{307,t} = C_{aq\text{-}aq}(h_{ra,t} - h_{fa,t}),$$

where the floodplain and regional hydraulic head values are taken from Rows 267 and 268 for the same season.

The equations in Row 307 are elaborated in one additional way. As discussed for Row 268, above, changes in storage in the regional aquifer only gradually to affect hydraulic heads in the regional aquifer along its boundary with the floodplain aquifer. Similarly, changes in storage in the floodplain aquifer cannot instantaneously affect average heads along this same boundary. Hydraulic conductivities are greater in the

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floodplain aquifer than in the regional aquifer (Vionnet, 1991; Vionnet and Maddock, 1992), however, and the floodplain aquifer is considerably smaller in volume and surface area than is the regional aquifer. It was reasoned, therefore, that it would not take 100 years for a change in storage in the floodplain aquifer to have its full effect on hydraulic heads in the floodplain aquifer along its boundary with the regional aquifer. A four-year lag was found to provide an adequate description of the system. The equations in Row 307 therefore incorporate a four-year moving average function, as well.

Row 308: Recharge to the Regional Aquifer from the City of Sierra Vista

The recharge of effluent from the City of Sierra Vista to the regional aquifer in any single season is a function of several factors: the amount of water supplied to customers in the city during that season (Row 280); the fraction of water supplied to consumers in the city that returns to the wastewater treatment facility as effluent (Row 88); the fraction of this effluent <u>not</u> lost to evaporation during treatment (1-Row 89); the fraction of the treated effluent diverted to the city's artificial wetland (Row 75); the fraction of the treated effluent that is not diverted to the artificial wetland, that is then recharged to the aquifer (Row 90); and the amount of the water diverted to the artificial wetland that eventually may recharge to the aquifer as well. The artificial wetland is assumed to recharge any water that it does not lose to evaporation. Thus, the amount of water diverted to the artificial wetland that eventually recharges to the aquifer is estimated by analogy with the behavior of stockponds supplied by surface water, i.e., as a function of the retention rate and surface area of the artificial wetland (Rows 170 and 76, respectively); and the open-water gross evaporation and precipitation rates (Rows 51 and 14). The resulting equation is,

$$V_{308,t} = \left(V_{280,t}(\text{Row}88)(1 - \text{Row}89)(\text{Row}75 + \text{Row}90)\right) - \left((\text{Row}170)(\text{Row}76)((\text{Row}51 - \text{Row}14)\right).$$

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Rows 309-316: Recharge to the Regional Aquifer from the Sierra Vista-Southeastern Suburbs, Fort Huachuca, Huachuca City, the City of Tombstone, the City of Bisbee, the Town of Naco, Rural Users in Water Service Areas, and Rural Users in Non-Service Areas

The recharge of effluent from these several census areas to the regional aquifer in any single season is a function of the same factors discussed for the City of Sierra Vista, above, except that none of these areas is modeled with diversions of effluent to any artificial wetland. The equations in these eight rows are thus identical in form to the first term in the RHS of the equation in Row 308, with the appropriate parameters and seasonal supply amounts (Rows 281-288) inserted for each census area.

Row 317: Irrigation Return to the Floodplain Aquifer in the Sierra Vista Sub-basin

The return of irrigation tailwater to the floodplain aquifer is assumed to be a function of irrigation efficiency. All water not consumed by the plants or lost to evaporation from the cultivated field surfaces is assumed to leak into the ground and so constitute a recharge to the floodplain aquifer. All agricultural irrigation is assumed to take place on the floodplain. The resulting equation is,

$$V_{317,t} = V_{289,t}(1-e),$$

where e is either the current or required irrigation efficiency for the sub-basin specified in Row 121 or 129, respectively, depending on the status of Row 179.

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Row 318: Mining Industrial Return to the Regional Aquifer in the Sierra Vista Sub-basin

Mining industrial recharges are assumed to take place exclusively to the regional aquifer, when they occur at all. The seasonal recharge volume is simply the product of the seasonal volume of mining industrial withdrawals (Row 290) and the fractional return rate for mining facilities in the sub-basin specified in Row 156.

Row 319: Other Industrial Returns to the Regional Aquifer in the Sierra Vista Sub-basin

Recharges from other industrial activities in the sub-basin are assumed to take place exclusively to the regional aquifer, when they occur at all. The seasonal recharge volume is simply the product of the seasonal volume of other industrial withdrawals (Row 291) and the fractional return rate for these other industrial facilities in the sub-basin specified in Row 157.

Row 320: SPRNCA Diversion of Groundwater into the River in the Sierra Vista Sub-basin

The model can be used to examine the effects that would occur if the BLM chooses to withdraw groundwater in order to supplement in-stream flows along the river, as discussed in Chapter 3. Any such withdrawals would constitute not only depletions from storage in the two aquifers but also gains for the river. Row 320 tabulates the seasonal total of these gains to the river as the sum of the seasonal values in Rows 296 and 297.

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Row 321: Recharge to the Floodplain Aquifer from an On-River Impoundment in the Sierra Vista Sub-basin

The model can be used to examine the effects that would occur if residents of the region choose to construct an impoundment on the main channel of the river, as discussed in Chapter 3. As also discussed in Chapter 3, however, no plans for such an impoundment currently exist and so it is not possible to estimate the retention, evaporation, or recharge rates of such a facility. Consequently, the present model retains "place-holding" rows for any future inclusion of equations to describe the effects of such a facility but otherwise contains no equations for its behavior. The value of Row 321 is simply set to 0.

4.6 INFLOWS TO BENSON SUB-BASIN

Row 324: Natural Inputs to Surface Waters in the Benson Sub-basin

The natural inputs to surface water flows in the Benson sub-basin consist of the river discharge from the Sierra Vista sub-basin plus tributary runoff from precipitation over the sub-basin watershed. Total seasonal inflow volume, $V_{324,t}$, is then estimated similarly to Row 273 as,

$$V_{324,t} = V_{304,t} + f_{P,t}T,$$

where $f_{P,t}$ is the fraction of precipitation taking place in season t, as specified in Rows 16-19; $V_{304,t}$ is the annual inflow volume from the Sierra Vista sub-basin as specified in Row 304; and T is the estimate of annual tributary inflow volume calculated using the Moosburner equation specified by Rows 13 and 20-22.

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Row 325: Natural Inputs to the Floodplain Aquifer in the Benson Sub-basin

The natural inputs to the floodplain aquifer in the Benson sub-basin consist exclusively of underflow within the floodplain aquifer from the Sierra Vista sub-basin. The seasonal underflows from the Sierra Vista sub-basin are specified in Row 300.

Row 326: Natural Inputs to the Regional Aquifer in the Benson Sub-basin

The natural inputs to the regional aquifer in the Benson sub-basin consist of underflow within the aquifer from the Sierra Vista sub-basin and mountain front recharge within the sub-basin. The model computes the seasonal volume entering the regional aquifer, $V_{326,t}$, for season t, similarly to the computations in Row 275, as,

$$V_{326,t} = V_{301,t} + \tfrac{1}{4} R_{28}(1+c),$$

where $V_{301,t}$ is the seasonal volume of underflow specified in Row 301. The remainder of the equation is as described for Row 275, above.

Row 327: Imported Water Stored in the Floodplain Aquifer in the Benson Sub-basin

The estimation of $V_{327,t}$ is identical to the estimation for Row 276 described above:

$$V_{327,t} = \tfrac{1}{4} V_{62}.$$

Row 328: Imported Water Stored in the Regional Aquifer in the Benson Sub-basin

The estimation of $V_{328,t}$ is identical to the estimation for Row 277 described above:

$$V_{328,t} = \tfrac{1}{4} V_{63}.$$

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4.7 BENSON SUB-BASIN LOSSES TO STORAGE

Rows 331-334: Use of Regional Aquifer by the City of Benson, the Town of St. David, the Town of Pomerene, and Rural Benson Sub-basin Water Service Areas

The residents of these four census areas all consume water pumped exclusively from the regional aquifer (ADWR, 1991), and all are charged for the delivery of their water. The model therefore computes the seasonal volumes of withdrawals from the regional aquifer in these census areas using the same equations described above for Row 280 except again that the V_{72} term is not present.

Row 335: Rural Benson Sub-basin Non-Service Area, Use of Regional Aquifer

The residents of this census area also consume water pumped exclusively from the regional aquifer (ADWR, 1991) but they are not charged for the delivery of their water by any regulated water service company. The model therefore estimates their seasonal volumes of withdrawals in a manner identical to that used for Row 288, above, except that the value of $F_{x,1}$ comes from Row 254 instead of Row 250.

Row 336: St. David Irrigation District Diversions of Surface Water

Irrigation practices in the Benson sub-basin differ from those carried out in the Sierra Vista sub-basin in that diversions from the San Pedro River provide a significant portion of the irrigation water supplied to the fields. The St. David Ditch, operated by the St. David Irrigation District, is the larger and more senior of the two diversions operating in the Benson sub-basin and has its diversion point located further upstream. The

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Pomerene Ditch, operated by the Pomerene Water Users Association, is the smaller and more junior of the two (see below).

The representation of the surface water diversions in the model requires the consideration of five factors that do not need to be considered for agricultural groundwater withdrawals:

(1) Surface diversions are governed by a legal doctrine of "appropriation," which stipulates that the holders of a more senior diversion right can divert 100% of their claimed water right even if doing so leaves no water in the stream for downstream holders of more junior rights. At the same time, it is physically impossible for any claimant to divert more water than is actually present in the stream at the point of diversion.

(2) Surface diversion rights are poorly defined for the St. David and Pomerene claimants (ADWR, 1991) and are presently included in the General Adjudication.

(3) Surface diversions do not lend themselves as well to taxation as do irrigation well withdrawals mainly due to legal precedent.

(4) Surface diversions can be less expensive to develop and maintain than well fields and therefore often comprise a preferred water source for irrigation. That is, irrigators with access to both surface water and groundwater are likely to try to fulfill their water needs first with surface water and turn to groundwater only when their supplies of surface water do not meet all of their needs. Surface water supplies vary through the seasons, however, due to their dependence on the annual natural cycle of precipitation and stream discharges.

(5) Conversely, if the number of acres under irrigation decrease, it may be possible that surface water diversions alone will be sufficient to supply the needs of an irrigation district during a particular season of the year. If the number of acres under irrigation

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decreases still further even the need for the surface diversions during that season will decline as well.

These five factors resulted in the following decisions for modeling the diversions:

(1) Demands for irrigation water in the St. David Irrigation District must be scaled relative to the number of acres under irrigation. If the need for irrigation water during a particular season falls below the historic quantity of diversion as a result of reductions in irrigated acreage then the demand for surface water must be scaled back accordingly. Otherwise, the district must be allowed to claim its entire historic quantity of diversion specified in Row 118.

(2) Any diversion of water from the river, however, must be limited to the volume of flow in the river, if this flow is less than the historic quantity of diversion. It should be noted that the diversion points for the St. David and Pomerene ditches lie close to the southern boundary of the Benson sub-basin. Consequently, the river discharges from the Sierra Vista sub-basin (Row 304, above) provide a useful approximation to the amount of river flow available for diversion.

(3) If the demand for surface water must be scaled back, to take account of major reductions in acreage within the district, this scaling back must be based on per-acre irrigation needs. These needs are measured as previously discussed in Chapter 3 for Rows 115-137 and in the present chapter for Row 289. The needs depend on average crop consumptive use requirements, effective precipitation, irrigation efficiency, and any imposed water management goals of decreased consumptive use or increased efficiency.

(4) Seasonal demand rates for surface water in the St. David Irrigation district were estimated based on historic patterns of use, as documented in ADWR (1991:Table 5-26). These historic patterns indicate that, within the total annual diversion, the following

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fractions were diverted in each season: Season I, .5057; Season II, .1770; Season III, .0056; Season IV, .3117.

The equation for Row 336 for $V_{336,t}$ for each season therefore has three parts nested within a minimizing function that selects the smallest value among these three:

(i) $V_{336,t}$ = a standard per-acre demand equation identical to that used in Row 289 except that the acreage figure is taken from Row 384 and except that no mechanism is provided for pricing (surcharge) regulation of demand;

(ii) $V_{336,t} = V_{118} f_{d,t}$, where V_{118} is the annual historic diversion given in Row 118 and $f_{d,t}$ is the fraction of the annual diversion assignable to the current season; and

(iii) $V_{336,t} = V_{304,t}$, the flow in the river itself.

Row 337: Pomerene Water Users Association Diversions of Surface Water

The diversion of water from the river into the Pomerene Ditch is estimated in a manner identical to that used for the St. David Ditch with one crucial exception. The diversion rights of the Pomerene Water Users Association are junior to those of the St. David Irrigation District. Thus, the ability to divert water into the Pomerene Ditch ultimately is limited not by the volume of flow of the river as it enters the sub-basin but by the volume of flow available after the St. David Irrigation District has claimed as much as it needs up to its full historic quantity of use. The three parts of the MIN expression for Row 337 therefore are:

(i) $V_{337,t}$ = a standard per-acre demand equation identical to that used in Row 289 except that the acreage figure is taken from Row 384 and except that no mechanism is provided for pricing (surcharge) regulation of demand;

(ii) $V_{337,t} = V_{120} f_{d,t}$, where V_{120} is the annual historic diversion given in Row 120 and $f_{d,t}$ is the fraction of the annual diversion assignable to the current season; and

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(iii) $V_{337,t} = V_{304,t} - V_{336,t}$, the flow in the river minus the water diverted by at the St. David Ditch.

The seasonal demand rates for surface water in the Pomerene Water Users Association also were estimated based on historic patterns of use, as documented in ADWR (1991:Table 5-15). These historic patterns indicate that within the total annual diversion the following fractions were diverted in each season: Season I, .5552; Season II, .1647; Season III, .0138; Season IV, .2663.

Row 338: Irrigation Use of Groundwater in the Benson Sub-basin

Irrigation use of groundwater in the Benson sub-basin also includes withdrawals from both the floodplain and regional aquifers (Roeske and Werrell, 1973; Putnam *et al.*, 1988; ADWR, 1991). The artesian conditions in the Benson-St. David area in particular encourage pumping from the regional aquifer. However, it is not clear to what extent the pumped wells take water from the regional versus the floodplain aquifer. As a result, it was necessary to tabulate the irrigation withdrawals in the sub-basin as withdrawals from the floodplain aquifer alone, as noted for Row 259, above.

The model represents irrigation demand for water in the sub-basin in a manner identical to that used for Row 289, above, with one crucial exception. The equation in Row 289 estimating irrigation demand for groundwater in the Sierra Vista sub-basin projects the total quantity of demand for irrigation water given the number of acres under cultivation and then assumes that 100% of this quantity is met by ground-water withdrawals. The equation for Row 338 also projects the total quantity of demand for irrigation water for the Benson sub-basin given the number of acres under cultivation in that sub-basin. However, some fraction of this quantity in the Benson sub-basin is met by the surface diversions tabulated in Rows 336 and 337.

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The equations in Row 338 thus have two parts: First, each equation estimates the total quantity of demand using the same form of equation used in Row 289. Second, each equation reduces this estimate of total quantity of demand by the amount of water supplied by the surface diversions (Rows 336 and 337). The final result of these calculations is an estimate of the total quantity of groundwater that will be pumped to complete each season's quantity of demand for irrigation water.

Row 339: Mining Industrial Use of the Regional Aquifer in the Benson Sub-basin

Mining activities in the Benson sub-basin also use water exclusively from the regional aquifer, as discussed in Chapter 3. The seasonal withdrawals by the mining industry in the sub-basin are estimated in a manner identical to that used in Row 290, above, except that V_y for 1990 takes its value from Row 158 when Row 175 = 0.

Row 340: Other Industrial Use of the Regional Aquifer in the Benson Sub-basin

All other industrial activities in the Benson sub-basin also use water exclusively from the regional aquifer, as discussed in Chapter 3. The seasonal withdrawals by these other industries in the sub-basin are estimated in a manner identical to that used in Row 291 except that V_y for 1990 takes its value from Row 159 when Row 175 = 0.

Row 341: Evaporation from Runoff-Supplied Stockponds and Reservoirs in the Benson Sub-basin

The net seasonal losses from runoff-supplied stockponds and reservoirs in the Benson sub-basin are estimated in a manner identical to that described for the Sierra Vista sub-basin for Row 292 above except that A_r, the area of runoff-supplied stockponds and reservoirs, is taken from Row 167.

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Row 342: Evaporation from Groundwater-Supplied Stockponds and Reservoirs in the Benson Sub-basin

The losses from groundwater-supplied stockponds and reservoirs in the Benson sub-basin are estimated using the same equation developed for the Sierra Vista sub-basin for Row 293 except that A_s, the area of the groundwater-supplied impoundments, is taken from Row 169.

Row 343: Phreatophyte Consumption from the Floodplain Aquifer in the Benson Sub-basin

Seasonal phreatophyte consumption in the Benson sub-basin is estimated using the same equations developed for the Sierra Vista sub-basin for Row 294 except that the value of A_p is taken from Row 262 and the value of C_p is taken from Row 145.

Row 344: Channel Evaporation from the Riverbed in the Benson Sub-basin

Evaporative losses along the riverbed in the Benson sub-basin arise from the same two sources described for the Sierra Vista sub-basin for Row 295: evaporation from open water surfaces; and evaporation from bare, unvegetated ground exposed along the water course. Seasonal channel evaporation losses therefore are estimated for the Benson sub-basin using the same equations developed for the Sierra Vista sub-basin with one crucial difference. The San Pedro River loses water to evaporation, recharge to the floodplain aquifer, and surface diversions all along its passage through the Benson sub-basin. As a result, the river can run dry before it reaches the northern boundary of the sub-basin.

Open-water evaporation clearly does not take place from a dry riverbed. However, bareground evaporation can continue to take place by drawing water from the

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riverbed and from surfaces wetted by runoff from precipitation events. The model has no means for estimating how much of the length of the riverbed in the sub-basin will go dry in a given season. It can only estimate whether or not the river will flow at the northern boundary of the sub-basin at the end of each season. Consequently, the model uses a simple expedient to determine whether open-water evaporation should be included in the estimation of channel evaporation losses at all, as follows: If the river loses more water than it receives along its passage through the sub-basin then the model estimates channel evaporation losses based on bareground evaporation alone. Otherwise, the model estimates the channel evaporation losses using the equation developed for the Sierra Vista sub-basin for Row 295, substituting the value of Row 353 for $Q_{R,t}$, the average river discharge in season t. If $Q_{R,t} \leq 0$, then the river is considered to be losing more water than it receives along its passage through the sub-basin in a given season.

Rows 345 and 346: SPRNCA Withdrawals from the Floodplain and Regional Aquifers in the Benson Sub-basin

Ground-water withdrawals by the BLM to supplement surface flows in the river in the Benson sub-basin are modeled using the same procedure developed for the Sierra Vista sub-basin for Rows 296-297 except that the quantities to be withdrawn are specified in Rows 150 and 151 rather than in Rows 148 and 149.

Rows 347 and 348: Exports from the Floodplain and Regional Aquifers in the Benson Sub-basin

Exports of groundwater from the Benson sub-basin are modeled using the same procedure developed for the Sierra Vista sub-basin for Rows 298 and 299 except that the quantities to be exported are specified in Rows 64 and 65 rather than in Rows 60 and 61.

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Rows 349 and 350: Underflows from the Floodplain and Regional Aquifers in the Benson Sub-basin

The equations in Rows 349 and 350 are identical to those developed for the Sierra Vista sub-basin for Rows 300 and 301.

Row 351: Potential Discharge from the Floodplain Aquifer to the River in the Benson Sub-basin

Summary equations to estimate the potential flow of water between the floodplain aquifer and the river in the Benson sub-basin were developed using the same methods of simulation applied to the Sierra Vista sub-basin described for Row 302, above. Figures 4-5, 4-6, and 4-7 summarize the results of the simulations for the Benson sub-basin. The summary linear equations are:

For $2 > h_{riv} > 0.045$ feet, $V_{351,t} = -\Delta H[705.81h_{riv} + 193.03]$, in acre-feet for a single season.

For $h_{riv} \leq 0.045$ feet, $V_{351,t} = -225\Delta H$, in acre-feet for a single season.

The equations in Row 351 also include a stream-aquifer volumetric conductance coefficient specified in Row 41. Again, this coefficient is a calibration parameter, the value of which may be adjusted in order to simulate alternative hydraulic conductances along the riverbed. The process of calibration is described in Chapter 5, below.

Row 352: Available Discharge from the Floodplain Aquifer to the River in the Benson Sub-basin

The equations in Row 352 have the same structure used for the equations in Row 303 for the Sierra Vista sub-basin.

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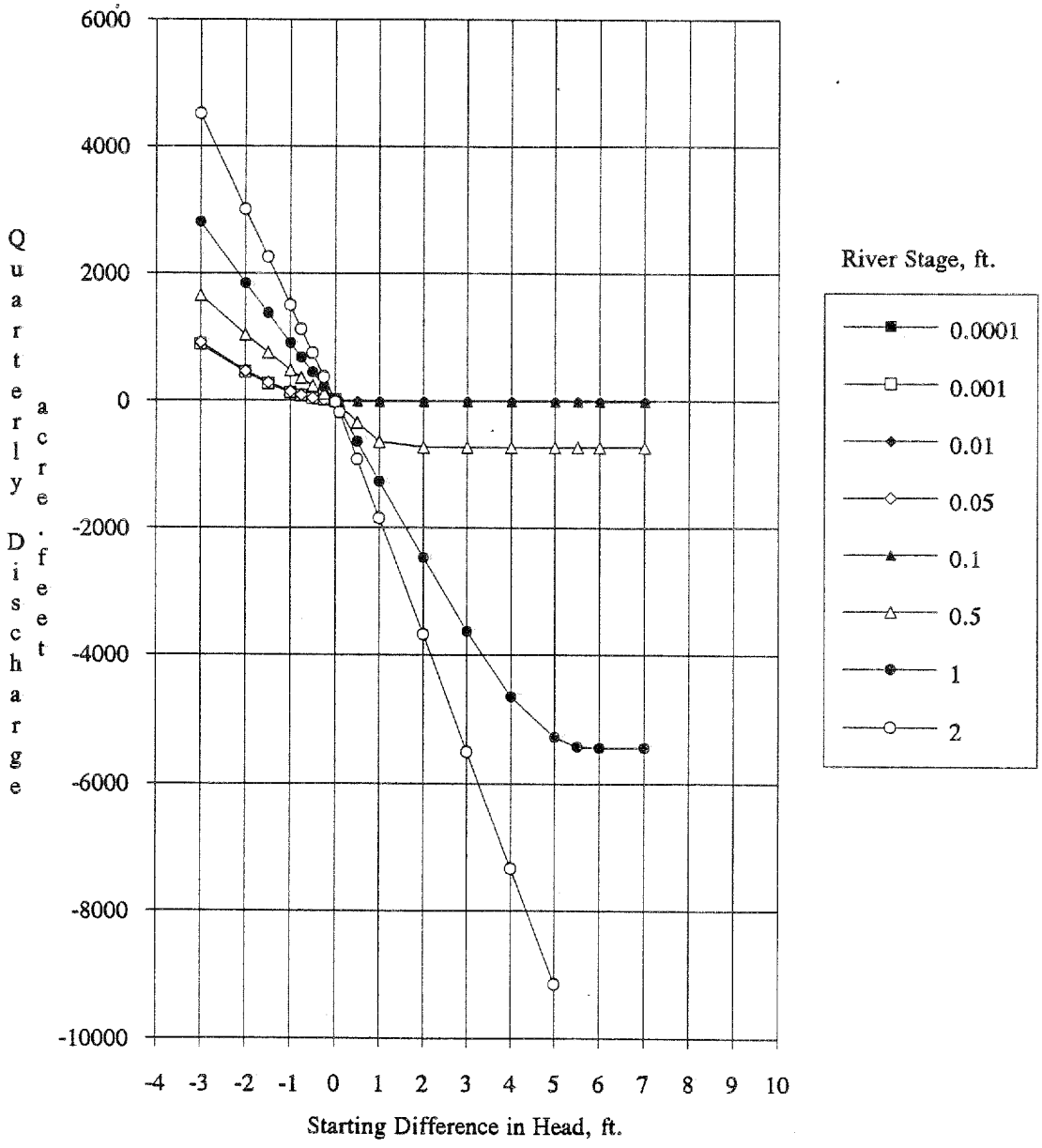
Quarterly Discharge from Aquifer to River
vs. Start-of-Quarter Difference in Head (River-Aquifer)
for Different Values of Start-of-Quarter River Stage,
Simulated Benson Sub-basin
Figure 4-5



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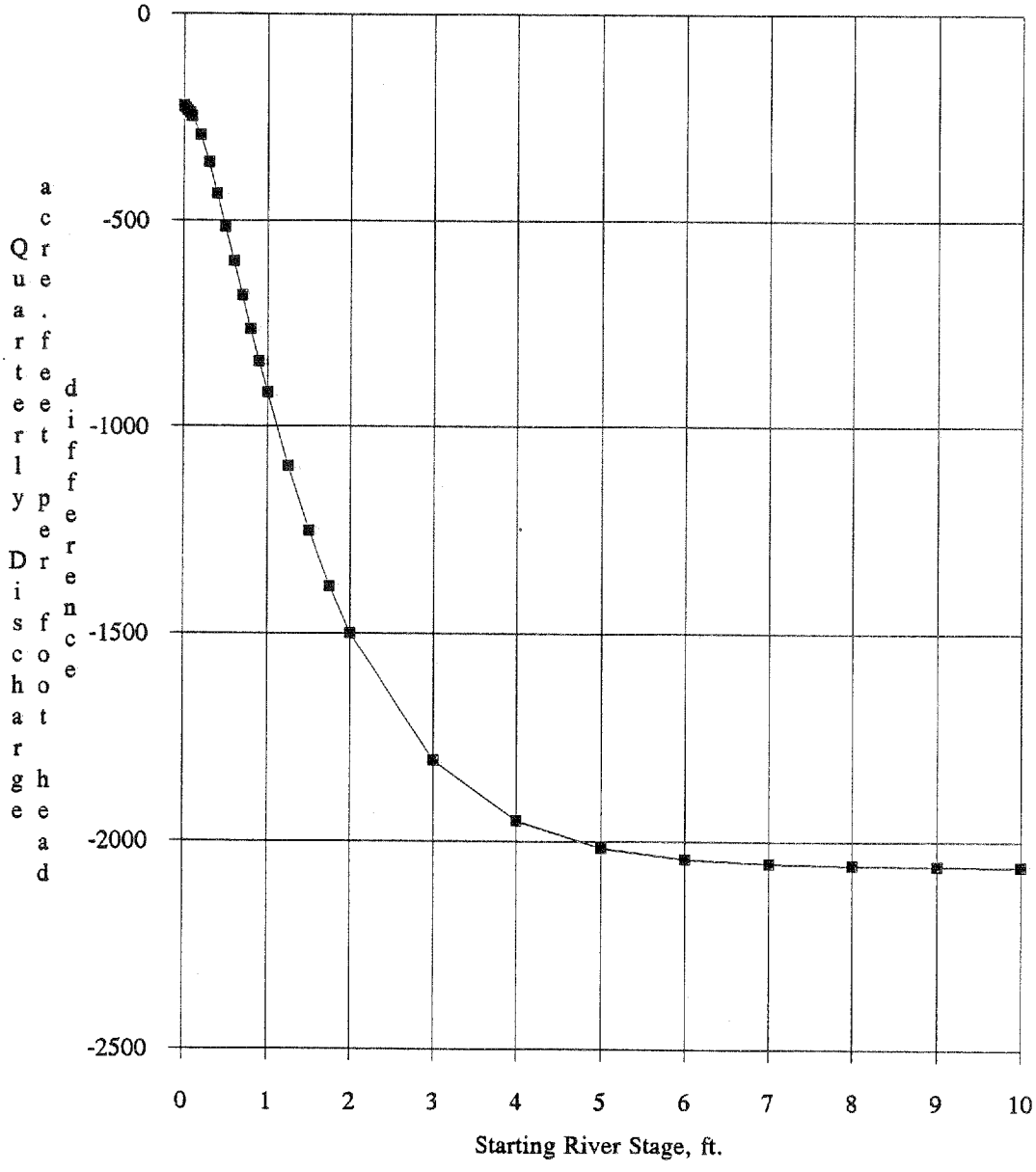
Quarterly Discharge from Aquifer to River
per Unit Start-of-Quarter Head Difference (River-Aquifer)
vs. Start-of-Quarter River Stage,
Simulated Benson Sub-basin
Figure 4-6



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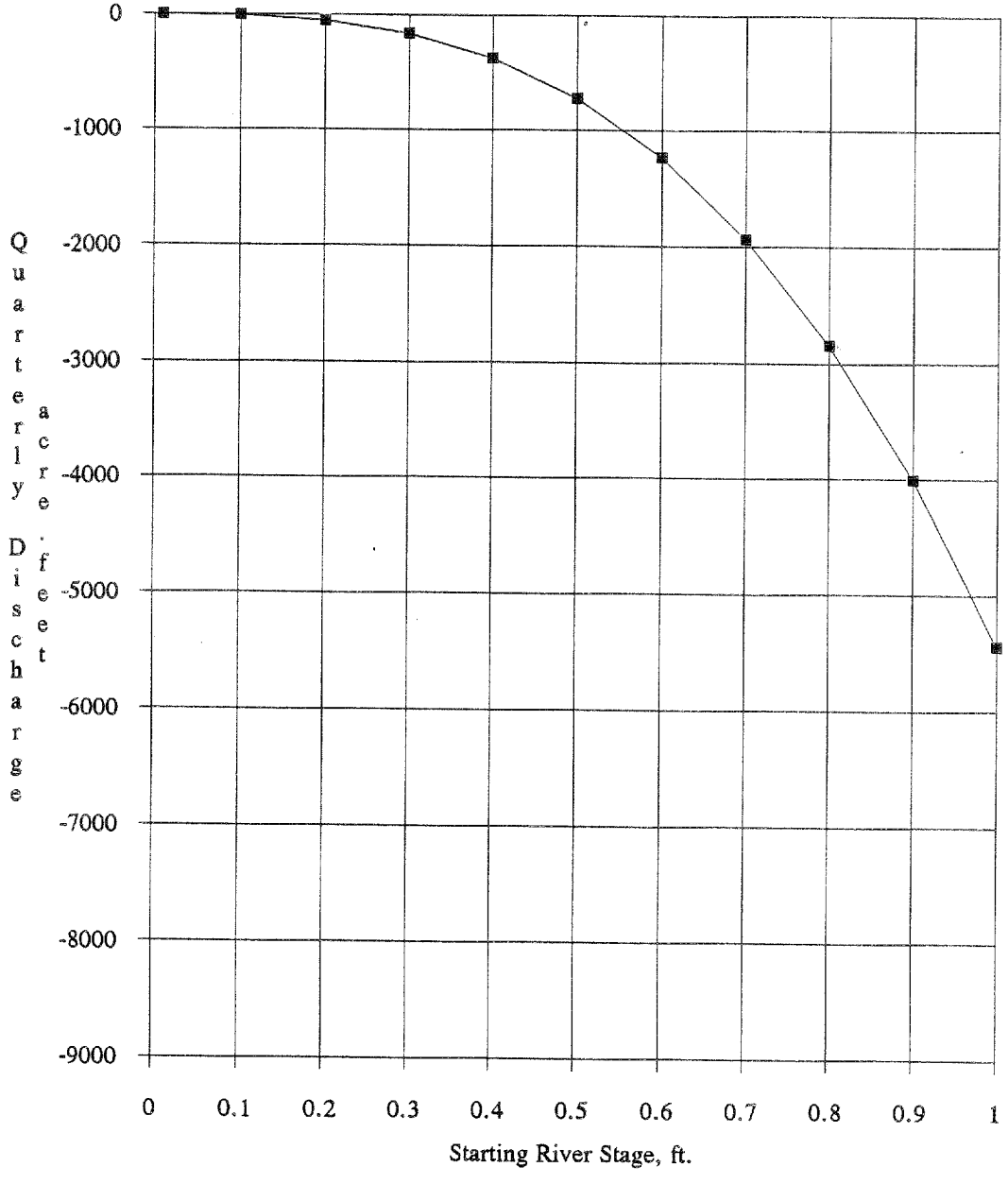
Quarterly Discharge from Aquifer to River,
"Leveling-Off" Discharge vs. Start-of-Quarter River Stage,
Simulated Benson Sub-basin
Figure 4-7



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The equation in Row 352 again consists of an IF/THEN/ELSE expression that detects two conditions:

(1) $\Delta H > 0$, (that is, $h_{riv} > h_{aq}$), and

(2) $V_{352,t} < -(V_{324,t} - V_{336,t} - V_{337,t} - V_{341,t} - V_{344,t} + V_{365,t})$,

where the terms in the RHS of the second statement are the inflow of surface waters to the river in the sub-basin (from Row 324, above), the losses of surface water to irrigation diversions (from Rows 336 and 337, above), the loss of surface runoff intercepted by stockponds and reservoirs (from Row 341, above), the loss of surface water to channel evaporation (from Row 344, above), and supplementation of in-stream flows in the SPRNCA by the BLM from groundwater (from Row 365, below), respectively, for season t. These six terms in the RHS of the second statement together constitute the flow of water in the river that is potentially available for discharge to the floodplain aquifer. The equation in Row 352 specifies that, if both of the above conditions are true, the available discharge of water from the river to the aquifer is equal to the value of the RHS of the second statement; otherwise, the discharge is equal to the potential discharge estimated in Row 351, above.

Row 353: River Discharge from the Benson Sub-basin

The equations in Row 353 tabulates the inputs and losses to river flow in the Benson sub-basin by season using the same form as the equations in Row 304 for the Sierra Vista sub-basin, as,

$$V_{353,t} = V_{324,t} - V_{336,t} - V_{337,t} - V_{341,t} - V_{344,t} + V_{352,t} + V_{365,t},$$

where $V_{352,t}$ is the result of the equation in Row 352 for season t, and all other terms are as stated above in the description of Row 352.

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4.8 BENSON SUB-BASIN RECHARGE AND RETURNS TO STORAGE

Row 356: Recharge from the Regional to the Floodplain Aquifer in the Benson Sub-basin

Equations for estimating the seasonal volume of recharge from the regional to the floodplain aquifer in the Benson sub-basin were developed using the same methods applied to the Sierra Vista sub-basin for Row 307. Again, it was necessary to assume that, at least in 1990, discharges from the regional aquifer to the floodplain aquifer were sufficient to balance 100% of the "potential" depletions taking place in the floodplain aquifer. The value of $(V_{325} + V_{326} + V_{327} + V_{362} - V_{338} - V_{343} - V_{345} - V_{347} - V_{349} - V_{350} - V_{352})$ again is calculated as 25% of the sum of Row 28 and Row 7 minus Row 25. The value of $(V_{325} + V_{326} + V_{327} + V_{362} - V_{338} - V_{343} - V_{345} - V_{347} - V_{349} - V_{350} - V_{352})$ is calculated as 25% of the annual sum, $(-V_{325} - V_{327} - V_{362} + V_{338} + V_{343} + V_{345} + V_{347} + V_{349} + V_{352})$ for 1990, the initialization year for the model. Note that the calculation of $V_{aq\text{-}aq,t}(1990)$ requires the prior estimation of V_{352}, the annual discharge from the floodplain aquifer to the river. Thus, again, the model must first be calibrated for accurate representation of the discharge from the floodplain aquifer to the river before it can be calibrated for accurate representation of the discharge from the regional to the floodplain aquifer. The calibration process is described fully, in Chapter 5. The equations in Row 356, finally, include the same four-year moving average function described for Row 307.

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Rows 357-361: Recharge to the Regional Aquifer from the City of Benson, the Town of St. David, the Town of Pomerene, Rural Users in Water Service Areas, and Rural Users in Non-Service Areas

The equations in these five rows are identical in form to those used in Rows 309-316, above, with the appropriate parameters and seasonal supply amounts (Rows 331-335) inserted for each census area.

Row 362: Irrigation Return to the Floodplain Aquifer in the Benson Sub-basin

The return of irrigation tailwater to the floodplain aquifer in the Benson sub-basin is estimated in the same manner applied to the Sierra Vista sub-basin, as discussed for Row 317, above.

Row 363: Mining Industrial Return to the Regional Aquifer in the Benson Sub-basin

Mining industrial recharges in the Benson sub-basin are estimated using the same procedure developed for the Sierra Vista sub-basin and discussed for Row 318, above.

Row 364: Other Industrial Returns to the Regional Aquifer in the Benson Sub-basin

Recharges from other industrial activities in the Benson sub-basin are estimated using the same procedure developed for the Sierra Vista sub-basin and discussed for Row 319, above.

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Row 365: SPRNCA Diversion of Groundwater into the River in the Sierra Vista Sub-basin

BLM withdrawals of groundwater in the Benson sub-basin to supplement in-stream flows along the river are estimated using the same procedure developed for the Sierra Vista sub-basin and discussed for Row 320, above, based on the sum of the seasonal values in Rows 345 and 346.

4.9 SEASONAL AND ANNUAL HYDROLOGICAL CHANGES

Row 368: Seasonal or Annual Change in Floodplain Aquifer Storage in the Sierra Vista Sub-basin

This row simply tabulates the change in storage from the immediately preceding season or year to the current season or year, using the values in Row 257, above.

Row 369: Seasonal or Annual Change in Regional Aquifer Storage in the Sierra Vista Sub-basin

This row tabulates the change in storage from the immediately preceding season or year to the current season or year, using the values in Row 258.

Row 370: Seasonal or Annual Change in Floodplain Aquifer Storage in the Benson Sub-basin

This row tabulates the change in storage from the immediately preceding season or year to the current season or year, using the values in Row 259.

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Row 371: Seasonal or Annual Change in Floodplain Aquifer Storage in the Benson Sub-basin

This row tabulates the change in storage from the immediately preceding season or year to the current season or year, using the values in Row 260.

Row 372: Seasonal or Annual Change in Floodplain Aquifer Depth to Water in the Sierra Vista Sub-basin

This row tabulates the change in depth to water from the immediately preceding season or year to the current season or year, using the values in Rows 368, 31 and 33.

Row 373: Seasonal or Annual Change in Regional Aquifer Depth to Water in the Sierra Vista Sub-basin

This row tabulates the change in depth to water from the immediately preceding season or year to the current season or year, using the values in Rows 369, 24 and 26.

Row 374: Seasonal or Annual Change in Floodplain Aquifer Depth to Water in the Benson Sub-basin

This row tabulates the change in storage from the immediately preceding season or year to the current season or year, using the values in Rows 370, 31 and 33.

Row 375: Seasonal or Annual Change in Floodplain Aquifer Depth to Water in the Benson Sub-basin

This row tabulates the change in depth to water from the immediately preceding season or year to the current season or year, using the values in Rows 371, 24 and 26.

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Row 376: Annual Change in Discharge of the River from the Sierra Vista Sub-basin

This row tabulates the change in river discharge between the preceding year and the current year, using the values in Row 304.

Row 377: Annual Change in Discharge of the River from the Benson Sub-basin

This row tabulates the change in river discharge between the preceding year and the current year, using the values in Row 353.

Row 378: Annual Change in the Potential Area of Riparian Vegetation in the Sierra Vista Sub-basin

This row tabulates the change in the potential area of riparian vegetation between the preceding year and the current year, using the values in Row 261.

Row 379: Annual Change in the Potential Area of Riparian Vegetation in the Benson Sub-basin

This row tabulates the change in the potential area of riparian vegetation between the preceding year and the current year, using the values in Row 262.

Rows 380 and 381: Cumulative Changes in Regional Aquifer Hydraulic Head Along Boundary, Sierra Vista and Benson Sub-basins

These two rows accumulate the 1/100 fractional increments of change in hydraulic head in the regional aquifer in the two sub-basin, adding 1/100 of the value of Row 373 or Row 375 for each year onto the cumulative total of these additions from all preceding

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years. The accumulated value is used in the calculation of the difference in head between the regional and floodplain aquifers, in Rows 268 and 270, above.

4.10 NET ANNUAL SOCIOECONOMIC CHANGES

Row 384: Total Population in the Upper San Pedro River Basin (excluding Bisbee)

This row tabulates the projected total population of the Upper San Pedro River Basin exclusive of Bisbee, by summing the values in Rows 204-208 and 210-217 for the end of each year.

Rows 385 and 386: Total Irrigated Acreage in the Sierra Vista and Benson Sub-basins

These rows tabulate the total acreage devoted to irrigated agriculture in the two sub-basins at the end of each year as a function the number of acres devoted to irrigation at the end of the preceding year (Rows 385 and 386); the annual rate of growth projected for irrigated acreage (Rows 127 and 128); and losses during the current year due to the return of formerly cultivated lands to natural vegetation (Rows 378 and 379). The area of riparian vegetation in the sub-basin is allowed to grow at the expense of irrigated acreage, but irrigated acreage is not allowed to grow at the expense of riparian acreage.

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Chapter 5
Calibration and Applications

The use of WATERBUD to examine the five scenarios and five groups of policy options discussed in Chapter 1 requires prior calibration of the model. As discussed in Chapters 3 and 4, WATERBUD is built around a large number of parameters. The values of most of these parameters are determined using published data. A few of these parameters, however, are meant to be adjusted or "calibrated," in order for the model to operate in an appropriate manner. These adjustable parameters include a pair of equation coefficients, and the estimates of average hydraulic heads in the floodplain and regional aquifers. If necessary, the estimated thickness of the riverbed also can be adjusted. This chapter first describes the process of calibration, and then presents the application of the model to the five scenarios and five groups of policy options discussed in Chapter 1.

5.1 CALIBRATION

All of the parameters presented in Chapter 3 affect the operation of the model, and hence affect the results of its application. As noted above, the values of most parameters derive from published data or from the results of other, independent studies. When making decisions based on the results of a simulation with the model, users must decide whether the values used for the majority of the parameters are acceptable. And the values of many parameters can be changed, to simulate different economic, climatic, or demographic conditions. However, as also noted above, the values for a small number of parameters are not selected based on independent, external sources of information. Instead, they must be adjusted to calibrate or "fine-tune" the operation of the model.

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The parameters requiring adjustment are those contained in Rows 29, 30, 39, 40, and 41: the Steady-State Elevation of the Regional Aquifer Water Table Above the Riverbed; the 1990 Estimated Elevation of the Regional Aquifer Water Table Above the Riverbed; the Steady-State Elevation of the Floodplain Aquifer Water Table Above the Riverbed; the 1990 Estimated Elevation of the Floodplain Aquifer Water Table Above the Riverbed; and the Stream-Aquifer Volumetric Conductance Coefficient, respectively. The term, Steady State, refers to estimated conditions in the upper basin prior to significant human impacts on the water budget.

Ordinarily, the model will not need to have the values for these calibration parameters changed. The values given in Chapter 3, and explained below, are the recommended default values. However, if a user of the model changes any of its equations, such as the equations for projecting agricultural consumption, tributary runoff, or municipal consumption, it may be necessary to adjust the values of the calibration parameters.

Calibration of the model must proceed in four steps: (1) The values in Rows 39 and 41 are adjusted, first for the Sierra Vista sub-basin and then for the Benson sub-basin; (2) the values in Row 29 are adjusted; (3) the values in Row 40 are adjusted, first for the Sierra Vista sub-basin and then for the Benson sub-basin; and (4) the values in Row 30 are adjusted.. Calibration does not require projecting a twenty-year water budget. Instead, the process only involves simulation of the model's initialization year, 1990. The process is carried out with a simplified version of the model, that only simulates this initialization year.

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5.1.1 Step 1: Calibration of Steady-State River-Aquifer Interactions

The most important step in calibration of the model is the adjustment of Rows 39 and 41. The values in these two rows control the flow of water between the river and the floodplain aquifer.

The rate of flow of water between the river and the floodplain aquifer depends on several properties of the hydrologic system, which affect the difference in hydraulic head between the river and the aquifer and the hydraulic conductance of the riverbed. The two hydraulic head values depend on the rate of flow of the river, and on the rate of recharge of water to the floodplain aquifer both from the river and from sources. If no external data are available, with which to control the process of calibration, a user of the model is confronted with the problem that a given rate of flow from the river to the aquifer (or vice versa) can be achieved in one of two ways: The user can hold the hydraulic head values constant and adjust the estimate of riverbed conductance; or hold the estimate of riverbed conductance constant and adjust the estimate of hydraulic head in the aquifer. Head in the river is controlled independently, as a function of the rate of flow of the river alone.

Avoiding this problem of having two independent ways to calibrate the model requires finding some way to fix either the hydraulic heads or the riverbed conductance based on independent information. Fortunately, the estimate of conductance of the riverbed (see Row 302, Chapter 4), may be taken as independently determined. Thus, in principal, only the values for hydraulic heads need to be calibrated. However, this assertion requires a caveat: If calibration proves impossible through the adjustment of the hydraulic head starting values alone, then the user must consider the possibility that the conductance value also must be adjusted.

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Initial calibration of the model, to determine if the estimate for riverbed conductance is acceptable, is accomplished by first running the model for steady-state conditions. In the language of numerical simulation, this calibration against steady-state conditions is referred to as setting the initial conditions for the model. Calibration against steady-state conditions makes use of a useful property of a steady state water budget, when analyzed for conditions in the absence of all human impacts on the system: By definition, there should be no change in average storage taking place in either aquifer. Simulating a steady state system, then, provides an independent means for estimating the average hydraulic head in the floodplain aquifer.

Simulating a steady-state system requires developing an accurate description of the upper basin's water budget in the absence of human activities. Only one aspect of the natural system has been affected sufficiently by human activities, that its behavior prior to human impacts is uncertain. This aspect is the area and species composition of the riparian corridor along the floodplain. The clearing of lands for agriculture and other human activities, and the withdrawal of water from the river and the floodplain aquifer, have both affected a reduction in the area occupied by phreatophytes in the upper basin (BLM, 1987; ADWR, 1991; Hereford, 1991).

Estimating the pre-development acreage and water consumption of the upper basin's riparian corridor therefore requires estimating how many acres have subsequently been lost, to land clearance and to declines in habitat viability. The number of acres lost to clearance, also known as "salvageable riparian acreage," has been estimated by ADWR and is discussed in Chapter, Rows 142 and 143, above. ADWR (1991:259-261 and Appendixes B, C, D, F) has also developed estimates of the effects of reductions in the availability of water on the viability of riparian habitat, based on comparisons to historic conditions in southeastern Arizona in general. It is estimated that, under pre-development

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conditions, the total acreage of phreatophytes would have been 12% greater than the combined total of existing and salvageable riparian acreage identified in 1990. These estimates by ADWR are recommended, for carrying out steady-state simulations with WATERBUD.

Carrying out a steady-state simulation with the model requires setting Rows 174 and 175 to "yes" (value = 1), and multiplying the values in Rows 140-143 by 1.12. These settings specify that the system is to be modeled without human depletions, that the salvageable riparian acres are to be included in the total riparian acreage, and that total riparian acreage is to be modeled as being 12% larger than specified for 1990.

Calibration for the steady state simulation requires the following steps:

(1.1) The user adjusts the value in Row 39, the elevation of the water table in the floodplain aquifer above the riverbed, until the model shows an absence of change in aquifer storage during the initialization year. For reasons discussed below, the model automatically forces the floodplain aquifer to remain at a constant value for the initialization year. Thus, it is only necessary to adjust the value in Row 41 to achieve an absence of change in the regional aquifer. The annual changes in storage in the floodplain and regional aquifers are displayed in Rows 257 and 258, Column I, for the Sierra Vista sub-basin; and Rows 259 and 260, Column I, for the Benson sub-basin.

(1.2) Adjusting the value in Row 41 does have an effect on the rate of flow of the river, however, which affects the model's calculation of average seasonal river stage. Thus, after each adjustment of Row 41, the user must re-adjust the value in Row 39 (usually only very slightly) as described for Step 1.1, above. Steps 1.1 and 1.2 are then repeated, until they have converged to an acceptable level of precision. It is necessary that these steps be repeated only to achieve an estimate for Row 41 that is stable to four decimal places.

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(1.3) If the river in either of the sub-basins is a gaining river, that is, if it receives more water from the aquifer than it discharges to the aquifer, then adjustment of the value of Row 39 will be sufficient to calibrate the model for steady state conditions. However, if the river is losing more water than it gains from the aquifer, this need not be the case. The river loses more than it gains from the floodplain aquifer only when average hydraulic heads are lower in the aquifer than in the river. It may also be the case, however, that the average head in the aquifer also lies below the bottom of the riverbed, for the thickness of the riverbed specified in Row 43. If the aquifer head is calculated to lie at a lower elevation than the bottom of the riverbed, then the rate of flow from the river to the aquifer will be a constant. This constant rate, as calculated in WATERBUD (see Row 302) may not be sufficient to calibrate the model for Step 1. The user must then decide which of two parameters requires additional adjustment: the riverbed thickness values in Row 43, or the stream-aquifer volumetric conductance coefficient in Row 41.

The position taken in this thesis is that the estimates of conductance used to develop the equations for Rows 302 and 351 are based on reasonable independent data. The estimates of riverbed thickness given in Rows 43, however, are arbitrary values, with no independent data for their evaluation. It is recommended, therefore, that, in the event that the user must choose between adjusting the values in Row 41 or Row 43, it is more appropriate to adjust the estimates in Row 43. Row 43 should be adjusted, so that it just exceeds the thickness necessary for the model to be calibrated for steady-state conditions. The values in Row 41 should be left at 1.000 unless compelling reasons exist to do otherwise.

It is also crucial to note, that the rate of flow of the river, and hence the average river stage in the Benson sub-basin, depend on the discharge of the river from the Sierra

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Vista sub-basin. Consequently, the above three Steps, 1.1-1.3, must be carried out first for the Sierra Vista sub-basin.

5.1.2 Step 2: Calibration of River-Aquifer Interactions in 1990

The completion of Steps 1.1-1.3 results in the acceptance of estimates for both riverbed conductance and riverbed thickness, that should then apply to both steady-state and developed hydrologic conditions in the upper basin. The next step in calibration of the model is to develop an appropriate description of flow between the river and the aquifer under 1990 conditions. With the values in Rows 41 and 43 fixed, it is only necessary to adjust the value in Rows 40, the 1990 estimated elevation of the floodplain aquifer water table above the riverbed. Specifically, the values in Row 40 are adjusted, so that the model correctly estimates the flow of water in the river at the end of 1990, based on the reference discharge values provided in Row 38 (Chapter 3), above.

The use of river discharge as the reference variable for Step 2 requires explanation. Under 1990 conditions, it cannot be assumed that storage is unchanging in either aquifer. Indeed, the fact that water is being pumped from both aquifers makes it unlikely that both aquifers are in equilibrium in either sub-basin. The discharge of the river from each sub-basin for the initialization year is known, however. And once the estimate of the conductance of the riverbed is fixed, river discharge becomes the property of the water budget most directly affected by the difference in hydraulic head between the aquifer and the river.

Conceivably, the value of Row 40 also could be estimated, based on a separate estimate of the net volume of water removed from storage in the floodplain aquifer since the start of human development of the basin. However, it is unlikely that such an estimate of net historic change in storage would be particularly accurate.

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Again, it is crucial to note that the rate of flow of the river in the Benson sub-basin depends on the discharge of the river from the Sierra Vista sub-basin. Consequently, as with Step 1, Step 2 must be carried out first for the Sierra Vista sub-basin.

5.1.3 Step 3: Calibration of Steady-State Regional-Floodplain Aquifer Interactions

The relationship between average hydraulic head in the regional aquifer (Row 29), average hydraulic head in the floodplain aquifer, and the rate of flow between the two under steady-state conditions was discussed in Chapter 4 in the explanation for Rows 307 and 356. As noted there, calibration for steady state conditions involves simply tabulating the total steady-state discharge and then calculating the value of the steady-state inter-aquifer head difference, X (see discussion for Row 307, above). The steady-state average hydraulic head in the regional aquifer is then calculated as X + the steady-state average hydraulic head in the floodplain aquifer estimated in Step 1, above.

Calculation of the values for Row 29 does not affect the simulation of the initialization year, but cannot be carried out until Steps 1 and 2 have been completed. Once these prior steps have been completed, Step 3 can be carried out for both sub-basins.

5.1.4 Step 4: Calibration of Regional-Floodplain Aquifer Interactions in 1990

The relationship between average hydraulic head in the regional aquifer (Row 30), average hydraulic head in the floodplain aquifer, and the rate of flow between the two under 1990 conditions also was discussed in Chapter 4 in the explanation for Rows 307 and 356. It is likely that the history of human development of the basin has resulted in changes in hydraulic heads in both aquifers. Unfortunately, there are few pieces of information available, with which to determine whether these changes in heads have already affected the rate of flow between the two aquifers. Vionnet's study (1991;

USF200010444

Vionnet and Maddock 1992), for example, suggests that the cone of depression of heads centered at the Fort Huachuca-Sierra Vista well fields has barely begun to affect heads in the regional aquifer along its boundary with the floodplain aquifer.

Operation of WATERBUD nevertheless requires the user to determine how the history of development of the two aquifers has affected their exchange of water. As discussed in Chapter 2, programs such as MODFLOW have the capability to simulate an entire history of development of a system, so that conditions at any single time can be represented as a product of the prior history of development of that system. WATERBUD and the MODSIM model developed for the UAWRRC Study Team (Summerside, 1991), however, have not been used to simulate the entire history of development of the upper basin. As a result, their operation requires making assumptions about the impacts of prior development. Chapter 6 discusses additional implications of this assumption.

The assumption used for WATERBUD (and for the MODSIM model), is that the rate of recharge of water from the regional aquifer to the floodplain aquifer in 1990 was in equilibrium with the difference in hydraulic heads between the two. That is, it was assumed that the rate of recharge was sufficient, to keep storage in the floodplain aquifer constant during that year. Although this assumption may appear arbitrary, it has the advantage of providing a readily defined reference point. As noted in Chapter 4 (see explanation for Row 307), too, users of the model may choose to make a different assumption about conditions in 1990, but then must develop data to support their alternative.

Assuming that the rate of recharge in 1990 was sufficient to keep storage in the floodplain aquifer constant, permits a rapid estimation of the value of, Y, the change in hydraulic head difference that has developed from the time of steady-state conditions up to 1990. As discussed in Chapter 4 for Row 307, the calculation of Y is based on a simple

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tabulation of the volume of water that the regional aquifer must recharge to the floodplain aquifer in 1990, in order for there to be no change in storage. This calculation can only be carried out, if Steps 1-3, above, have already been completed. The equation for calculating Y is presented in Chapter 4, in the discussion of Row 307. Once the value of Y has been calculated, the 1990 average hydraulic head in the regional aquifer can be calculated as $X + Y +$ the 1990 average hydraulic head in the floodplain aquifer estimated in Step 2, above.

5.1.5 Calibration Results and Limitations

Calibration of WATERBUD was carried out following the above four steps. For Step 1, the values for riverbed conductance and thickness given in Rows 41 and 43 did not interfere with the adjustment of the estimates for Row 39. The estimates for Row 39 obtained were 0.8823 and -0.8962 feet for the Sierra Vista and Benson sub-basins, respectively. Note that the elevation for the Benson sub-basin lies below the top of the riverbed, indicating that the river in this sub-basin was a losing rather than a gaining river overall, even under steady-state conditions.

Step 2 proved more complicated, at least for the Benson sub-basin, than did Step 1. It was found that, with a specified riverbed thickness of 5 feet and a conductance coefficient of 1.00 (see above), it was not possible to find a value for Row 40 that resulted in model calibration. Instead, the equations did not allow enough water to discharge from the river into the aquifer, resulting in an incorrect value for river discharge from the Benson sub-basin. The calculations for the Sierra Vista sub-basin did not exhibit this behavior.

Completion of Step 2 therefore required increasing the estimated thickness of the riverbed (Row 43), until a thickness was reached which would allow the river to discharge

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the correct amount into the aquifer under 1990 conditions. It was found that the thickness needed to exceed 15 feet, for purposes of Step 2 calibration. Increasing the estimated thickness has no effect on the results from Step 1, above. The results of Step 2 therefore were an estimate for the Sierra Vista sub-basin of 1.4440 feet (Row 40), and an estimate of -7.7229 feet for the Benson sub-basin accompanied by an adjustment of Row 43 to 15 feet.

The results for Step 2 suggest two features of the 1990 hydrologic system. First, heads in the floodplain aquifer in the Sierra Vista sub-basin are slightly higher on average, than were estimated for steady-state conditions. The difference between the 1990 and steady-state estimates is slight, however, and most likely reflects the consequences of the assumption that floodplain aquifer storage was at equilibrium in 1990. Second, heads in the floodplain aquifer in the Benson sub-basin are significantly lower, than were estimated for steady-state conditions. This finding is consistent with ADWR (1991) findings, that both river discharges and floodplain aquifer water tables have declines in the Benson sub-basin during the history of development of this sub-basin's water resources.

The results for Steps 3 and 4 are straightforward consequences of the results for Steps 1 and 2. For Row 29, the steady-state elevation of the regional aquifer water table above the riverbed, calibration gives estimates of 2.4922 and 0.5634 feet for the Sierra Vista and Benson sub-basins, respectively. For Row 30, the 1990 elevation of the regional aquifer water table above the riverbed, calibration gives estimates of 3.5052 and -6.4072 feet for the Sierra Vista and Benson sub-basins, respectively. These values are consistent with expectations, as discussed for Step 2, above.

USF200010447

5.2 APPLICATION: SCENARIOS AND POLICY OPTIONS

WATERBUD analyses were carried out, in order to examine the five scenarios and five policy options described Chapter 1. These scenarios and policy options are listed again, below, along with information on their specific numerical settings and on their specific codification in WATERBUD.

5.2.1 Scenarios

5.2.1.1 Scenario A

Scenario A projects the effects of current population growth patterns; all other parameters at default settings. [Spreadsheet parameter settings: default settings for all parameters].

5.2.1.2 Scenario B

Scenario B projects a 'worse-case' scenario, in which population growth, climate, and agricultural growth all have high impacts on water use. Population growth is projected at 0.02 greater than current rates. A block of 3000 personnel is added to the Fort Huachuca staff in 1995 along with 4500 dependents; 50% of the total increase is allocated to residences on the base and the remainder is allocated to the city of Sierra Vista (3750 persons allocated to each node). Conditions are made "dry" by multiplying all precipitation-related values by 0.725, based on Scott Summerside's estimate that the driest year in the past 20 years experienced a 72.5% reduction in precipitation. Conditions are made "hot" by multiplying all evapotranspiration demands by 1.1, to estimate a 10% increase in potential evaporation due to higher mean daily temperatures. And agricultural

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demands are allowed to increase by 3.5% per year by increasing effective irrigated acreage by this amount. This last action projects the 1970-1990 rate of growth in agricultural acreage as continuing for the next twenty years as well. [Spreadsheet parameter settings: add 0.02 to all values in Row 83; set Cells B107=3000, B108=1995, B109=4500, B110=0.5; multiply Cells B5, B13, C13, B14, C14, B15, C15, B125, B126 by 0.725; multiply Cells B48, C48, B51, C51, B77, B123, B124, B144, B145 by 1.10; set Cells B127 and B128=0.035].

5.2.1.3 Scenario C

Demographic parameters (including Fort) are set as in Scenario B (Rows 83 and 107-110), climate and agricultural parameters set as in Scenario A. This scenario thus provides information on the impacts of population growth while holding other stresses constant at 1989-1990 levels.

5.2.1.4 Scenario D

Climate parameters are set as in Scenario B (Rows 5, 13-15, 125, 126, 48, 51, 77, 123, 124, 144, 145), demographic and agricultural parameters set as in Scenario A. This scenario thus provides information on the impacts of climatic stress while holding other stresses constant at 1989-1990 levels. It should be noted, however, that the WATERBUD simulations handle Scenario D in a different manner than do the MODSIM simulations. In the MODSIM analyses, a ten-year cycle of actual precipitation and streamflow data was run twice in succession, to simulate a twenty-year climate record. The ten-year period selected for this purpose exhibited conditions consistently drier than normal. The WATERBUD analyses for Scenario D examine climatically more stressful conditions. It defines a severe-case year, during which precipitation is 27.5% lower than normal, and

USF200010449

evaporation rates are 10% higher than normal as a consequence of higher temperatures. This severe-case year is then repeated twenty times, to produce a twenty-year sequence of sustained, severe drought. As a result, Scenario D in the WATERBUD analyses entails a more severe and more sustained drought than does Scenario D in the MODSIM analyses.

5.2.1.5 Scenario E

Agricultural parameters are set as in Scenario B (Rows 127-128); demographic and climate parameters set as in Scenario A. This scenario thus examines the impacts of agricultural stress while holding other stresses constant at 1989-1990 levels.

5.2.2 Policy Options

5.2.2.1 Policy 1

Policy 1 projects the effects of allowing the status quo to continue with no further management of water resources. Since no actions are projected, the results of Scenarios A and D provide the necessary data with no further modification.

5.2.2.2 Policy 2

Policy 2 projects the effects of a management program that enforces a ceiling on domestic consumption based on a gallons-per-capita-per-day (gpcd) criterion, enforces an increase in irrigation efficiency to a minimum of 85%, and retires agricultural land from irrigation as needed to achieve some goal (a specified condition in the water balance, such as "safe yield"). Note that this policy will have no effect on consumption at the Fort, or in rural areas with no regulated delivery services There are three variants examined here:

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Policy 2-1 forces a 150 gpcd maximum on all domestic users in water-service areas and an 85% efficiency level for irrigation in both sub-basins. Some domestic delivery areas already (1989-1990) experience demand levels below 150 gpcd. The runs here set all user levels to 150 gpcd, based on the assumption that users currently demanding less than this level either will increase their usage (so as not to get "cheated") or will allow their delivery companies to sell water to over-consuming areas in order to profit from the excessive demand levels in these other areas. Rural users in non-delivery areas currently are modeled as demanding water at a rate of 0.17 acre-feet per person per year, which is equivalent to 152 GPCD. [Parameter settings: Cells B87..O87 set to 150 except D87, J87, O87 set to 255, 152, and 152 respectively; Cells B129 and B130 set to 0.85; Cell B176 set to 3; and Cell B179 set to 1].

Policy 2-2 is the same as Policy 2-1, except that 50% of irrigation land is retired, to show an intermediate effect of agricultural land retirement. Agricultural lands classifiable as riparian salvage lands are not allowed to revert to riparian conditions at faster than natural rates [Parameter settings: same as for Policy 2-1, but divide B115 and B116 by 2].

Policy 2-3 is the same as Policy 2-2, except that 100% of irrigation land is retired, to show the maximum benefit to be derived from agricultural land retirement. Again, agricultural lands classifiable as riparian salvage lands are not allowed to revert to riparian conditions at faster than natural rates [Parameter settings: same as for Policy 2-2, but set B115 and B116=0].

5.2.2.3 Policy 3

This policy option projects the effects of a management program that raises the price charged domestic users in water service areas, and charges a "pump tax" on

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irrigation wells. Note that this policy will have no effect on consumption at the Fort or on domestic consumption in rural areas that lack regulated delivery services. Water users are charged an additional fixed dollar amount per unit of water taken, in several increments:

Policy 3-1 adds $1.00 per 1000 gallons ($325 per acre-foot) to current prices. [Parameter settings: set Cells B96..O96 to 1.00; B137=325; B180=1].

Policy 3-2 adds $2.00 per 1000 gallons ($650 per acre-foot) to current prices. [Parameter settings: set Cells B96..O96 to 2.00; B137=650; B180=1].

Policy 3-5 adds $5.00 per 1000 gallons ($1625 per acre-foot) to current prices. [Parameter settings: set Cells B96..O96 to 5.00; B137=650; B180=1].

Policy 3-10 adds $10.00 per 1000 gallons ($3250 per acre-foot) to current prices. [Parameter settings: set Cells B96..O96 to 10.00; B137=650; B180=1].

5.2.2.4 Policy 4

Policy 4 projects the combined effects of "augmenting" water supplies by recharging treated effluent, and enhancing precipitation by cloud seeding. Note that this policy does not affect recharge at the Fort, which is presently not subject to local regulation. Thus, this option recharges 100% of all treated effluent at all nodes except the Fort. This affects all nodes with water treatment facilities. All domestic users are assumed (default settings) to return 50% of the water they use. Users with septic treatment are assumed to recharge 100% of this returned effluent. Municipal treatment facilities are assumed to lose 15% of the effluent flow to evaporation during treatment (default settings). Note also that cloud seeding would only affect recharge during the winter months. However, the present spreadsheet distributes this recharge evenly over the entire year to maintain the appearance of an aquifer head that does not vary over the seasons. Further, changes in recharge along the mountain front ordinarily would take

USF200010452

centuries to affect head at any user nodes in the basin. On the other hand, changes in recharge do affect storage balances, and it is this effect that is simulated by Policy 4. [Parameter settings: Cells B90..O90=1.00 except D90=0; B68 and B69=0.1].

5.2.2.5 Policy 5

Policy 5 projects the effects of maximal conservation efforts (regardless of how these are achieved) on the part of both domestic and agricultural users, by simulating a 25% reduction of domestic demand from what would otherwise be the normal demand levels, and an increase in irrigation efficiency to 85%. The projection assumes that the Fort does not participate in the domestic conservation efforts. [Parameter settings: Cells B94..O94=0.25 except D94=0.00, B129 and B130=0.85, and B176 and B179=1].

5.3 APPLICATION RESULTS

Each scenario was simulated under Policy 1, that is, under an assumption of no change in water management policies in the upper basin. Each of the other policy options was then simulated under only two conditions: the "normal" conditions for population growth, climate, and agricultural growth, as specified in Scenario A ; and the sustained severe drought conditions as specified in Scenario D. The UAWRRC Study Team (see Chapter 1, above) deliberately selected these two scenarios as the basis for comparing policy options, to permit comparisons under both average and extreme conditions (UAWRRC, 1991).

5.3.1 General Patterns in Results

Figures 5-1 - 5-3 illustrate the operation of WATERBUD over the course of a twenty-year projection. These three figures show the projected storage levels in the

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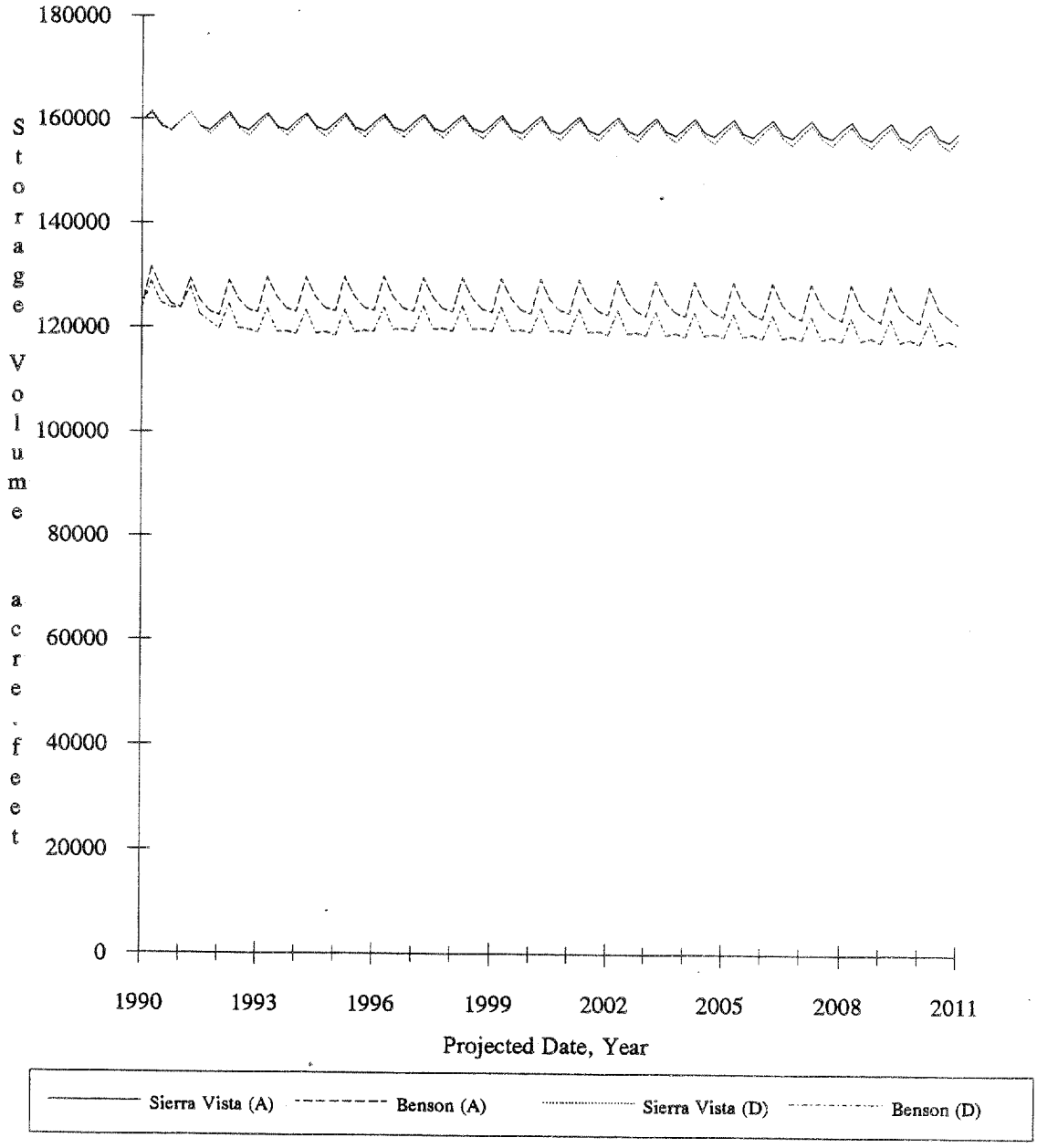
Projected Storage in Floodplain Aquifer
by Sub-basin for "Normal" (Scenario A) and "Drought"
(Scenario D) Conditions Under Policy 1
Figure 5-1



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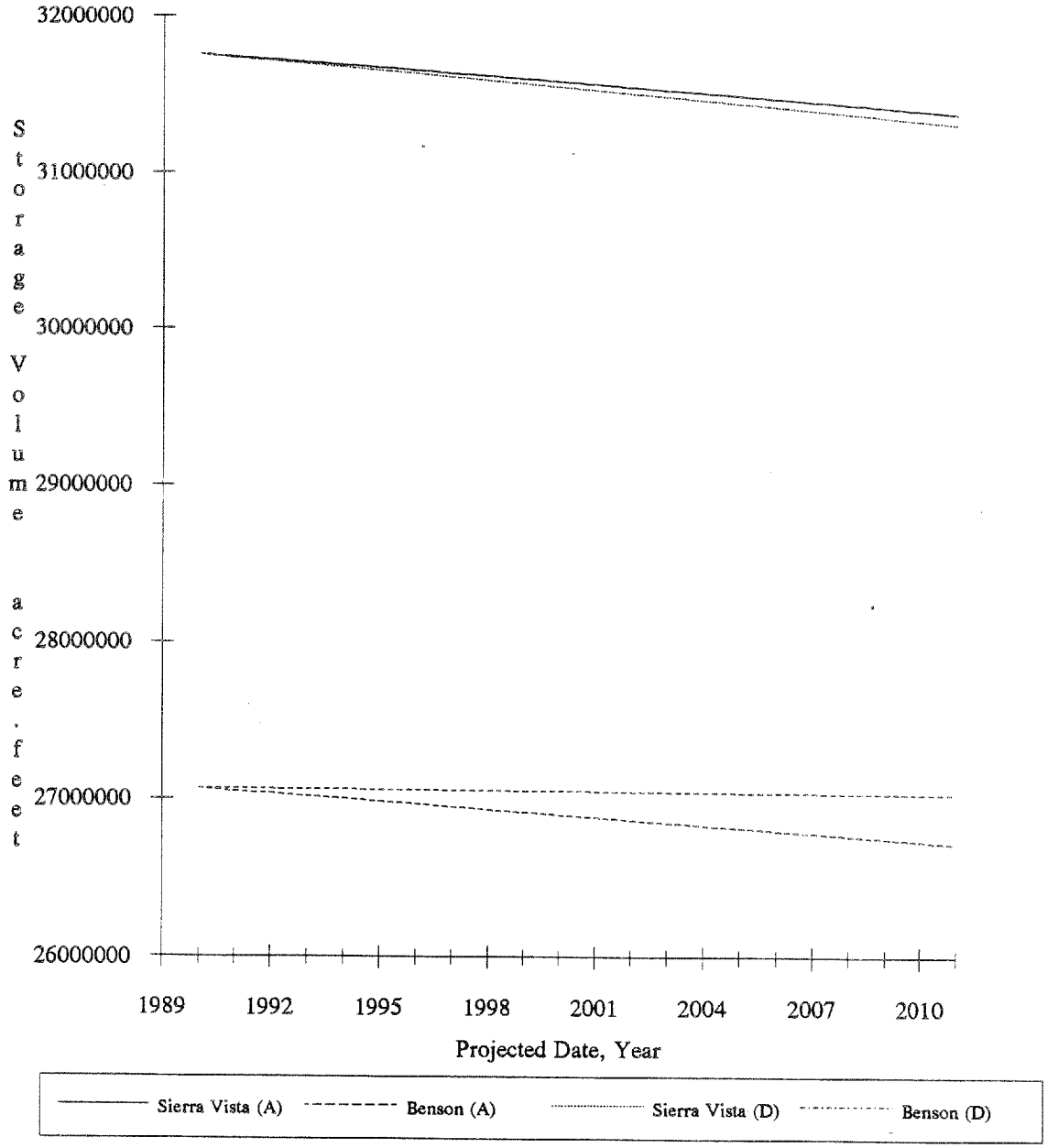
Projected Storage in Regional Aquifer
by Sub-basin for "Normal" (Scenario A)" and Drought"
(Scenario D) Conditions Under Policy 1
Figure 5-2



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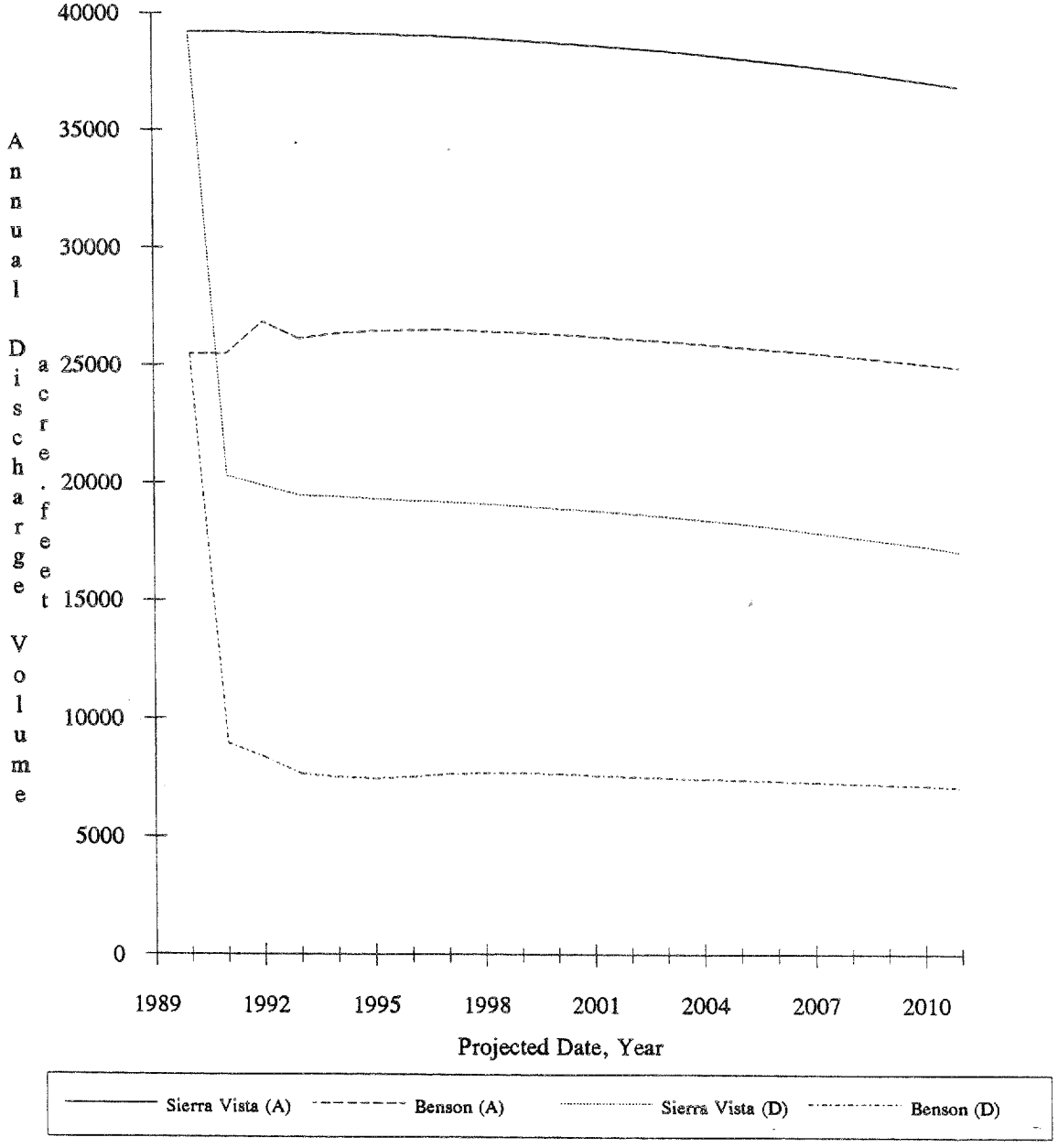
Projected Annual River Discharge
by Sub-basin for "Normal" (Scenario A) and "Drought"
(Scenario D) Conditions Under Policy 1
Figure 5-3



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Summary of WATERBUD Results

Projected Cumulative Effects of Alternative Scenarios and Policies after Twenty Years Relative to 1990 Conditions

Table 5-1

	Regional Aquifer Sierra Vista Sub-basin (acre feet)	Floodplain Aquifer Sierra Vista Sub-basin (acre feet)	San Pedro River Sierra Vista Sub-basin (acre-feet/year)	Regional Aquifer Benson Sub-basin (acre feet)	Floodplain Aquifer Benson Sub-basin (acre feet)	San Pedro River Benson Sub-basin (acre-feet/year)
"Normal" 1990 Conditions	31737573	159609	39200	27064109	123681	25500
1990 Effect of a "Drought"	-5384	0	-18916	-16878	0	-16542
TWENTY-YEAR EFFECTS OF POLICY 1						
Scenario A	-363134	-1742	-2347	-33927	-2570	-579
Scenario B	-561910	-5990	-23830	-528679	-13401	-19781
Scenario C	-440002	-1972	-2623	-39375	-2849	-778
Scenario D	-429528	-2919	-22136	-346897	-6627	-18391
Scenario E	-403386	-3518	-4780	-175397	-8637	-3514
TWENTY-YEAR EFFECTS OF POLICY 2						
Policy 2-1, Scenario A	-331689	-1604	-2165	-35887	-2387	-446
Policy 2-1, Scenario D	-397973	-2779	-21981	-348605	-6398	-18355
Policy 2-2, Scenario A	-282088	-766	-972	98814	-498	2148
Policy 2-2, Scenario D	-336815	-1736	-20813	-153824	-3837	-17593
Policy 2-3, Scenario A	-233892	77	209	209790	1605	4849
Policy 2-3, Scenario D	-275821	-720	-19597	38598	-856	-16792
TWENTY-YEAR EFFECTS OF POLICY 3						
Policy 3-1, Scenario A	-231487	-100	-27	219255	3548	3860
Policy 3-1, Scenario D	-273866	-873	-19781	36548	-1480	-16828
Policy 3-2, Scenario A	-208209	31	154	221762	3842	4094
Policy 3-2, Scenario D	-250410	-737	-19617	43300	-1130	-16786
Policy 3-5, Scenario A	-178469	177	373	224743	4339	4419
Policy 3-5, Scenario D	-220480	-567	-19426	50128	-952	-16713
Policy 3-10, Scenario A	-159398	291	497	226583	4541	4565
Policy 3-10, Scenario D	-201289	-432	-19330	53828	-799	-16675
TWENTY-YEAR EFFECTS OF POLICY 4						
Scenario A	-245468	-1211	-1650	3273	-1827	-78
Scenario D	-311438	-2377	-21552	-308576	-5907	-18216
TWENTY-YEAR EFFECTS OF POLICY 5						
Scenario A	-307377	-1504	-2032	-29438	-2014	-197
Scenario D	-373965	-2675	-21889	-341910	-6334	-18335

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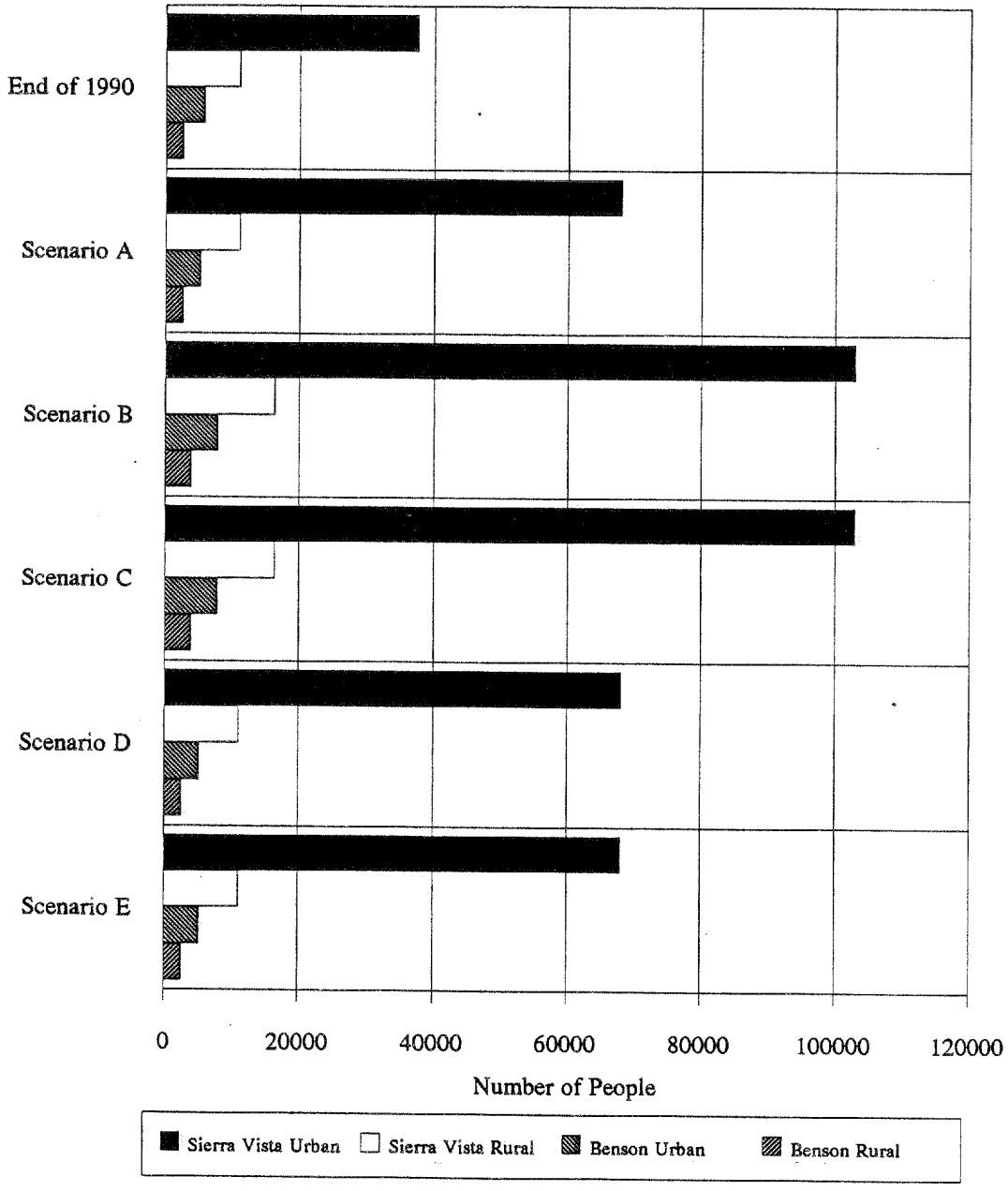
Total Urban and Rural Populations After 20 Years
Under Different Scenarios, by Sub-basin
(with 1990 Populations Shown for Comparison)
Figure 5-4



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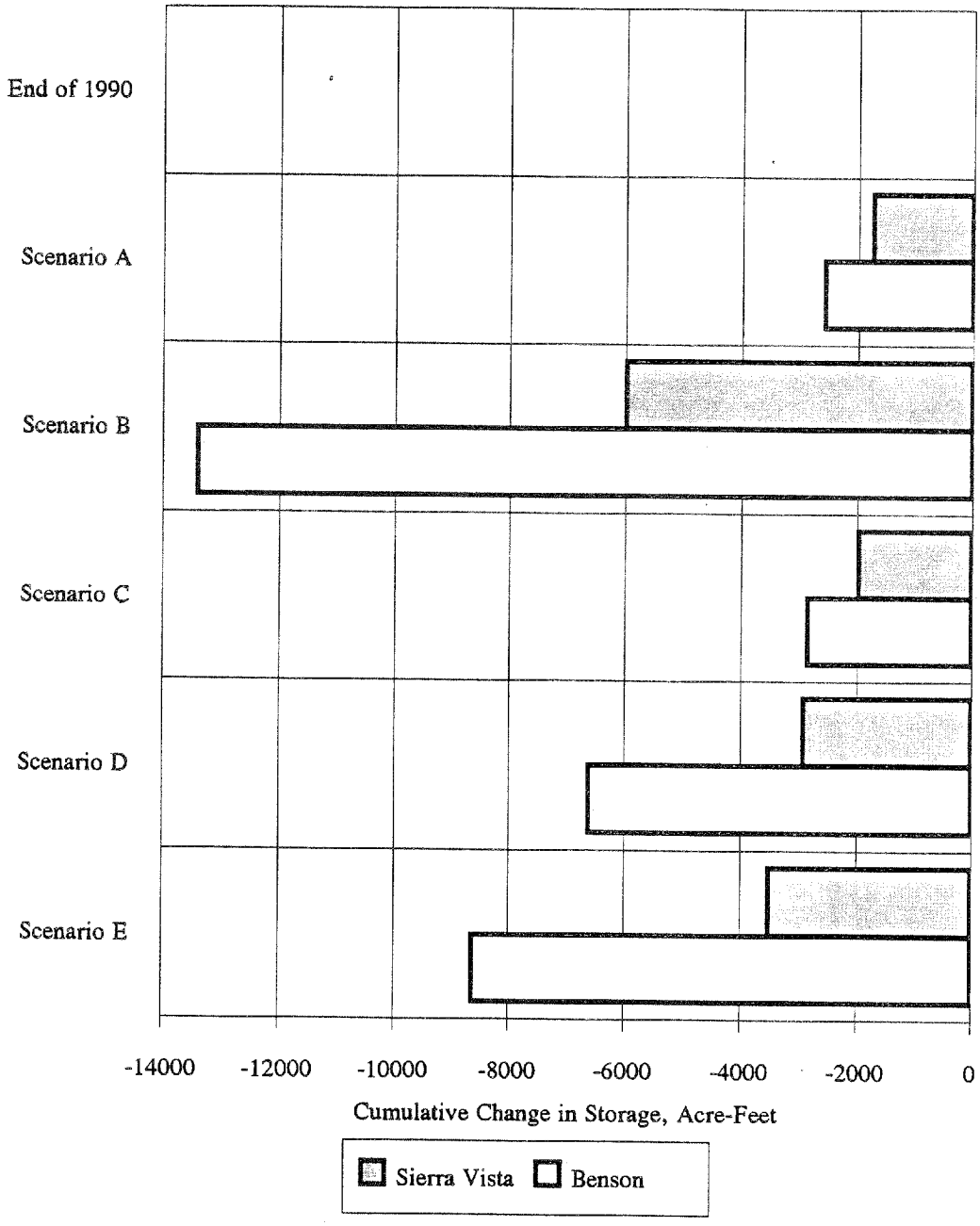
Cumulative Change in Floodplain Aquifer Storage After 20 Years Under the Different Scenarios, by Sub-basin
Figure 5-5



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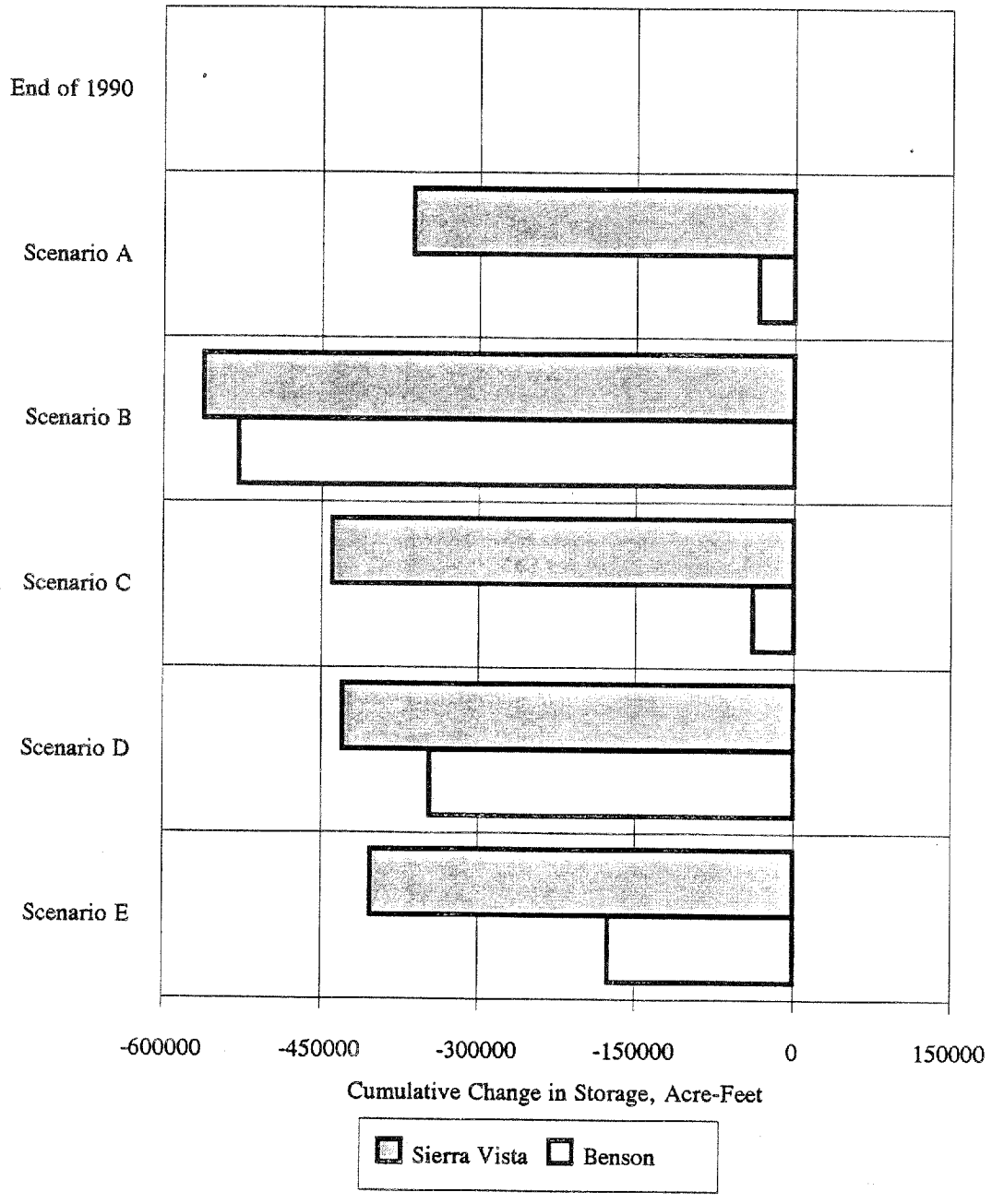
Cumulative Change in Regional Aquifer Storage After 20 Years
Under the Different Scenarios, by Sub-basin
Figure 5-6



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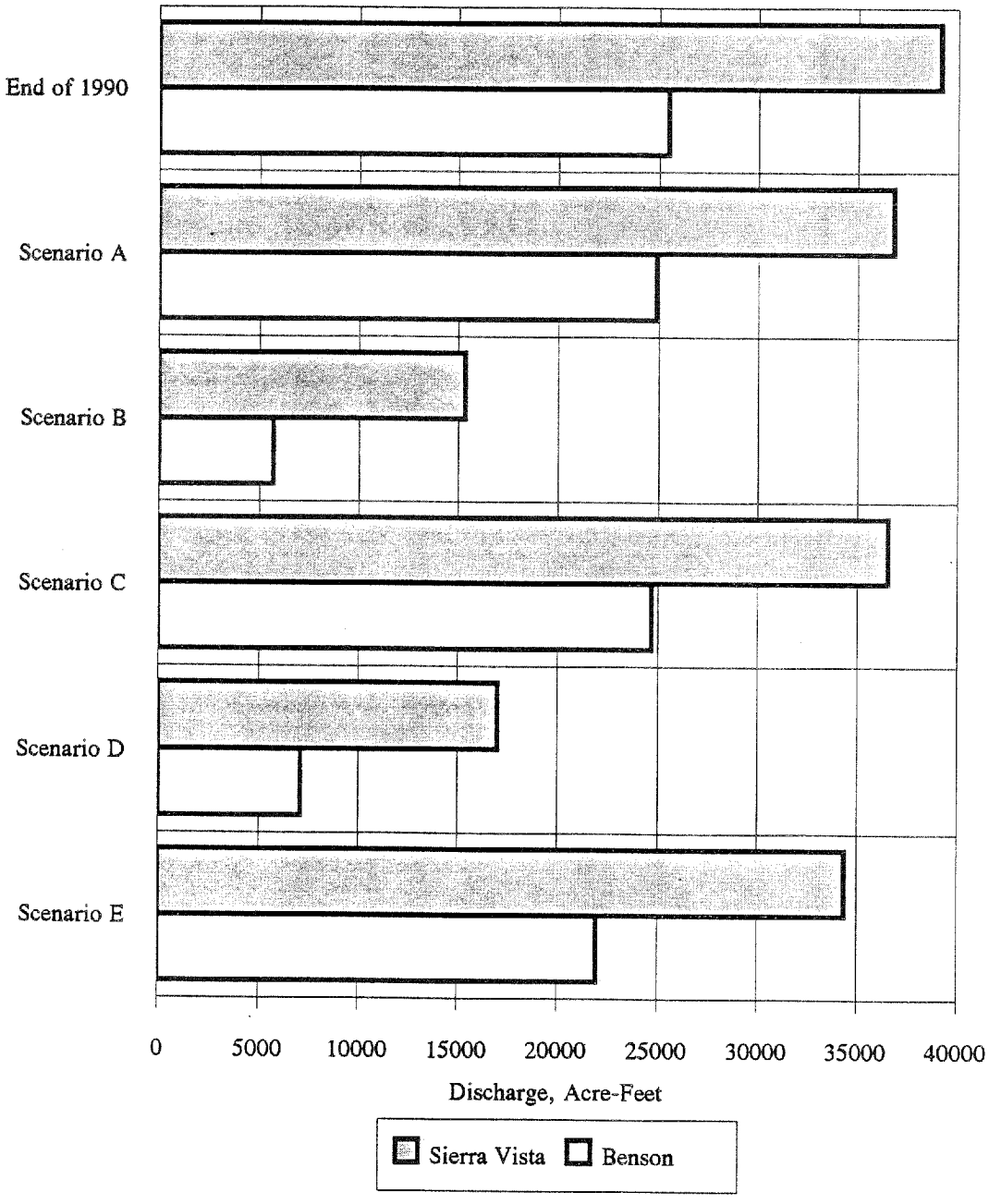
Annual Discharge of San Pedro River After 20 Years
Under the Different Scenarios, by Sub-basin
Figure 5-7



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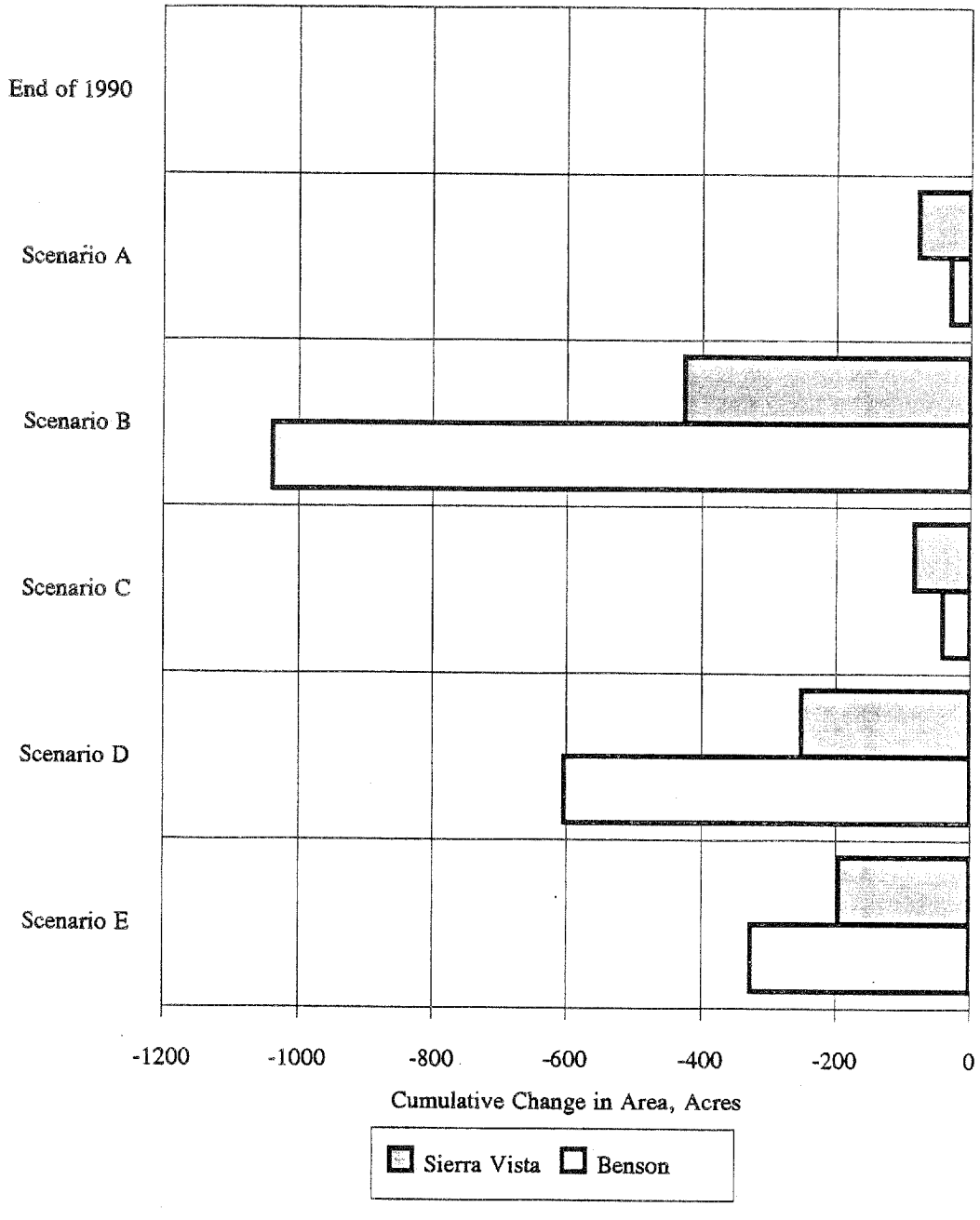
Cumulative Change in Area of Riparian Vegetation After 20 Years
Under the Different Scenarios, by Sub-basin
Figure 5-8



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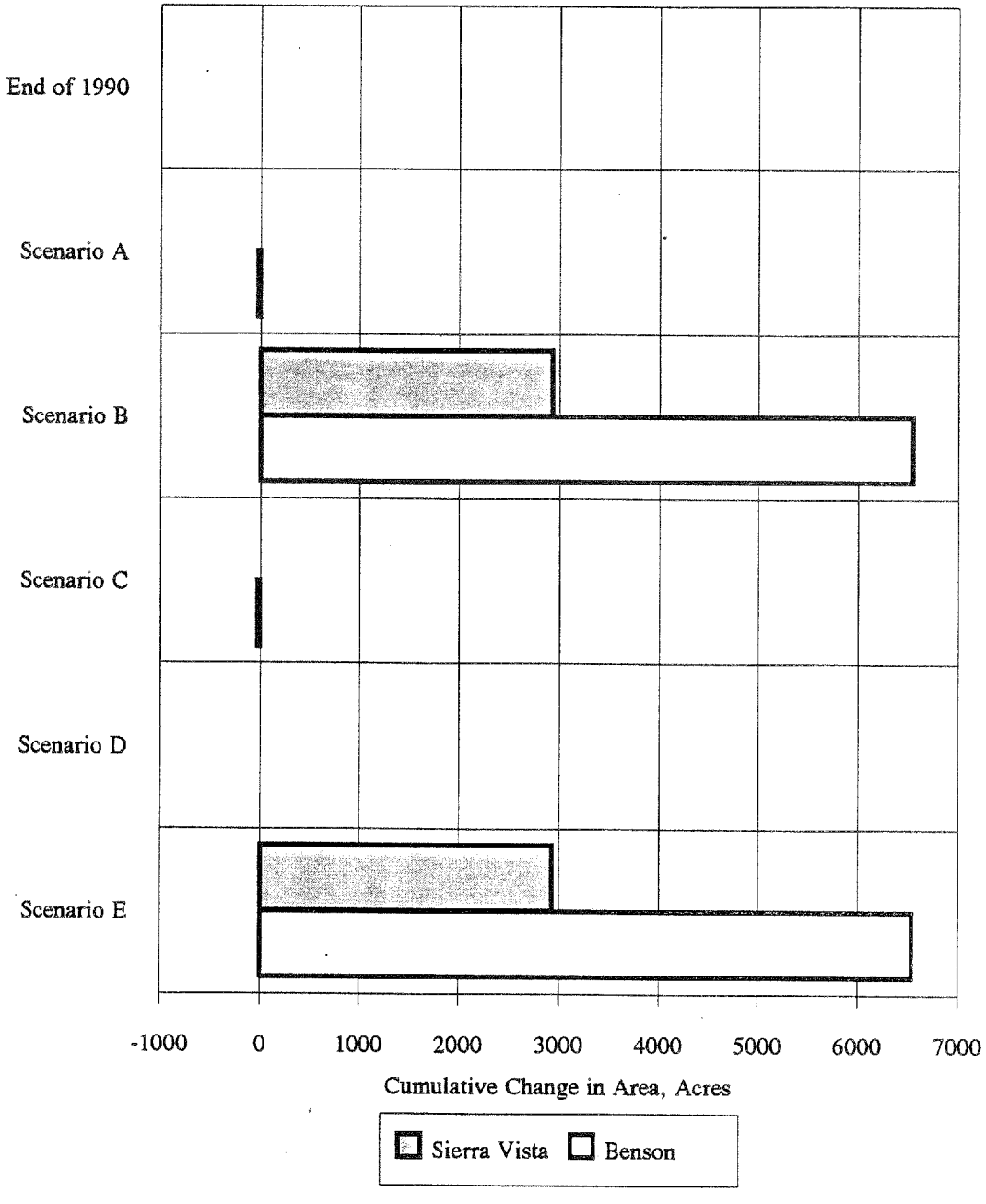
Cumulative Change in Effective Irrigated Acreage After 20 Years
Under the Different Scenarios, by Sub-basin
Figure 5-9



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declines in both sub-basins under all five scenarios, with the declines more pronounced in the Benson sub-basin than in the Sierra Vista sub-basin. Taken alone, agricultural growth has the greatest impact on storage in the floodplain aquifer, followed closely by drought conditions. It should be noted that population growth rates are low in the Benson sub-basin even under the worst-case demographic conditions projected in Scenarios B and C.

Population growth reduces storage in the regional (basin fill) aquifer in the Sierra Vista sub-basin (Figure 5-6) more severely than does either a prolonged drought or agricultural growth taken alone. In turn, storage in the regional aquifer in the Benson sub-basin is not greatly affected by local population growth, and is reduced more by drought conditions than by agricultural growth.

Annual river discharges (Figure 5-7) decline most severely under a severe drought; population growth and agricultural growth have much smaller impacts on river discharges. The same pattern of change in river discharges is evident in both sub-basins. All five scenarios result in reductions in the viability of riparian habitat in both sub-basins (Figure 5-8), with drought conditions having the greatest impact, followed closely by agricultural growth. It should be noted that agricultural growth is assumed to involve the expansion of irrigation to lands away from the river that are not presently either farmed or protected as riparian reserves. Consequently, the decline in riparian acreage forecast under the five scenarios results from reductions in water tables and streamflows, which then together cause damage to the existing riparian stands. It should also be noted that only Scenarios B and E involve increases in irrigated acreage (Figure 5-9). Finally, median household income (not illustrated; see also Figure 5-20, below) does not change under any of the five scenarios.

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5.3.3 Floodplain Aquifer Storage under Policies 2, 3, 4, and 5

Policy options 2, 3, 4, and 5 have different effects on storage in the floodplain aquifer. These effects differ between the two sub-basins, and also differ between normal and drought conditions (Figures 5-10 and 5-11). Policies 2-1 to 2-3 have increasingly positive effects on reducing losses to storage in the floodplain aquifer, in both sub-basins. Under normal climatic conditions in both sub-basins, Policies 2-1 and 2-2 result in smaller losses, while Policy 2-3 results in gains to storage in the floodplain aquifer. Under drought conditions, these three policies reduce the rate of loss to floodplain storage, but do not produce a gain to storage even under Policy 2-3.

All four variants of Policy 3 under normal climatic conditions result in gains to storage in the floodplain aquifer in the Benson sub-basin, and all except Policy 3-1 do so in the Sierra Vista sub-basin as well. All four variants help greatly to reduce the losses to floodplain aquifer storage in both sub-basins under drought conditions, but do not eliminate these losses. Policies 4 and 5 are only slightly more effective in reducing the losses to storage in the floodplain aquifer than would be the status quo of no management policy at all, under both normal and drought conditions in both sub-basins.

5.3.4 Regional Aquifer Storage under Policies 2, 3, 4, and 5

Policy options 2, 3, 4, and 5 have different effects on storage in the regional aquifer; these effects also differ between the two sub-basins, and between normal and drought conditions (Figures 5-12 and 5-13) Policies 2-1 to 2-3 again have increasingly positive effects in reducing losses to storage in the regional aquifer. Under normal conditions in the Benson sub-basin, Policy 2-1 helps reduce the losses to storage while Policies 2-2 and 2-3 result in gains to storage. All three variants of Policy 2 help reduce,

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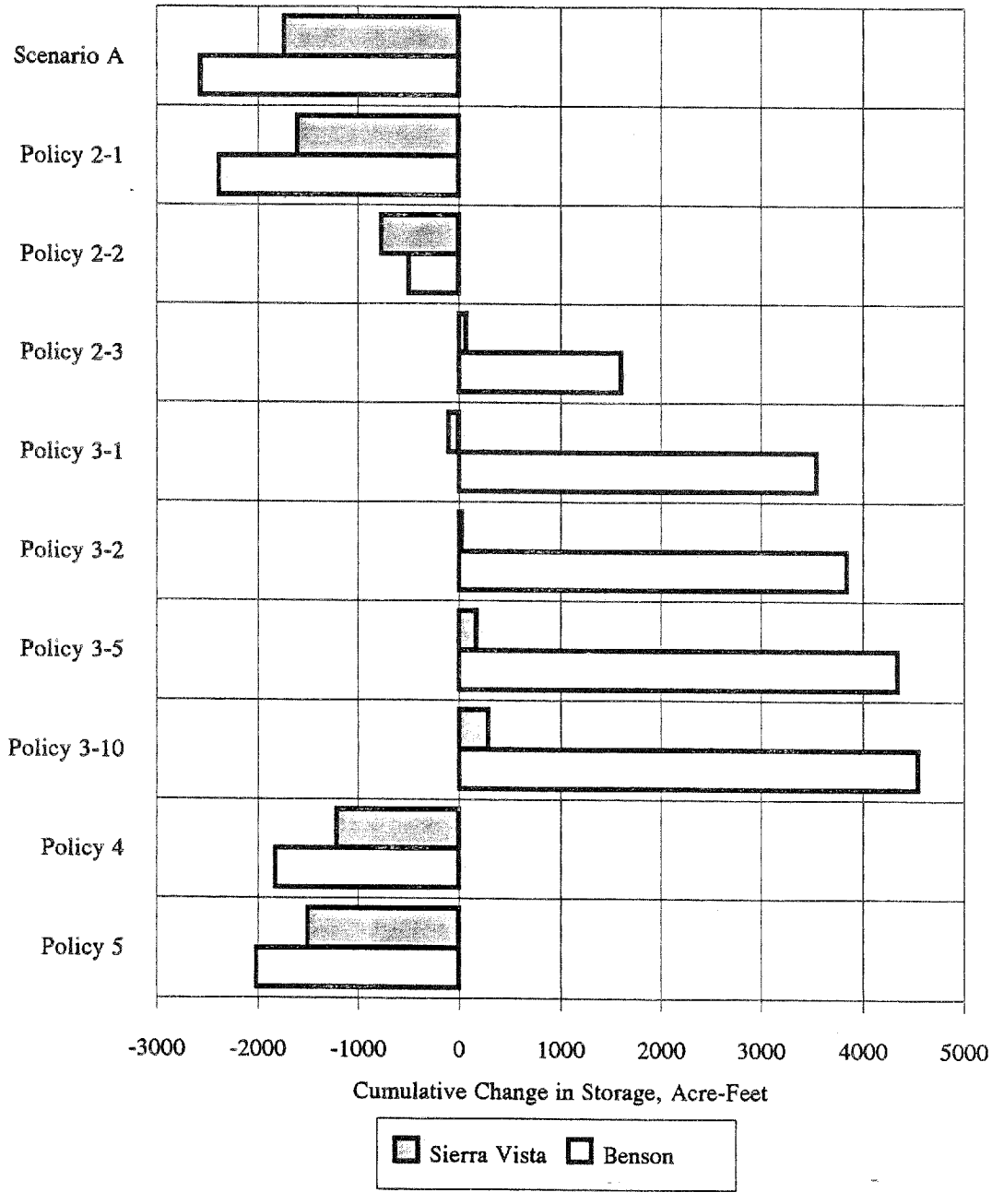
Cumulative Change in Floodplain Aquifer Storage After 20 Years
Under Different Policies and Scenario A Conditions, by Sub-basin
Figure 5-10



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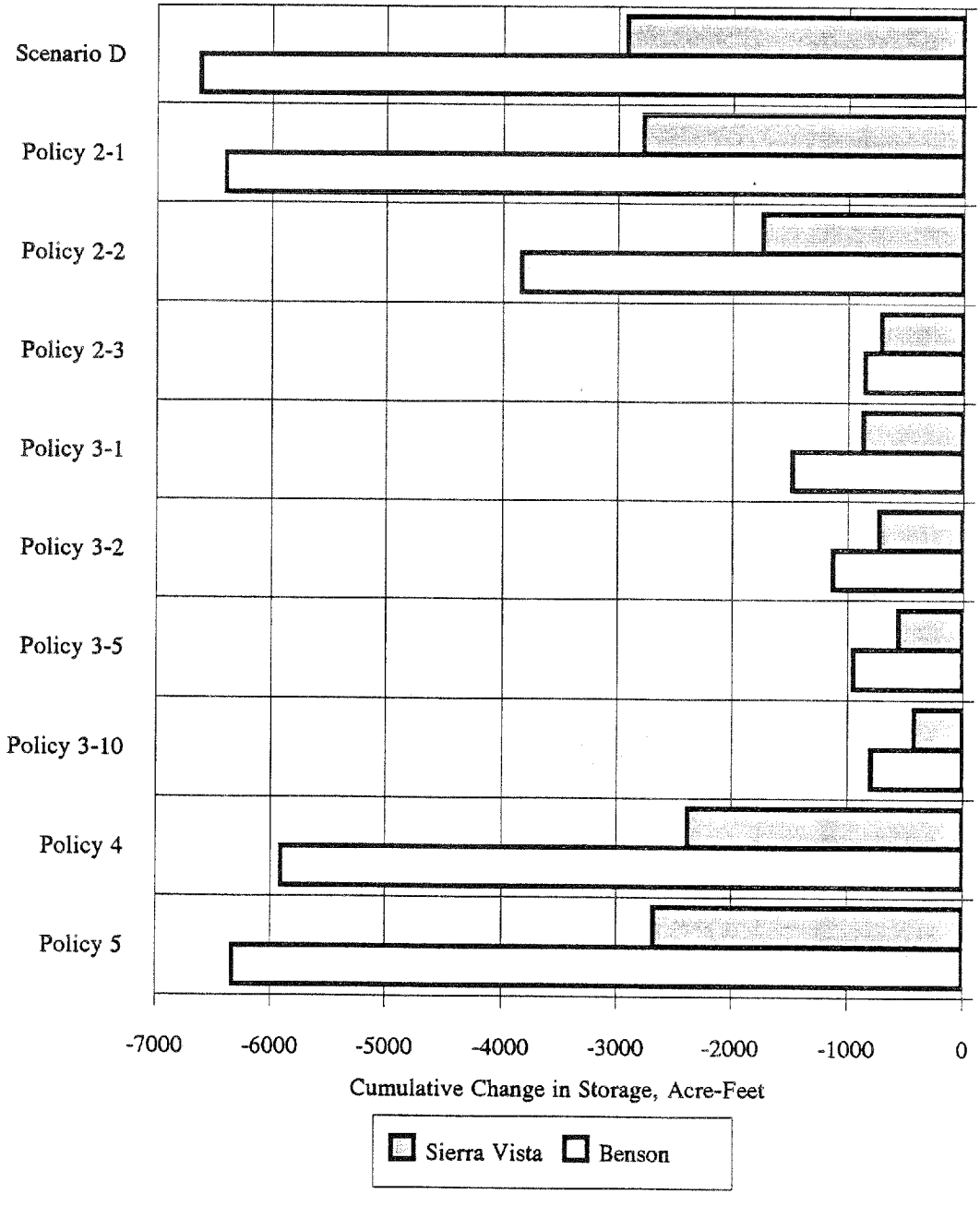
Cumulative Change in Floodplain Aquifer Storage After 20 Years
Under Different Policies and Scenario D Conditions, by Sub-basin
Figure 5-11



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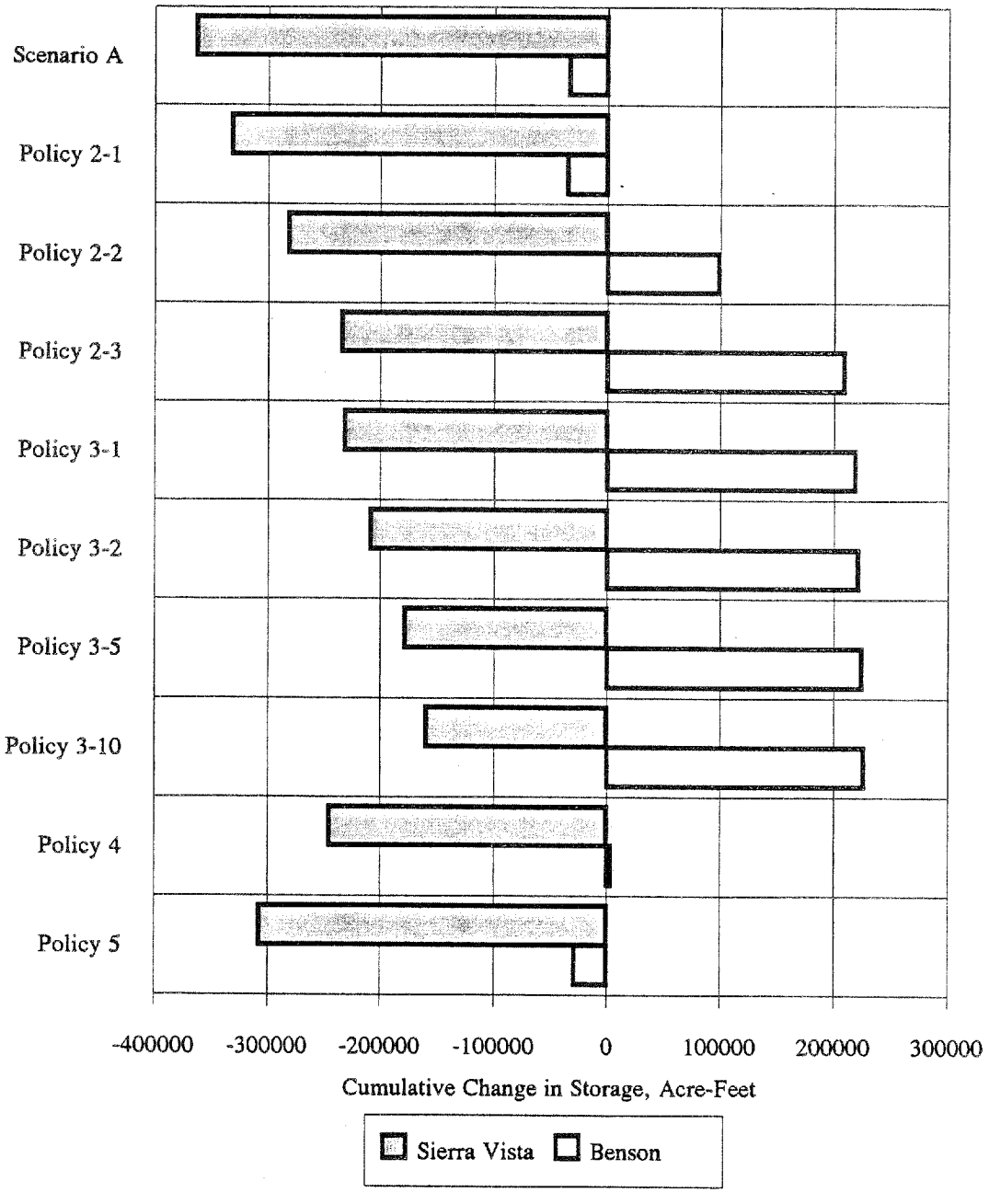
Cumulative Change in Regional Aquifer Storage After 20 Years
Under Different Policies and Scenario A Conditions, by Sub-basin
Figure 5-12



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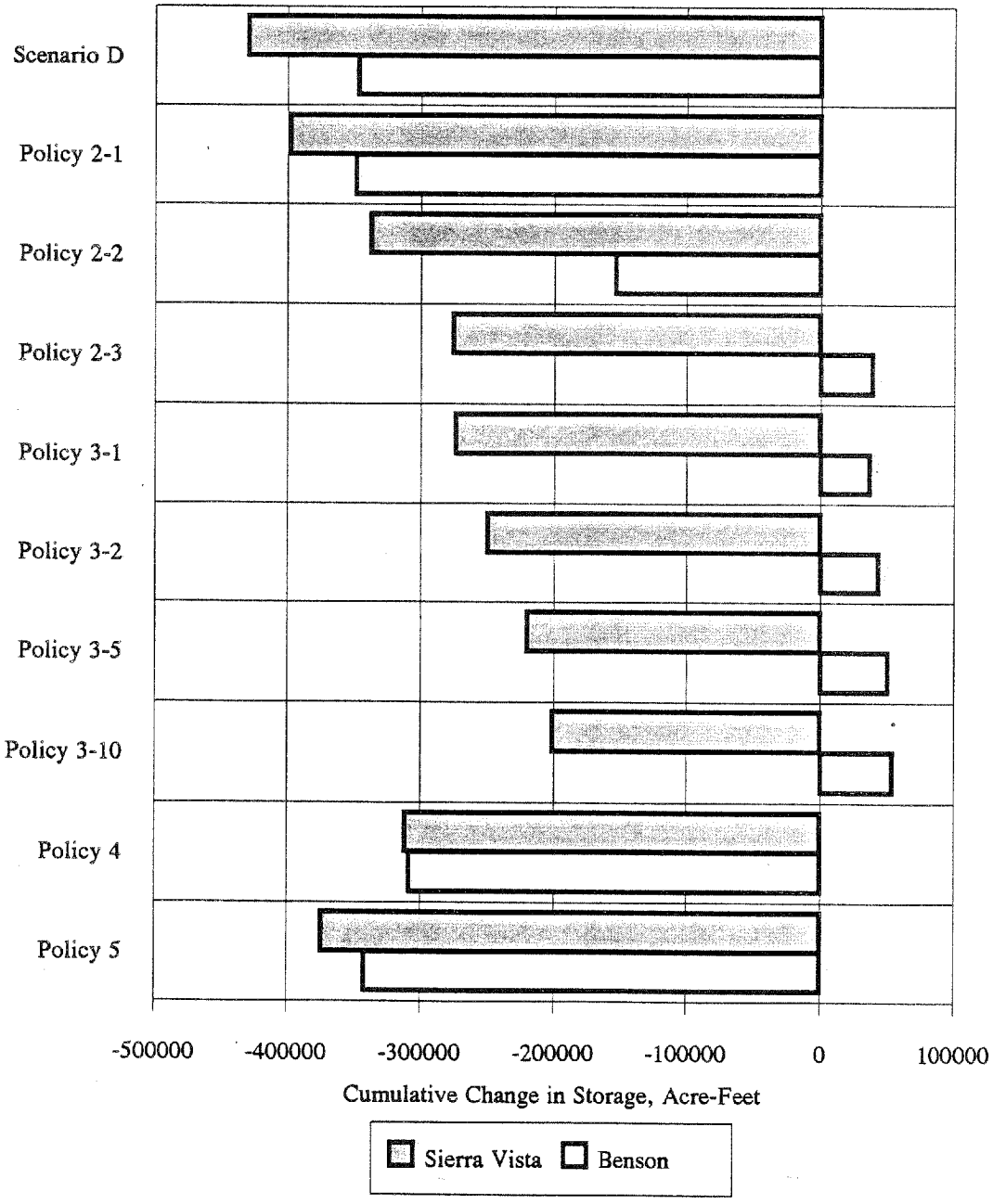
Cumulative Change in Regional Aquifer Storage After 20 Years
Under Different Policies and Scenario D Conditions, by Sub-basin
Figure 5-13



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but not eliminate, the losses to storage in the Sierra Vista sub-basin. Under drought conditions, Policy 2 helps reduce the losses to storage in the regional aquifer in both sub-basins, although only Policy 2-3 results in a gain to storage in either sub-basin and then only in the Benson sub-basin.

All four variants of Policy 3 results in gains to storage in the regional aquifer in the Benson sub-basin under both normal and hot/dry climatic conditions, although the amount of this gain is small under drought conditions. The four variants of Policy 3 reduce but do not eliminate the losses to storage in the Sierra Vista sub-basin, under both normal and hot/dry conditions. Policies 4 and 5 result in gains to storage in the regional aquifer in the Benson sub-basin under normal conditions. However, Policy 4 helps reduce the losses to storage in the regional aquifer in both sub-basins, under both normal and hot/dry climatic conditions, and even results in a very slight gain to storage under normal conditions in the Benson sub-basin. Policy 5 is only marginally more effective than having no policy at all, under both normal and hot/dry climatic conditions, in both sub-basins.

5.3.5 River Discharges under Policies 2, 3, 4, and 5

Policy options 2, 3, 4, and 5 have similar effects on river discharges from the two sub-basins (Figures 5-14 and 5-15). All policies result in higher river discharges than would be the case in the absence of any management policy, with Policy 2-3 and the four variants of Policy 3 having the greatest effect. This pattern holds even under drought conditions, although the gains under a severe drought would not be great (note the difference in scale between Figure 5-14 and 5-15). Policies 4 and 5 have little impact on river discharges under any conditions in either sub-basin.

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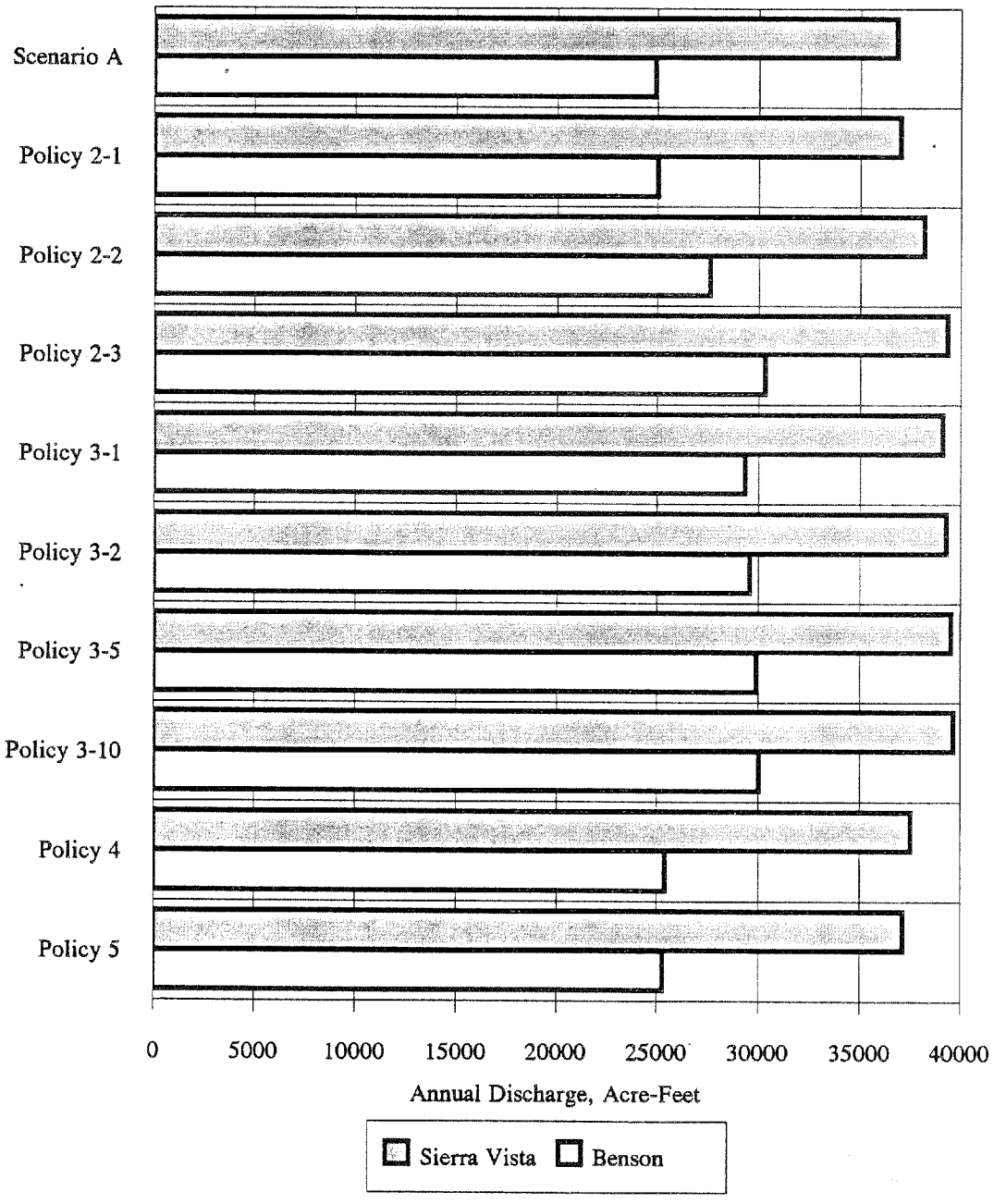
Annual Discharge of San Pedro River After 20 Years
Under Different Policies and Scenario A Conditions, by Sub-basin
Figure 5-14



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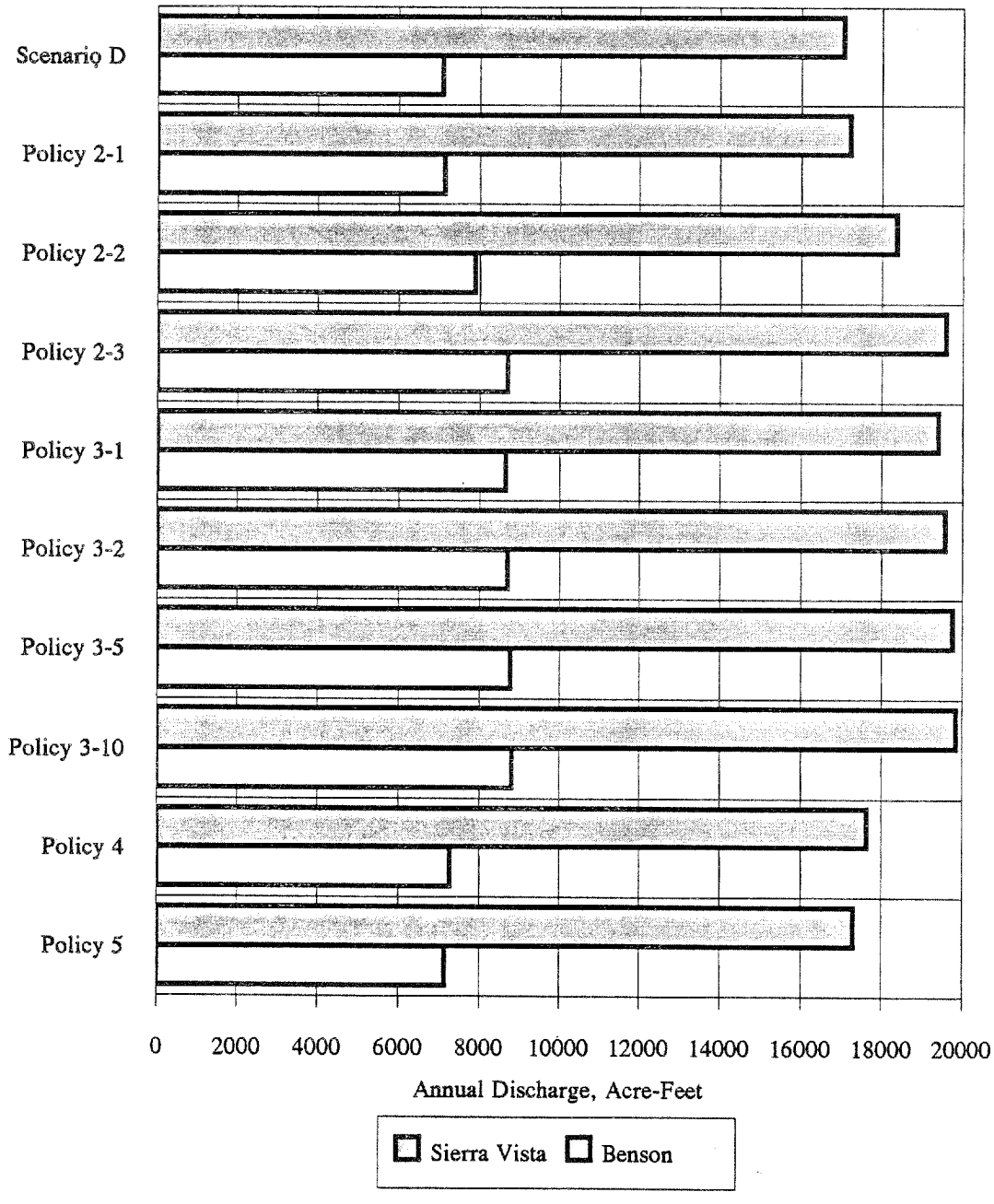
Annual Discharge of San Pedro River After 20 Years
Under Different Policies and Scenario D Conditions, by Sub-basin
Figure 5-15



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5.3.6 Riparian Acreage under Policies 2, 3, 4, and 5

WATERBUD is designed to simulate changes in riparian acreage that could result from changes in river discharges or from changes in irrigated acreage. Specifically, increases in riparian acreage should result from any combination of increased river discharges and the retirement of agricultural land. This pattern is evident in the results of the simulations under both normal and hot/dry climatic conditions (Figures 5-16 and 5-17). In particular, those policies that are most effective in increasing river discharges (see above) are also most effective in reducing or reversing losses to riparian habitat in both sub-basins. Among the three variants of Policy 2, riparian acreage increases most strongly when irrigation acreage is most strongly reduced. Among the four variants of Policy 3, riparian acreage increases more strongly, the greater the reduction in agricultural activity produced by that Policy. Policies 2-2, 2-3, and the four variants of Policy 3 result in increases rather than simply in reduced losses to riparian habitat, under normal climatic conditions in both sub-basins. Policy 4 even manages to produce an increase in riparian acreage in the Sierra Vista sub-basin, under normal climatic conditions. Only Policy 2-3 and the four variants of Policy 3 result in increases in riparian habitat, under drought conditions in the two sub-basins.

5.3.7 Irrigated Acreage under Policies 2, 3, 4, and 5

Policies 2, 3, 4, and 5 have effects on the total acreage of irrigated lands that are similar under normal and hot/dry climatic conditions (Figures 5-18 and 5-19). Irrigated acreage declines markedly under Policy 2, as is the policy's intent, and declines slightly under the four variants of Policy 3. The declines under Policy 3 all result from allowing riparian vegetation to reclaim previously irrigated lands. The effects of Policy 3 are

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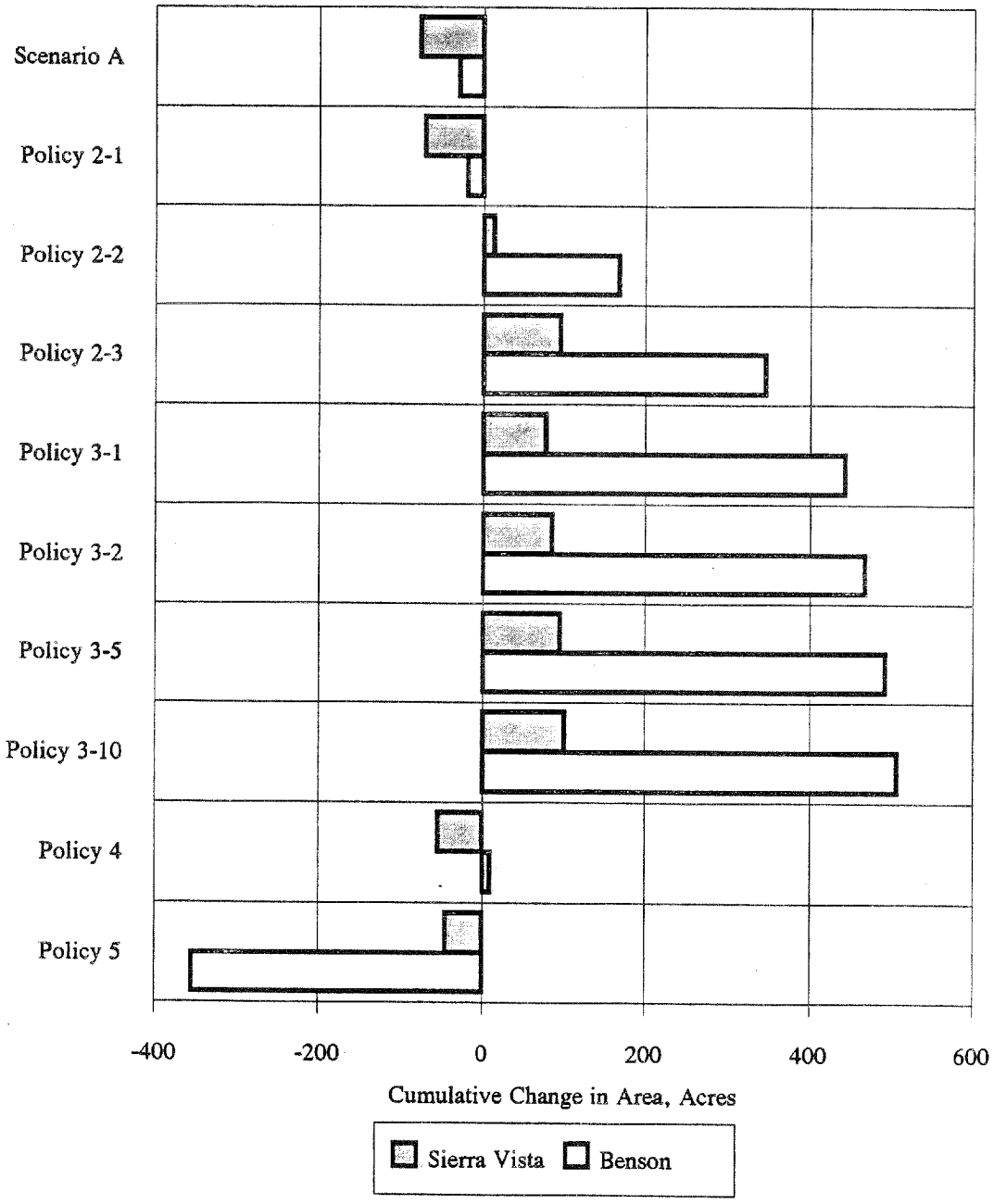
Cumulative Change in Area of Riparian Vegetation After 20 Years
Under Different Policies and Scenario A Conditions, by Sub-basin
Figure 5-16



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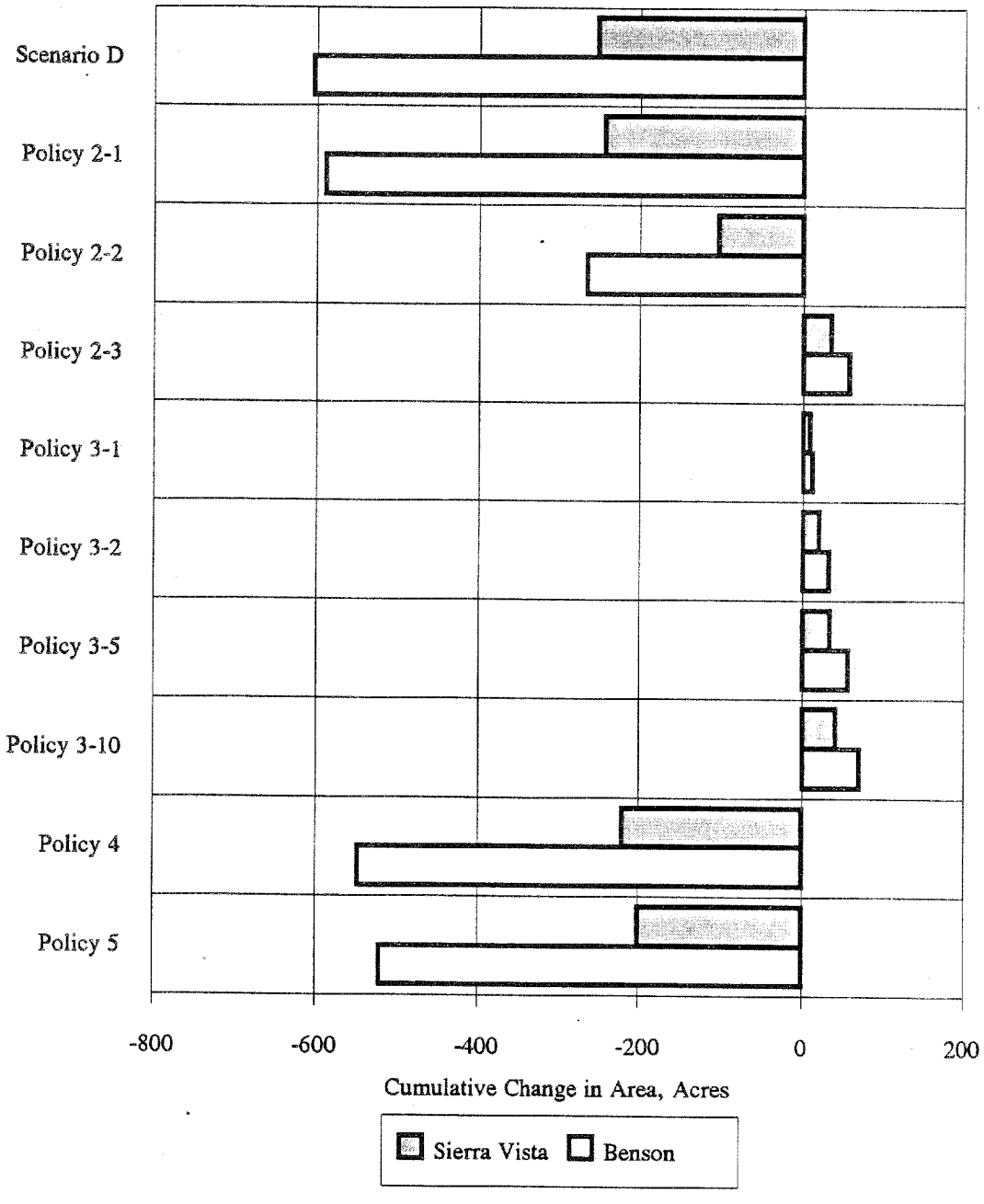
Cumulative Change in Area of Riparian Vegetation After 20 Years
Under Different Policies and Scenario D Conditions, by Sub-basin
Figure 5-17



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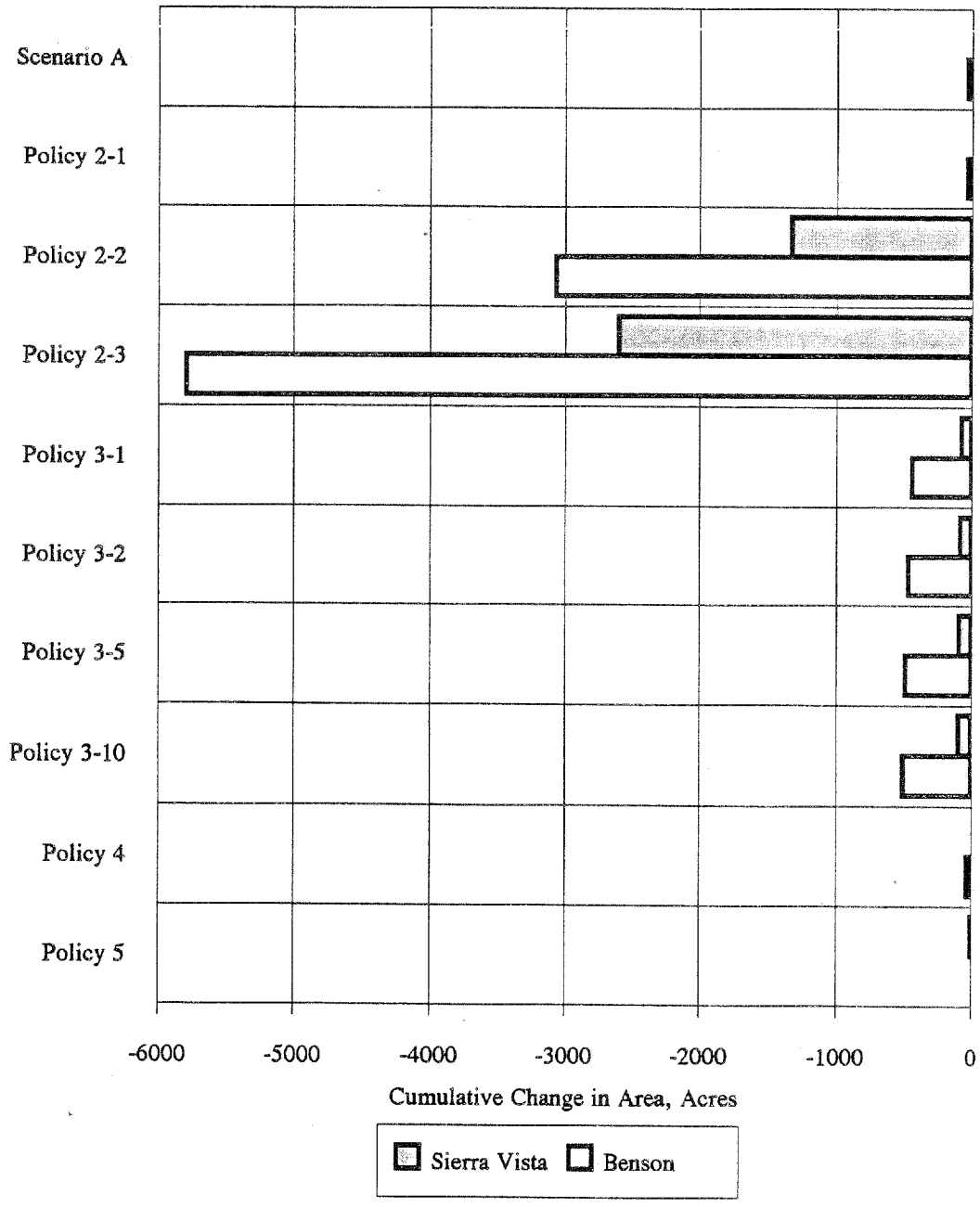
Cumulative Change in Irrigated Acreage After 20 Years
Under Different Policies and Scenario A Conditions, by Sub-basin
Figure 5-18



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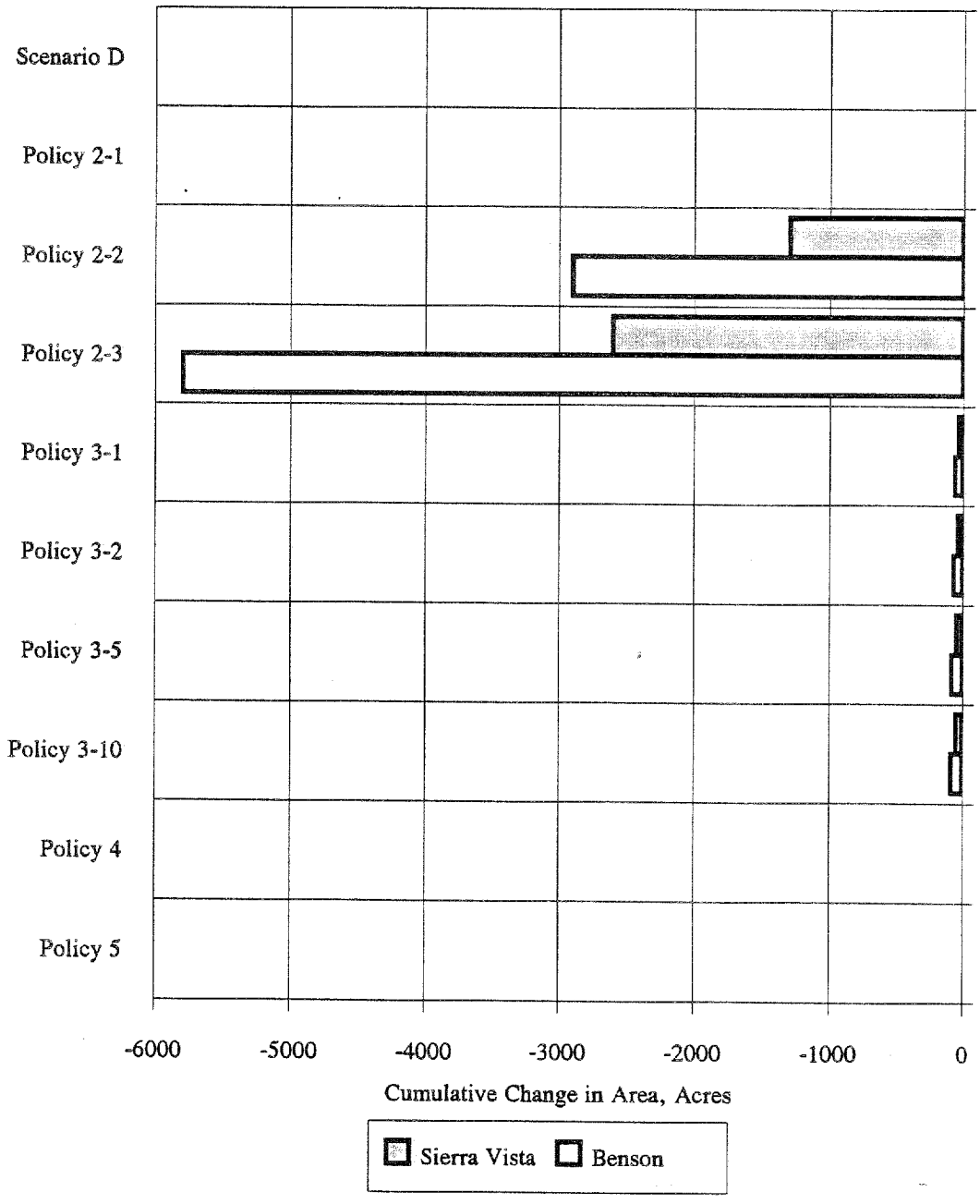
Cumulative Change in Irrigated Acreage After 20 Years
Under Different Policies and Scenario D Conditions, by Sub-basin
Figure 5-19



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greatly muted by a drought; Policy 2 reduces irrigated acreage in an identical manner under both normal and drought conditions.

5.3.8 Median Household Income under Policies 2, 3, 4, and 5

Policies 2, 3, 4, and 5 also have the same effects on median household income under normal climatic conditions as they do under drought conditions (Figure 5-20). Median household income for the entire upper basin improves slightly under Policy 2. Policy 3 results in progressively larger declines in median household incomes as the water surcharge increase, as a result of the financial burden imposed by the charges. Policy 4 has no effect on median household income, while Policy 5 results in a slight decline as a result of its imposition of stringent conservation measures.

5.4 SUMMARY OF APPLICATION RESULTS

In general, policies that reduce agricultural consumption have the largest single beneficial effects on the overall water balance. These beneficial effects are achieved primarily through pumping surcharges or the actual retirement of irrigated land. The beneficial effects include gains or at least reduced losses to storage in the floodplain aquifer and increased river discharges, which in turn encourage the growth of riparian vegetation. Gains or reduced losses storage in the floodplain aquifer also result in reduced discharges from the regional (basin fill) to the floodplain aquifer, which helps reduce the losses to storage in the regional aquifer. However, modifying agricultural activities alone does not eliminate the drawdowns to storage in the regional aquifer. The regional aquifer is under far more stress in the Sierra Vista sub-basin than in the Benson sub-basin, due to the higher population size and higher population growth rates in the Sierra Vista area. Losses to storage in the regional aquifer, in the Sierra Vista sub-basin, are reduced only

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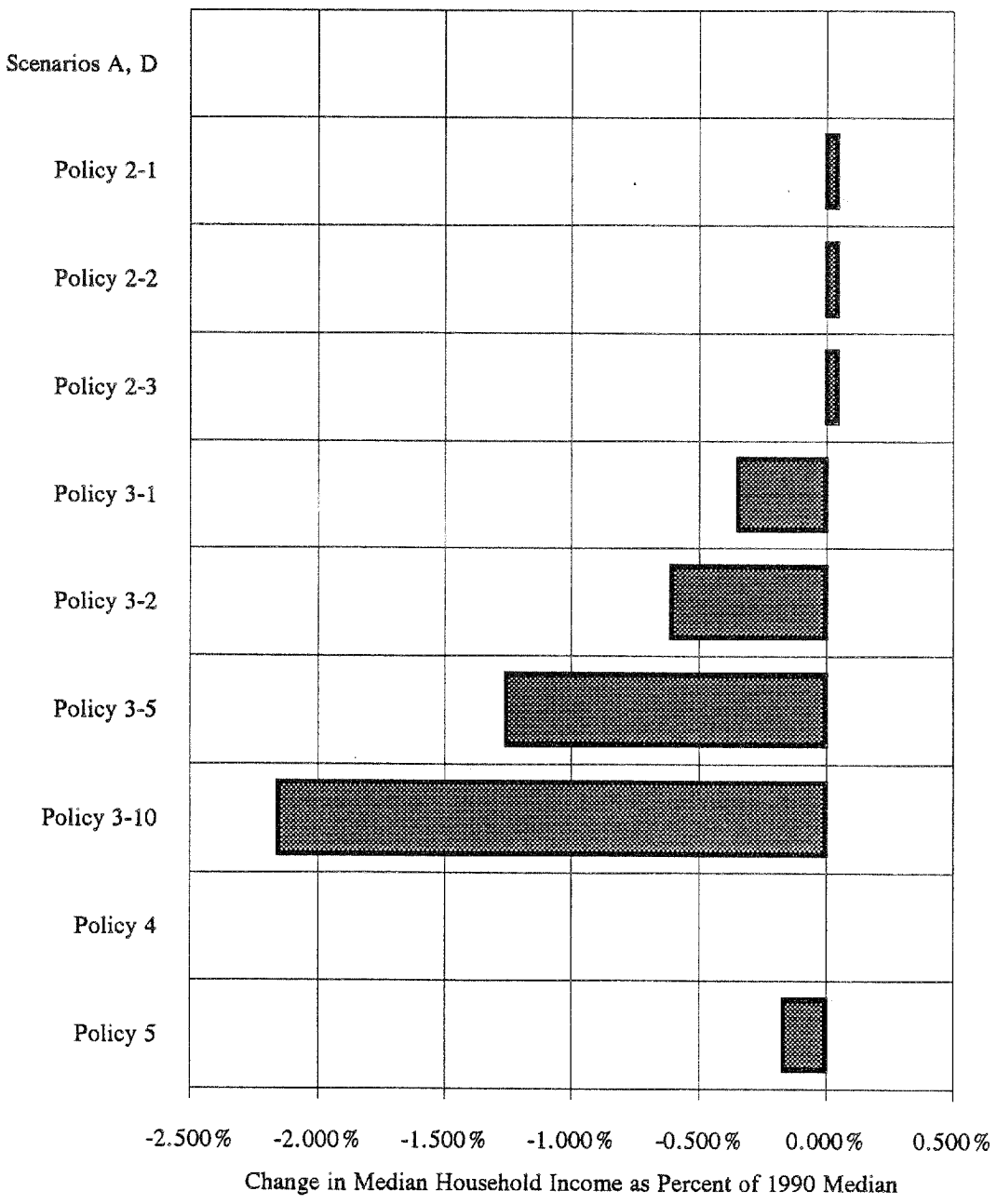
Change in Median Household Income Under Different Policies
Under Both Normal and Drought Conditions
Figure 5-20



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through municipal water conservation in this sub-basin, although none of the policies examined appears capable alone of eliminating these losses. Drawdowns in the regional aquifer in the Sierra Vista sub-basin thus comprise the most intractable problems identified by the WATERBUD simulations, under all scenarios and policy options.

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Chapter 6
Evaluation and Conclusions

This final chapter discusses three topics: (1) the performance of the model in comparison to other studies carried out in the Upper San Pedro Basin; (2) limitations of the model dictated by the nature of lumped-parameter water budget modeling and by certain properties of spreadsheet programs; and (3) the capabilities of the model for further applications.

6.1 EVALUATION: MODEL PERFORMANCE

The model carries out two basic functions: (1) it tabulates the total inputs and outputs to the water budget of each sub-basin; and (2) it allocates the gains and losses of the water budget to storage in the two aquifers and to the annual discharge of the river. These two functions can be termed the "tabulation" and "allocation" functions of the model. In turn, the model carries out these two functions in two modes: (1) it tabulates and allocates the gains and losses to describe conditions in 1990; and (2) it projects the ways in which these conditions could change over a twenty-year period of projection. The performance of the model therefore can be evaluated with respect to its tabulations and allocations for 1990 and with respect to its tabulations and allocations for projected future conditions in the basin.

6.1.1 Tabulation of Overall Water Budget for 1990

Two studies provide comparative material, with which to evaluate the performance of WATERBUD in tabulating the overall water budget for 1990: the water budget analysis

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by ADWR (1991) and the ground-water modeling work of Vionnet (1991; Vionnet and Maddock, 1992). The ADWR water budget results for 1990 are presented here as Table 6-1. This table can be compared directly with the estimates developed with WATERBUD and presented in Table 2-1, above, although the ADWR results use fewer categories than does WATERBUD.

Summary Annual Water Budget Computed by ADWR (1991:250), 1989-1990 Conditions, by Sub-basin (quantities are in acre feet)
Table 6-1

	Sierra Vista	Benson
Inputs and Outputs		
Underground Inflow	+3200	+0
Natural Recharge	+13860	+11760
Irrigation Depletion	-4590	-14230
Domestic/Municipal Depletion	-8150	-1010
Stockpond&Reservoir Depletion	-1620	-1140
Industrial Depletion	-50	-380
Underground Northward Outflow	-0	-120
Phreatophyte Consumption	-14450	-17690
River Inflow	+23420	+39200
Tributary Stream Inflow	+17300	+11800
River Channel Evaporation	-950	-770
River Outflow	-39200	-25500
Net Changes in Storage		
Gain(+) or Loss(-) of Groundwater	-11230	+1920

Comparison of Tables 2-1 and 6-1 shows that WATERBUD estimates slightly greater losses to storage overall in 1990 than does the ADWR analysis. WATERBUD shows a total change in storage in 1990 of -15669 acre-feet for the Sierra Vista sub-basin and -574 acre-feet for the Benson sub-basin. The ADWR analysis gives matching figures of -11230 and +1920, respectively.

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The differences between the ADWR and WATERBUD results for 1990 appear to arise largely because WATERBUD estimates return flows from human activities to be far less than does the ADWR analysis (see ADWR, 1991:Appendix F). A second difference is that the ADWR analysis uses a much smaller estimate of the number of households in rural areas who are not supplied by regulated water delivery services, resulting in a significantly smaller estimate of rural water use. This latter difference is apparent in a comparison of the census and consumption figures used by WATERBUD (Table 3-1, above) with those used by ADWR (1991:Appendix F). Minor differences include WATERBUD's use of higher estimates for mountain front recharge to and underflow discharges from the Sierra Vista sub-basin; and higher estimates of channel evaporation and losses from stockponds and reservoirs in both sub-basins. Altogether, these differences result in WATERBUD's tabulation of approximately 4400 acre-feet of additional losses in the Sierra Vista sub-basin and approximately 2500 acre-feet of additional losses in the Benson sub-basin in comparison to the ADWR results.

The selection of parameter values in WATERBUD is discussed in Chapters 3 and 4. It was noted in these chapters that the methods used to estimate return flows from municipal, domestic, industrial, and irrigation activities should provide more accurate results than the more general methods used by ADWR. One of the advantages of a model such as WATERBUD is that its parameter values can be changed in order to describe the system in alternative ways. The differences between the ADWR and WATERBUD estimates for 1990 result from the use of slightly different assumptions about the patterns of use of water in the upper basin. The differences thus provide insight into the effects of alternative assumptions about the hydrologic system rather than insight into any problems in the WATERBUD model.

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The final MODFLOW output files generated by Vionnet (1991, 1992 personal communication; Vionnet and Maddock, 1992) contain data on overall gains and losses to storage in a portion of the Sierra Vista sub-basin. Vionnet found a net storage loss of 7340 acre-feet for 1988, the last simulated year in her version of the MODFLOW model.

The storage loss estimated by the MODFLOW model is roughly half that estimated by WATERBUD. However, the MODFLOW model does not include several features of the system, specifically water consumption by the communities of Naco, Bisbee, and Tombstone and water consumption by rural households not supplied by regulated water delivery services or by registered wells. Together, these uses consume over 3000 additional acre-feet than are tabulated by the MODFLOW model. The pumping figures used in the MODFLOW model, further, were provided by ADWR, which appears to have adjusted the figures to take into account its estimates of return flows. As noted above, WATERBUD uses estimates of return flows that are significantly smaller than those used by ADWR. It therefore seems likely that the differences between the MODFLOW and WATERBUD results for 1990 stem from differences in assumptions concerning return flows (implicit in the ADWR pumping figures) and differences in the geographic coverage of the two models.

6.1.2 Allocation of Water for 1990

The allocations of gains and losses to storage in the two aquifers and to flow in the river in 1990 by WATERBUD were fixed by two assumptions: (1) The parameters controlling the allocation of water between the river and the floodplain aquifer were calibrated so that the river discharge matched the known 1970-1990 mean annual flow, as discussed in Chapter 5, above. (2) The allocation of water between the floodplain and regional aquifers was fixed by assuming that, at least in 1990, storage in the floodplain

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aquifer was constant. Thus, all losses to ground-water storage were allocated to the regional aquifer alone. This latter decision was necessary in order to provide a starting point for the simulations as discussed in Chapter 5.

The ADWR analyses do not provide estimates of the distribution of gains and losses to storage in the two aquifers or the flows in the river in 1990. Comparative data could be generated using the MODFLOW model but are not presently available. The MODSIM results (Summerside, 1991) potentially also provide an independent study for comparison. However, Summerside (1991) found that the MODSIM program did not allocate gains and losses between the river and the two aquifers as well as intended and identified this problem of allocation as a shortcoming in his results.

Other studies (e.g., Roeske and Werrell, 1973; Konieczki, 1980) and general data presented by ADWR (1991) indicate that there have been cumulative changes in hydraulic heads at many wells in both aquifers, in both sub-basins, at least since the 1940s. However, only the regional aquifer in the Fort Huachuca-Sierra Vista area exhibits a measurably depressed water table over any significant area. It is not known, whether the changes at individual wells in the floodplain aquifer reveal an overall loss to storage in that aquifer. In fact, geomorphologic analyses carried out by Hereford (1991) suggest that the floodplain sediments along the riverbed have not witnessed any additional down-cutting since the late 1930s. These findings suggest that average water tables in the floodplain aquifer have been stable since that time. As discussed in Chapter 5, the applications of WATERBUD presented here did not attempt to take the pre-1990 history of gains and losses systematically into account in estimating the water budget for 1990. The assumption of constant storage volume in the floodplain aquifer in both sub-basins in 1990 nevertheless appears reasonable.

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The allocations of gains and losses for the two aquifers carried out by WATERBUD for 1990 thus are largely shaped by a small number of pivotal assumptions, for which independent evaluative data are scarce. These assumptions provide a necessary starting point, however, from which to develop projections of future conditions. And, as with most other aspects of the model, alternative assumptions can be developed and used to select alternative parameter settings for its operation. Additionally, WATERBUD could be used to model the earlier history of development of water resources in the basin. The capabilities of the model do not limit its application only to the projection of future conditions.

6.1.3 Tabulations in Projected Future Water Budgets

The MODSIM results developed by Summerside (1991) provide the only estimates of future conditions in the upper basin for comparison with the full range of application results developed with WATERBUD (see Chapter 5). Table 6-2 summarizes the MODSIM results (Summerside, 1991; UAWRRC, 1991). This table can be compared directly with Table 5-1, above. It should be noted first, however, that WATERBUD and the MODSIM model differ in three crucial ways: (1) The MODSIM model was not configured to simulate the effects of changes in water delivery pricing and so was not used to simulate the effects of Policy 3. MODSIM does have to capability to simulate the effects of changing economic conditions but these capabilities were not exploited in the present study. (2) The MODSIM model employs an actual record of climatic conditions in its simulation of drought conditions in the basin (Scenarios B and D). It does not impose a set of constant "drought" conditions as was done with WATERBUD. WATERBUD could be modified in order to simulate a variable climate over the course of individual twenty-year projections. However, the present version does not have this

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Summary of MODSIM Results, from Summerside (1991)
Projected Cumulative Effects of Alternative Scenarios and Policies after Twenty Years Relative to 1990 Conditions
Table 6-2

	Regional Aq. Sierra Vista Sub. (acre feet)	Floodplain Aq. Sierra Vista Sub. (acre feet)	San Pedro River Sierra Vista Sub. (acre-feet/year)	Regional Aq. Benson Sub. (acre feet)	Floodplain Aq. Benson Sub. (acre feet)	San Pedro River Benson Sub. (acre-feet/year)
INITIAL CONDITIONS						
1990, "Normal" Conditions	31730841	159609	39190	27065444	123681	25500
	total change	total change	average change	total change	total change	average change
TWENTY-YEAR EFFECTS OF POLICY 1						
Scenario A	-310600	206	-6229	-138030	29199	751
Scenario B	-483268	-73902	-19460	-359163	-38798	-3175
Scenario C	-352484	0	-6229	-142860	29078	751
Scenario D	-378602	0	-18180	-252368	3250	-2062
Scenario E	-373176	-73696	-7999	-239995	-6470	-2062
TWENTY-YEAR EFFECTS OF POLICY 2						
Policy 2-1, Scenario A	-236701	206	-5124	-15345	27675	3418
Policy 2-1, Scenario D	-304703	0	-17075	-129683	1726	605
Policy 2-3, Scenario A	-114500	206	-2508	114338	30581	8637
Policy 2-3, Scenario D	-182502	0	-14459	0	4632	5823
TWENTY-YEAR EFFECTS OF POLICY 4						
Scenario A	-237394	206	-6099	-110314	29287	834
Scenario D	-305396	0	-18050	-224652	3338	-1980
TWENTY-YEAR EFFECTS OF POLICY 5						
Scenario A	-225181	206	-3562	-9772	27790	3418
Scenario D	-293183	0	-15513	-124110	1841	605

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capability. (3) The MODSIM model used parameter values from the Arizona Department of Water Resources' 1990 Preliminary Hydrographic Survey Report for the San Pedro Basin (ADWR, 1990), which reported much greater irrigation consumption in the upper basin than does the 1991 report (ADWR, 1991) on which WATERBUD is based.

Generally, WATERBUD estimates greater losses from aquifer storage in the Sierra Vista sub-basin under all scenarios and policies than does the MODSIM model. At the extreme, WATERBUD estimates the cumulative twenty-year losses under Policy 2-3 and Scenario A in this sub-basin to be nearly 120,000 acre-feet greater than does the MODSIM model. The two models agree closely on the effects of Policy 4 under both scenarios in the Sierra Vista sub-basin. The MODSIM model estimates greater losses from storage in the Sierra Vista sub-basin only for Scenario E under Policy 1. The picture is less consistent for the losses from storage in the Benson sub-basin. At the one extreme, WATERBUD projects nearly 230,000 acre-feet greater cumulative losses for both Policy 2-1 and Policy 5 under Scenario D. At the other extreme, the MODSIM model projects nearly 80,000 acre-feet greater cumulative losses for Policy 4 under Scenario A.

The two models project similar river discharges after twenty years from the Sierra Vista sub-basin under all scenarios and policy options. The estimates agree within $\pm$2000-5000 acre-feet per year. There is less agreement for the projected river discharges from the Benson sub-basin. WATERBUD generally estimates these discharges to be lower than does the MODSIM model: from 900 af/yr lower for Policy 4 under Scenario A, to nearly 23,000 af/yr lower for Policy 2-3 under Scenario D. MODSIM generates a lower estimate of river discharge from the Benson sub-basin only for the simulation of Scenario E.

The reasons for these differences between the WATERBUD and MODSIM results are not immediately obvious. In general, WATERBUD appears to project more severe

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losses from aquifer storage than does the MODSIM model, despite using the same demographic and industrial data and lower irrigation demand data than does the MODSIM model. That is, projected demands for water for human use in the upper basin should be greater in the MODSIM model than in WATERBUD. This result suggests that the MODSIM model calculates much higher rates of return flows or recharge from human activities in the upper basin than does WATERBUD. It is also expectable that WATERBUD would project greater losses under Scenario D conditions, since the "drought" conditions modeled with WATERBUD are more sustained and more severe than those modeled with MODSIM. A comparison of the detailed output of WATERBUD with that of MODSIM (Summerside, 1991), further, suggests that the two models use demographic data in a different manner to project future municipal and domestic demands.

Unfortunately, it is not presently possible to state that one or the other program is more correct in its estimates. And it must be emphasized that the two models in fact agree on the relative effects of the different scenarios and policy options; they only disagree over the absolute magnitudes of these effects. Both sets of simulations indicate that climatic stresses have the greatest impacts on the system, followed by economic growth, among the five scenarios examined. Both sets of simulations also indicate that the retirement of irrigation lands is crucial to the success of Policy 2; that Policy 2-1 produces effects very similar to those projected from Policies 4 and 5; and that Policy 2-3 reduces aquifer and river losses much more than do Policies 2-1, 2-2, 4 or 5. As noted above, Policy 3 was not evaluated with the MODSIM model.

6.1.4 Allocation in Projected Future Water Budgets

Two studies provide potentially comparable information on the distribution of losses between the two aquifer and the river estimated for the future in the upper basin.

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Again, these two studies are the MODFLOW analyses carried out by Vionnet (1991, 1992 personal communication), and the MODSIM analyses carried out by Summerside (1991).

Vionnet (1992 personal communication) did carry out some projections of future conditions in the area covered by the MODFLOW model. These projections take the 1988 pumping conditions estimated by ADWR and project them forward for an additional twenty years. The results of these projections are thus comparable to the results obtained for Scenario A (normal climatic conditions) and Policy 1 (no changes in water management) by WATERBUD. As noted above, the pumping figures used in these projections were adjusted by ADWR to take into account its estimates of return flows.

Vionnet found in the twenty-year projections with the MODFLOW model that losses to storage in the regional aquifer in the Fort Huachuca-Sierra Vista area would increase over the period of projection. She also found that the effects of these losses eventually of would spread to the interface between the regional and floodplain aquifers. Declines in hydraulic heads in the regional aquifer along this interface would then begin to reduce the rate at which the regional aquifer discharges water to the floodplain aquifer and could even result in a capture of water by the regional aquifer from the floodplain aquifer. Hydraulic heads in the floodplain aquifer then potentially also would begin to decline.

Vionnet's (1992) findings are similar to those produced by WATERBUD for Scenario A under Policy 1. Both studies project continuing losses to storage in the system with an increasing allocation of some of these losses to the floodplain aquifer. Figures 5-1 and 5-2, above, show this accelerating allocation of losses to the floodplain aquifer in the WATERBUD results. Because of the connection between hydraulic heads in the floodplain aquifer and flow in the river, this accelerating allocation of losses to the floodplain aquifer will entail an increasing loss of flow in the river, as well.

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The MODSIM projections of allocations summarized here in Table 6-2 also potentially are comparable to those of WATERBUD. However, it must be emphasized that the allocations of water between the two aquifer and between the river and the floodplain aquifer are head-dependent processes. Because of the differences in the estimated losses to storage between the WATERBUD and MODSIM results, therefore, the patterns of allocation among the two aquifers and the river estimated by MODSIM are not easily compared to the patterns estimated by WATERBUD. Tables 5-1 and 6-2 also show that regardless of how it allocates losses between the two aquifers the MODSIM model projects similar losses to river flows in the Sierra Vista sub-basin and smaller losses in the Benson sub-basin when compared to WATERBUD.

The allocation of gains and losses among the two aquifers and the river in the WATERBUD results also can be examined as consequences of the assumptions used in calculating this allocation. As discussed in Chapters 4 and 5, four sets of assumptions affect this allocation: (1) calibration assumptions used to estimate the volumetric conductances between the two aquifers and between the floodplain aquifer and the river in each sub-basin; (2) an assumption that the estimates of hydraulic conductivity of the riverbed are correct and therefore that only the estimates of hydraulic head in the floodplain aquifer needed to be calibrated for estimating discharges between the floodplain aquifer and the river; (3) an assumption that it takes 100 years for changes in storage in the regional aquifer to affect completely its average hydraulic head along its interface with the floodplain aquifer; and (4) an assumption that it takes 4 years for changes in storage in the floodplain aquifer to affect completely its average hydraulic head along its interface with the regional aquifer.

It is likely that changing these assumptions would have greater effects on the allocation results of WATERBUD than would changing any single input or output

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parameter of the model. Unfortunately, there are presently no independent means for evaluating these assumptions. The allocation of water between the two aquifers could be examined using a detailed ground-water flow model developed with programs such as MODFLOW. However, no single model or set of models as yet exists, covering all of the upper basin, with which to draw comparisons. The model developed by Vionnet (1991; Vionnet and Maddock, 1992) covers only a portion of the Sierra Vista sub-basin. A model developed by Freethey (n.d.) for the Benson area also does not cover all of the Benson sub-basin and does not include an adequate representation of either the floodplain aquifer or the river for purposes of examining the allocation of water. Finally, programs such as MODFLOW do not have the capability to include surface runoff water in their calculations and so cannot simulate an important component of the overall water budget affecting stream-aquifer interactions (Vionnet, 1991; Vionnet and Maddock, 1992). Thus, further evaluation of those assumptions in WATERBUD, which shape the allocation of gains and losses within the system, must await the development of more detailed and comprehensive surface/ground-water models for the region.

6.2 EVALUATION: LIMITATIONS IN MODELING METHODS

The construction of the model was constrained by certain properties of spreadsheet programs and by the nature of lumped-parameter water budget modeling.

6.2.1 Spreadsheet Programming

The major difficulty in using a spreadsheet program lies in the ways by which such programs carry out iterative calculations. As discussed in Chapters 3 and 4, the model must carry out iterative calculations in order correctly to adjust the discharge of water between the two aquifers and between the floodplain aquifer and the river. Ideally, a

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programmer would want a model to carry out such iterations individually for each projected season, not even beginning the calculations for a new season until the iterations have converged on a stable solution for each current season.

Unfortunately, none of the spreadsheet programs examined, among LOTUS 1-2-3® v3.1, EXCEL® v2.0, and QUATTRO-PRO®, has this capability. Instead, these programs carry out each iterative cycle by proceeding columnwise (left to right) through the entire spreadsheet, carrying out a single iteration for each successive column in turn. This process is repeated for the entire width of the spreadsheet until one of two criteria is met. Either the maximum number of iterations requested by the user has been reached or the iterative calculations for the last (right-most) column values have achieved the convergence criterion requested by the user.

This manner of calculation has one notable result for a system of equations such as those used in WATERBUD. During any individual cycle of iterations through the entire spreadsheet, a small fluctuation in a crucial cell value in an "early" column will propagate itself into a larger and larger fluctuation as that iteration cycle proceeds across the remaining columns. For example, a slight adjustment of floodplain aquifer storage in one season will result in a change in the rate of aquifer-river discharge estimated for the next season, which will affect the estimates of both river flow and aquifer storage for the end of that second season, which will result in a further change in the rate of aquifer-river discharge for the next season, and so forth.

The resulting oscillation of values in each column gradually do decrease as the iteration process continues. However, the oscillations during the first few iteration cycles have the potential to produce extremely large (several orders-of-magnitude) fluctuations for several rows in the right-most columns. These fluctuations can be either positive or negative. As a consequence, they can entail cell values that lie outside of the

USF200010493

mathematically acceptable range for some equations and so produce errors. For example, negative cell values will produce calculation errors when passed as input to equations that use square-root or logarithm functions. Unfortunately, once a cell registers a calculation error, in all three programs examined, the cell takes on an error code that is not removed by later iterations. Any cells in other rows or columns whose values depend on the value of this "error" cell then also take on an error code and also cease to be recalculated by later iterations. Thus, extreme fluctuations have the potential effectively to shut down the iteration process for rows toward the right-hand side of the spreadsheet.

This limitation of currently available spreadsheet programs can be overcome. As discussed in Chapter 4, it was necessary to modify error-sensitive equations in order to keep their values from fluctuating outside of appropriate mathematical bounds during individual iteration cycles. For some equations, it was necessary only to specify that the cell not be allowed to take on a zero or negative number during intermediate iterations (e.g., Row 304). For other equations, it was necessary to limit the range over which the values would be allowed to oscillate (e.g., Rows 257 and 259) by confining the value of each cell within a range proportionate to the value of the same cell in the immediately preceding year's columns. This latter modification has the effect of keeping "early" fluctuations from propagating themselves into excessively large "late" fluctuations during any individual iteration cycle. This latter modification also incidentally has the additional property of keeping the signs (+/-) of individual cell values consistent along a row for equations where this is mathematically appropriate. These error-trapping modifications to the equations have no effect on the final convergent value of cells. They simply help keep the process of iteration from producing extreme or mathematically inappropriate intermediate calculations; as a useful consequence, they also help reduce the calculation time per simulation.

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6.2.2 Lumped Parameter Modeling

Limitations of lumped parameter modeling were discussed in Chapter 2, as they pertain to the modeling of hydrologic systems. These limitations are worth restating. A water budget model such as WATERBUD necessarily works with highly aggregated variables such as total aquifer storage, average water table elevations, quarterly river discharges, and annual mountain-front recharge. WATERBUD contains only limited spatial information: the division of the upper basin into two U.S. sub-basins; and the use of 100-year and 4-year lag functions to describe the relationship between changes in storage and changes in hydraulic head relationships between the regional and floodplain aquifers, respectively, along their shared interface.

The use of highly aggregated data and estimation methods does not affect the ability of a model such as WATERBUD to tabulate overall gains and losses to a hydrologic system. The lack of spatial control only constrains the ability of such a model to allocate these gains and losses to individual aquifers and to the flow in the river. This process of allocation must take into account estimated average hydraulic head relationships between the two aquifers along their interface; and between the river and the floodplain aquifer along their riverbed interface.

Head-dependent flows between hydrogeologic units in an actual hydrologic system will vary from one physical location to another due to local variations in hydraulic conditions and in the properties of the geologic media; and they will vary from one instant of time to the next. Consequently, models with high spatial and temporal resolution are necessary for evaluating the accuracy of lumped parameter models such as WATERBUD. Unfortunately, hydrologists do not agree how best to model such head-dependent flows even at high spatial and temporal resolution, as illustrated by the availability of several

USF200010495

alternative means for modeling stream-aquifer interactions using MODFLOW (McDonald and Harbaugh, 1988; Prudic, 1989; Kraeger-Rovey, 1987; Schenk, 1990).

Simple numerical simulations were used to develop methods within WATERBUD for summarizing processes taking place at finer scales of time than actually employed by the model. These simulations were used specifically to develop ways to summarize the hydrologic interaction of the river with the floodplain aquifer, although they did not incorporate any spatial information finer than the distinction between the two sub-basins. The results obtained by Vionnet (1991; Vionnet and Maddock, 1992) with MODFLOW provide the only spatially detailed information, with which to evaluate the performance of WATERBUD. And as noted above, the WATERBUD results are at least generally consistent with those obtained by Vionnet. Thus, WATERBUD does contain finer temporal information implicitly in its methods and does produce results that are at least generally consistent with a spatially and temporally more detailed model of the system.

6.3 EVALUATION: CAPABILITIES OF THE MODEL

Two crucial features of WATERBUD are its ability to accept alternative parameter values and its ability to model the system under a modest range of alternative conditions and alternative water management policies. The model thus is not simply a description of the system but a tool for examining alternative descriptions of the system. It is therefore useful to consider what additional capabilities might be included in any revision of WATERBUD or in the development of similar models.

Discussions in this chapter and in Chapters 3-5 have pointed out two potentially useful additional features. First, it would be useful to be able to simulate a continuous climatic sequence instead of having climatic conditions hold constant for each individual

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simulation. Second, it would be useful to simulate an entire history of development of a basin instead of having the simulations start out "cold" at some later point in that history.

Incorporating the first capability would require some changes in equations in the present model so that an array of seasonal climatic parameter values could be used as an alternative to a prescribed set of constant values. This would not be difficult but was not considered necessary for the present model version. The second capability already is present implicitly in the model. There is nothing to prevent a user from simulating an entire history of development in a basin with WATERBUD. A user could develop input parameter values for the start of the history of development, simulate the first twenty years of that development, use the final results of that first simulation as input to a second simulation with new parameter settings as necessary, use the final results of the second simulation as input to a third with further adjustments in parameter settings as necessary, and so forth. This process would be cumbersome. The model is presently constructed to operate with only a twenty-year span of projection; the user also would have to restart each successive period of simulation manually after assembling its input parameter values from the results of the preceding simulation and from independent data sources.

The model might also be modified in a third way to speed up its calculations and further overcome the peculiarities of spreadsheet iteration methods. The equations for any single year of projection are identical to those for every other year in virtually all respects. They differ only in the spreadsheet column reference cells, from which they take their input values. It would be possible to rewrite the entire projections section of the model in order to take advantage of this repetitiveness. The projection equations for a single year could be entered into a spreadsheet "macro." This macro could call on a starting set of columns for its input information, carry out the necessary iterative calculations to arrive at a stable solution for that year, and write its results to a new set of columns. The data in

USF200010497

the new set of columns would then be used as input for simulation of the next year, and so forth. With the iteration cycle limited to only a single year at a time, both processing time and the iteration problems described above could be greatly reduced. Such programming elegance was not a primary goal of the present project but would be worth pursuing for any revision of WATERBUD or for the development of other, similar models.

Finally, WATERBUD could also be modified to include information on water quality in its projections. That is, in addition to simulating gains and losses to storage and river flows, the model has the potential to simulate improvements or degradations to the quality of water supplies. The model could be modified to keep track of the overall quality (e.g., total dissolved solids or concentrations of conservative constituents) of each class of water in the region. These classes include groundwater from each of the two aquifers, surface water, and both treated and untreated return flows from agricultural, industrial, and municipal users. The quality of each class of water at the end of each year could be simulated as a function of its quality and volume at the start of the year and the quality and volume of waters added to it or removed from it during the course of the year.

6.4 CONCLUSIONS

WATERBUD uses spreadsheet programming to model the water budget and water management systems of the Upper San Pedro River Basin, Arizona. The model was developed as part of a group of studies carried out by the University of Arizona for Cochise County, Arizona, to examine how hydrologic, demographic, climatic, and economic conditions affect this budget; and how water management policies may affect the budget over the next twenty years. The model represents relationships among urban and rural population and median incomes; urban and rural domestic water consumption; agricultural and industrial consumption; domestic, agricultural, and industrial return

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flows; phreatophyte and other evapotranspiration losses; natural surface and ground-water recharges and discharges; head-dependent flow between a floodplain aquifer and the river; head-dependent flow between a regional aquifer and the floodplain aquifer; and changes in aquifer storage.

The model has been used to simulate several alternative scenarios and policy options in order to see how these affect hydrologic conditions in the upper basin. The application results indicate that stringent conservation measures and reductions in irrigation are necessary to significantly reduce ongoing losses to storage in both aquifers, which also threaten river discharges and the viability of riparian habitat in the basin.

Comparisons of these results with other studies of the upper basin indicate that the WATERBUD results are similar to those of the other studies. The results appear to differ primarily as a result of assumptions made in the initial parameter settings of WATERBUD, which estimate significantly lower rates of return or recharge of water from human activities in the basin than those assumed in the other studies. And WATERBUD easily can be used to simulate the system using alternative assumptions about return flows and recharges. Perhaps more so than any of the other studies of the upper basin, WATERBUD provides the flexibility to examine the behavior of the system under a wide range of alternative assumptions about numerous aspects of the system. Thus, while the present set of application results should be useful by themselves it is hoped that the model will serve as a tool for further investigations in the upper basin, to help its residents develop their water management practices.

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Chapter 7
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Appendix A
Using the Model

The model consists of a worksheet written for spreadsheet programs compatible with LOTUS 1-2-3® Releases 2 and 3, Microsoft EXCEL® Releases 2 upward, and QUATTRO-PRO®. The senior author has carried out runs with the model using both LOTUS and EXCEL.

The size of the spreadsheet limits the kinds of equipment on which the model can run. Each simulation requires nearly 1.2M of disk storage space, and will only run on DOS (or OS/2) systems with more than 2.5M of memory (RAM and virtual memory). Run times vary depending on the number of parameters changed to initiate each run. Users with 80286-based systems will probably find that the model takes considerable time to run on their systems. The model takes approximately 45-60 minutes to run as a LOTUS spreadsheet on a 16 MHz 80386SX system with 2M of RAM and no math co-processor. In comparison, the model takes approximately 6-10 minutes to run as an EXCEL or LOTUS spreadsheet on a 24 MHz 80386DX system with 8M of RAM and a co-processor. EXCEL operates more efficiently than LOTUS in its calculations, due to its ability to control iterations with a convergence criterion rather than with a limit on the number of iterations alone. However, EXCEL's reliance on the Microsoft WINDOWS® operating environment limits its operating speed. As a result, the model takes roughly the same time to run with EXCEL as with LOTUS.

The following paragraphs describe the operation of the model using LOTUS 1-2-3, to provide a common frame of reference for all users. The description below also assumes that the reader is (or will become) familiar with the basic operation of 1-2-3,

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QUATTRO-PRO, or EXCEL. Appendixes B and C provide listings of the model default settings and equations. The equations are given in EXCEL format, which differs only slightly from LOTUS 1-2-3 format.

A.1 RUNNING THE MODEL

Running the model involves six steps:

1. Start LOTUS 1-2-3

2. Load the model into 1-2-3 using the **/FILE RETRIEVE** command. The model is stored in a Read-Only file named WATERBUD.WK1. Once the file is loaded, the **CIRC** indicator will appear in the Status Line at the bottom of the screen. This does not indicate a system error, and requires no action on your part; the model contains many iterative ("circular") cell references.

2.a. If you have spare disk space, you may want to use the **/FILE SAVE** command and give an alternative file name to your active working copy of the worksheet. This step will allow you to save your initial settings and results without writing over the master copy of the model. Attempting to write over the master copy will produce an error message, since the master copy is tagged as Read-Only.)

3. Move to the cells containing the parameter values you wish to change, and type in the values you prefer. If you write over a default value and then wish to change the cell back to that default, refer to Appendix B to find that default value and type it back in. You can also use the **UNDO** command to correct a mistake, if you have activated this feature of 1-2-3, and if you catch the mistake immediately after you make it. Once you begin to make changes in the model, the **CALC** indicator also will appear in the Status Line at the bottom of the screen. This is not an error message, and requires no action on your part.

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4. When you are satisfied with the settings for your initial conditions, press the [F9] key to issue the **CALCULATE** command. The worksheet has been set to operate in **MANUAL** recalculation mode (**/WORKSHEET GLOBAL RECALC MANUAL**), so that it will not begin to run the 20-year projection until you press the [F9] key. Your screen will display **WAIT** in the Mode Indicator area, while the program carries out its calculations. When the Mode Indicator returns to **READY**, the program has finished the calculations.

5. Look over the results and decide whether to save them. Rows 200 to 386 in the worksheet will contain the season-by-season results and year-end totals for the 20-year projection. For convenience, the year-end totals for most variables also repeat in rows 400-575. Usually, you will need to save only the year-end totals. You can save the results in one of three ways:

5.a. You can save the season-by-season and/or the year-end totals as numerical values in a separate file. Use the **/FILE EXTRACT VALUES** command to select the portion (**RANGE**) of the worksheet that you wish to save, and assign an appropriate file name. For example, to save only the year-end totals, select A400..W575. Saving your results by this step will reduce greatly the amount of disk space needed for the results. If you do not save the parameter settings (rows 1 to 179), be sure to write down the values you used in place of the default settings for any parameters you changed.

5.b. You can save the entire worksheet, but as numerical values only, using the **/FILE EXTRACT VALUES** command to select the entire worksheet and save it under a new file name.

5.c. You can save the entire worksheet with its original equations but with the new parameter values using the **/FILE SAVE** command. As noted above, it is advisable

USF200010513

to save any modified worksheets using alternative names that will not be confused easily with the default worksheet.

6. Use the graphing and other utilities to examine the results, or to carry out statistical analyses. You can also change parameter settings and run the model again (restart at step 3, above), without exiting 1-2-3. When you have finished, and saved or printed your results and graphs, exit 1-2-3 using the /**QUIT** command. If you have not saved your current working copy of the spreadsheet, the program will prompt you, to see if you want to save this working copy before exiting. If you have saved your results to a separate file and recorded your choices of parameter settings, you need not save your working copy of the entire spreadsheet.

A.2 SPECIAL INSTRUCTIONS

Users of WATERBUD should also consider the following special instructions, to use the model most effectively.

A.2.1 Controlling Convergence

The methods of calculation used by a spreadsheet program affect the manner and rate at which it converges on the solution to a circular or iterative calculation, as discussed in Chapter 6. As discussed in Chapters 4 and 6, WATERBUD contains several mechanisms for limiting the range of oscillation of several crucial equations and for increasing its rate of convergence. These mechanisms have been tested over a range of simulated conditions. However, it is conceivable that some untested combination of parameter settings could still result in problems of convergence.

Both LOTUS 1-2-3 and EXCEL allow the user to specify the number of iterations the program can use, for solving iterative or circular calculations. LOTUS 1-2-3 will

USF200010514

carry out the specified number of iterations regardless of whether the calculations converge completely during those iterations or not. Therefore, it is recommended that users of WATERBUD with 1-2-3 take an additional precaution: For a given simulation, run the model first with the number of iterations set to 50 (**/WORKSHEET GLOBAL RECALC ITERATION**). Before starting the calculations (see above), move to Row 257 or 259 of Column DZ, the annual summary column for the last simulation year. Then begin the calculations and watch the values in DZ257 and DZ259 to see if they stabilize before the end of the 50 iterations. If you cannot tell whether the values have stabilized, before the end of the 50 iterations, then reset the number of iterations to a small number (e.g., 2) and start calculation again with the [F9] key. If the values of these two cells change during this repeating of the calculations, then they have not converged. At this point, reset the number of iterations back to 50 and repeat the calculation cycle again and watch (or double-check) again to make sure that the analysis has reached a stable solution.

EXCEL combines specification of the number of iterations with specification of a convergence criterion. This criterion identifies the maximum difference allowable for cells containing circular references, from one iteration to the next. If the difference between successive iteration values of <u>any</u> cell exceeds this criterion, then the program carries out still another iteration until all such cells meet the specified criterion.

The convergence criterion in EXCEL applies to all cells containing a circular reference. The iteration process in EXCEL therefore is controlled by those cells that contain circular references in the rightmost column in the spreadsheet. In WATERBUD, this rightmost column is Column DZ. That is, EXCEL will not stop carrying out iterations in WATERBUD until all cells in Column DZ, and therefore all cells in all preceding columns, have met the convergence criterion. If a given simulation involves significant changes in parameter settings, however, it is conceivable that EXCEL will

USF200010515

reach the maximum number of iterations specified by the user before achieving convergence. EXCEL displays the number of iterations completed during a calculation cycle in the upper left corner of its status bar. Users should watch this number and note whether the calculations reach the requested maximum number of iterations. If this maximum number is reached, the user should start a new calculation cycle with the [F9] key in order to allow the program to achieve convergence.

Users also should use discretion in selecting a convergence criterion. It might seem reasonable to select a criterion of 0.001, for example, under an assumption that the calculation of aquifer heads need not be carried out to an accuracy greater than ± 0.001 feet. However, it is important to recognize that EXCEL applies the same convergence criterion to all cells containing a circular reference and that the calculations of total storage in the floodplain aquifer also contain circular references. Thus, specifying a criterion of 0.001 would also impose a convergence criterion of ± 0.001 acre-feet on estimates of storage in the floodplain aquifer. Such a level of accuracy is not needed; requiring an accuracy of ± 10 or ± 100 acre-feet for storage in the floodplain aquifer should serve well for virtually all simulations. Fortunately, requiring an accuracy of ± 10 or ± 100 acre-feet for storage in the floodplain aquifer also simultaneously forces a very high level of accuracy for the estimation of floodplain aquifer heads.

A.2.2 Convergence Errors

Reasonable efforts have been taken to ensure that the calculations carried out in WATERBUD do not result in numerical errors due to their exceeding the mathematical range of operation of any equation, as discussed in Chapters 4 and 6. Nevertheless, it is still conceivable that a user could specify a unique set of initial parameter values that might result in numerical errors. If such errors develop, the user will see calculation error

USF200010516

messages in one or more cells of a given column and in all later columns, i.e., in all columns to the right of the column in which the error(s) first appears. Two methods can be used, to clear the error messages.

First, the user can proceed to the first set of seasonal and annual equations immediately preceding the year of projection in which the error first appears. The set of unaffected columns (including the preceding blank column) should then be repeatedly copied over all succeeding, error-locked column sets. The model can then be run again.

Second, the user can take advantage of the fact that the spreadsheet retains the results of each simulation in its final cell values. The user can discard an error-locked version of the model and start over with less extreme parameter settings. After completing calculations with this less extreme set of parameter values, the user can take the resulting spreadsheet and change its parameter values to more extreme settings and repeat the calculations. By carrying out simulations that shift parameter values in increments, the user can work up to a simulation of the most extreme conditions of interest without encountering numerical errors in any single simulation.

A.3 TRIAL AND CALIBRATION RUNS

WATERBUD comes in three versions, the complete twenty-year version, a five-year version, and a one-year version. The five-year version is provided with the name, WATERBD5; the one-year version is provided with the name, WATERBD1.

WATERBD5 allows users to explore the effects of alternative parameter settings without taking the time to run the projections out for an entire twenty-year period. This option can be extremely helpful for users with slower computer systems, on which an individual twenty-year simulation can take 45 minutes or more. Five-year simulations require approximately one quarter the time of twenty-year simulations. And five-year trial

USF200010517

simulations can provide enough information to evaluate whether a given set of alternative parameter values is going to produce meaningful and interesting results. If a five-year trial simulation does produce interesting results, then the user can decide whether to take the time to carry out a complete twenty-year run.

WATERBD1 provides a simulation of the initialization year alone, and serves two purposes. First, it should be used for all calibration runs, which do not require the simulation of any year except the initialization year. Second, it can be used to simulate the current water budget without carrying out any projections of future conditions. It thus permits comparison of the effects of alternative assumptions on the modeling of the current budget, for example the effects of the assumptions used by ADWR (1991) versus those used to develop the default parameter settings for WATERBUD.

A.4 COPIES OF THE MODEL

Master copies of WATERBUD, WATERBD5, and WATERBD1 are available on diskette in LOTUS and EXCEL format at the University of Arizona, Water Resources Research Center, in the files assembled by the Interdisciplinary Study Team. Master copies also have been provided to the Cochise County, Arizona, Flood Control District. Questions concerning operation of the model can be directed to the author.

USF200010518

Appendix B
Parameters of the Model
Recommended Default Values

USF200010519

	A	B	C	D	E	F	G	H	I	J
1	GENERAL PARAMETERS FOR UPPER SAN PEDRO BASIN MANAGEMENT MODEL									
2	(quantities are for an average year unless otherwise indicated)									
3										
4	I. INFLOW FROM MEXICO									
5	Inflow of Surface Water from Mexico	23420	acre-feet							
6	Inflow of Groundwater to Floodplain Aquifer from Mexico	900	acre-feet							
7	Inflow of Groundwater to Regional Aquifer from Mexico	2100	acre-feet							
8										
9	II. SUB-BASIN NATURAL CHARACTERISTICS									
10	Sub-basin Name	Sierra Vista	Benson							
11	--PRECIPITATION AND RUNOFF									
12	Watershed Area Tributary to Streamflow North of Border	1038	758.2334	sq.miles						
13	Annual Gross Precipitation over Entire Watershed	1.497	1.444	a.f./acre						
14	Annual Gross Precipitation Rate over Floodplain	0.92	1	a.f./acre						
15	Annual Effective Precipitation Rate over Floodplain	0.43	0.36	a.f./acre						
16	Fraction of Annual Precipitation Falling in Season I	0.2143	0.2143							
17	Fraction of Annual Precipitation Falling in Season II	0.0952	0.0952							
18	Fraction of Annual Precipitation Falling in Season III	0.5952	0.5952							
19	Fraction of Annual Precipitation Falling in Season IV	0.0952	0.0952							
20	Runoff Estimator (Moosburner) Equation, Constant Term	16.813	16.813							
21	Runoff Estimator (Moosburner) Equation, Area Exponent	0.77	0.77							
22	Runoff Estimator (Moosburner) Equation, Precipitation Exponent	3.94	3.94							
23	--AQUIFERS									
24	Surface Area of Regional Aquifer	464554.6	398416.7	acres						
25	Steady-State Regional Aquifer Underflow	410	0	acre-feet						
26	Average Specific Yield of Regional Aquifer	0.08	0.08	vol/vol						
27	1990 Total Storage in Regional Aquifer	31753242	27064683	acre-feet						
28	Recharge to Regional Aquifer by Precipitation	15440	11620	acre-feet						
29	Steady-State Elevation of Regional Aquifer Water Table Above Riverbed	2.4922	0.5634	feet						
30	1990 Estimated Elevation of Regional Aquifer Water Table Above Riverbed	3.5052	-6.4072	feet						
31	Surface Area of Floodplain Aquifer	22167.6	17170.8	acres						
32	Steady-State Floodplain Aquifer Underflow	240	120							
33	Average Specific Yield of Floodplain Aquifer	0.12	0.12	vol/vol						
34	1990 Total Storage in Floodplain Aquifer	159609	123681	acre-feet						
35	Pre-Development Recharge to Floodplain Aquifer by Regional Aquifer	17130	12030	acre-feet						
36	Inter-Aquifer Volumetric Conductance Coefficient	2660.112	2060.496	acre/quarter-year						
37	--STREAM-AQUIFER INTERACTIONS									
38	1970-90 Average River Discharge Volume	39200	26500	acre-feet						
39	Steady-State Elevation of Floodplain Water Table Above Riverbed	0.8823	-0.8962	feet						
40	1990 Estimated Elevation of Floodplain Water Table Above Riverbed	1.4440	-7.7229	feet						
41	Stream-Aquifer Volumetric Conductance Coefficient	1.0000E+0	1.0000E+0							
42	Effective Length of Riverbed	188496	170544	feet						
43	Average Thickness of Riverbed	5	15	feet						
44	Discharge Exponent for Estimating Average River Stage	0.4265	0.3446							
45	Discharge Coefficient for Estimating Average River Stage	0.010111	0.028046							
46	--EVAPORATION									
47	Area of Unvegetated Bare Ground on Riverbed	966.3	838.1	acres						
48	Bare-Ground Consumptive Use (Evaporation) Coefficient	1.132	1.155	a.f./acre						
49	Discharge Exponent for Estimating Average River Width	0.3802	0.4032							
50	Discharge Coefficient for Estimating Average River Width	0.6318	0.6004							
51	Open-Water Gross Evaporation Rate	5.417	5.417	a.f./acre						
52	Fraction of Annual Potential Evaporation Occuring in Season I	0.1762	0.1772							
53	Fraction of Annual Potential Evaporation Occuring in Season II	0.2996	0.2967							

USF20001052

	A	B	C	D	E	F	G	H	I	J
54	Fraction of Annual Potential Evaporation Occuring in Season III	0.3367	0.3364							
55	Fraction of Annual Potential Evaporation Occuring in Season IV	0.1885	0.1897							
56										
57	III. BASIN-WIDE CULTURAL SUPPLY AND DEMAND									
58	Imported Water Recharged to Floodplain Aquifer, Sierra Vista Sub-basin	0	acre-feet							
59	Imported Water Recharged to Regional Aquifer, Sierra Vista Sub-basin	0	acre-feet							
60	Export of Water from Floodplain Aquifer, Sierra Vista Sub-basin	0	acre-feet							
61	Export of Water from Regional Aquifer, Sierra Vista Sub-basin	0	acre-feet							
62	Imported Water Recharged to Floodplain Aquifer, Benson Sub-basin	0	acre-feet							
63	Imported Water Recharged to Regional Aquifer, Benson Sub-basin	0	acre-feet							
64	Export of Water from Floodplain Aquifer, Benson Sub-basin	0	acre-feet							
65	Export of Water from Regional Aquifer, Benson Sub-basin	0	acre-feet							
66	SurfaceArea of River Impoundment in Sierra Vista Sub-basin	0	acres							
67	Fraction of Impounded River Water Recharged to Regional Aquifer	0								
68	Fraction Increase in Recharge from Cloud Seeding, Sierra Vista Sub-basin	0								
69	Fraction Increase in Recharge from Cloud Seeding, Benson Sub-basin	0								
70										
71	IV. SPECIAL SIERRA VISTA CITY ACTIVITIES									
72	City Use of its Own Wells to Supply Municipal Facilities	193	acre-feet							
73	Surface Area of Runoff Impoundment in Sierra Vista	0	acres							
74	Fraction of Captured Runoff Recharged to Regional Aquifer	0								
75	Fraction of Treated Effluent Diverted to Artificial Wetland	0								
76	Surface Area of Artificial Wetland	0	acres							
77	Artificial Wetland Consumptive Use (Evaporation) Coefficient	5.417	a.f./acre							
78										
79	V. DOMESTIC CONSUMPTION									
80	Census Area Name	SV CITY	SV S.E.	Ft.HUAC	HC CITY	TOMB.	BISBEE	NACO	RUR.SVS	RUR.SVS
81	Regulated Water Delivery System? (yes/no)	(yes)	(yes)	(no)	(yes)	(yes)	(yes)	(yes)	(yes)	(no)
82	1990 Census Population	23773	1182	9210	1782	1220	6288	496	294	10844
83	Projected Annual Per Capita Population Growth Rate	0.0422	0.0071	0	0.0071	-0.0287	-0.0128	-0.00013	-0.00013	-0.00013
84	1980 Median Household Income, $	16740	9769	#N/A	13988	9769	10882	10882	9769	9769
85	Number of Water Service Connections, 1989	10330	446	#N/A	650	550	3221	265	111	4338
86	Acre-Feet of Delivered Water, 1989	4719.13	126.06	2712	310.07	200.16	1528.66	82.08	29.12	1843.48
87	Target Water Consumption Rate, Gallons Per Capita Per Day	0	0	0	0	0	0	0	0	0
88	Fraction of Domestic Water Returned to Basin as Treatable Effluent	0.5	0.5	0.5	0.5	0.5	0	0.5	0.5	0.5
89	Fraction of Effluent Lost to Evaporation During Treatment	0.15	0.15	0.15	0.15	0.15	0	0.15	0	0
90	Fraction of Treated Effluent Recharged to Regional Aquifer	0	0	0	0	0	0	0	0	0
91	Fraction of Treated Effluent Used to Supplement In-Stream Flow	0	0	0	0	0	0	0	0	0
92	Fraction of Households in 1989 with Lowflow Fixtures	0	0	0	0	0	0	0	0	0
93	Fraction of Older Structures Annually Refitted with Low-Flow Fixtures	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05
94	Fraction Required Conservation from 1989 Demand	0	0	0	0	0	0	0	0	0
95	1989 Service Price, $ per 1000 Gallons Delivered	1.27	2.41	0.00	1.10	0.79	2.20	1.33	0.33	0.00
96	Imposed Additional Water Charges, $ per 1000 Gallons	0	0	0	0	0	0	0	0	0
97	Seasons I-IV Indoor Use, Demand Equation Coefficient	0.5811	0.5404	#N/A	0.6247	0.498	0.846	0.4933	0.2765	#N/A
98	Season I Outdoor Use, Demand Equation Coefficient	0	0	#N/A	0	0	0	0	0	0
99	Season II Outdoor Use, Demand Equation Coefficient	0.5166	0.8444	#N/A	0.4814	0.2851	1.2166	0.461	0.0721	#N/A
100	Season III Outdoor Use, Demand Equation Coefficient	0.4501	0.741	#N/A	0.4231	0.2503	1.069	0.3963	0.0632	#N/A
101	Season IV Outdoor Use, Demand Equation Coefficient	0.2127	0.3626	#N/A	0.2008	0.12	0.5079	0.1884	0.03	#N/A
102										
103	VI. MISCELLANEOUS DOMESTIC CONSUMPTION PARAMETERS									
104	Price Elasticity, Indoor Domestic Use	-0.3								
105	Price Elasticity, Outdoor Domestic Use	-1.2								
106	Income Elasticity, Indoor and Outdoor Domestic Use	0.4								

USF2000105 22

	K	L	M	N	O
54					
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76					
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79					
80	BENSON	St.DAVID	POME.	RUR.BS	RUR.BS
81	(yes)	(yes)	(yes)	(yes)	(no)
82	3824	1468	676	1160	1532
83	-0.0091	-0.00013	-0.00013	-0.00013	-0.00013
84	12831	12831	12831	9769	9769
85	1229	325	187	434	613
86	668.19	145.38	176.82	123.78	260.44
87	0	0	0	0	0
88	0.5	0.5	0.5	0.5	0.5
89	0.16	0	0	0	0
90	0	0	0	0	0
91	0	0	0	0	0
92	0	0	0	0	0
93	0.06	0.06	0.06	0.06	0.06
94	0	0	0	0	0
95	0.76	0.80	0.76	1.87	0.00
96	0	0	0	0	0
97	0.6471	0.5611	1.1427	0.4993	#N/A
98	0	0	0	0	0
99	0.3533	0.318	0.624	0.8416	#N/A
100	0.3104	0.2802	0.548	0.5648	#N/A
101	0.1476	0.1331	0.2606	0.2794	#N/A
102					
103					
104					
106					
106					

USF200010523

	A	B	C	D	E	F	G	H	I	J
107	Number of Personnel to be Added to Fort Huachuca Staff	0		Allocated to Base:		0				
108	Year in Which Above Personnel Will be Added to Fort Staff	0	date							
109	Average Number of Additional Family Members Arriving with New Staff	0		Allocated to City:		0				
110	Fraction of New Personnel and Families Who Will Live Off-Base	0								
111	Estimated Consumption Per Person in Rural Non-Service Areas	0.17	af/person							
112	Estimated Household Size in Rural Non-Service Areas	2.5	persons							
113										
114	VII. AGRICULTURAL CONSUMPTION									
115	Effective Irrigated Acreage, Sierra Vista Sub-basin	2597.7	acres							
116	Effective Irrigated Acreage, Benson Sub-basin	5782.6	acres							
117	Surface Diversion Right, St. David Irrigation District	#N/A	acre-feet							
118	Average Actual Surface Diversions, St. David Irrigation District	4426.6	acre-feet							
119	Surface Diversion Right, Pomerene Water Users Association	#N/A	acre-feet							
120	Average Actual Surface Diversions, Pomerene Water Users Association	1563.5	acre-feet							
121	1990 Average Overall Irrigation Efficiency, Sierra Vista Sub-basin	0.65								
122	1990 Average Overall Irrigation Efficiency, Benson Sub-basin	0.6								
123	1990 Weighted Average Crop Consumptive Use Requirement, Sierra Vista Sub-basin	3.37	a.f./acre							
124	1990 Weighted Average Crop Consumptive Use Requirement, Benson Sub-basin	3.56	a.f./acre							
125	Weighted Average Effective Precipitation for Irrigation, Sierra Vista Sub-basin	0.78	a.f./acre							
126	Weighted Average Effective Precipitation for Irrigation, Benson Sub-basin	0.78	a.f./acre							
127	Long-Term Per-Acre Change in Irrigated Acreage, Sierra Vista Sub-basin	0								
128	Long-Term Per-Acre Change in Irrigated Acreage, Benson Sub-basin	0								
129	Required Irrigation Efficiency, Sierra Vista Sub-basin	0								
130	Required Irrigation Efficiency, Benson Sub-Basin	0								
131	Target Weighted Average Crop Irrigation Requirement, Sierra Vista Sub-basin	0	a.f./acre							
132	Target Weighted Average Crop Irrigation Requirement, Benson Sub-basin	0	a.f./acre							
133	Per-Acre Irrigation Demand Equation Coefficient, Sierra Vista Sub-basin	4.68								
134	Per-Acre Irrigation Demand Equation Coefficient, Benson Sub-basin	5.61								
135	Price Elasticity of Irrigation Demand, Sierra Vista Sub-basin	-0.3644								
136	Price Elasticity of Irrigation Demand, Benson Sub-basin	-0.5624								
137	Imposed Irrigation Well Pumping Tax, $ Per Acre-Foot	0	$/acre-ft							
138										
139	VIII. RIPARIAN HABITAT AND MANAGEMENT STATUS									
140	Area of Riparian Vegetation in 1990, Sierra Vista Sub-basin	5894	acres							
141	Area of Riparian Vegetation in 1990, Benson Sub-basin	6045	acres							
142	1990 Salvagable Riparian Acreage, Sierra Vista Sub-basin	760	acres							
143	1990 Salvagable Riparian Acreage, Benson Vista Sub-basin	924	acres							
144	Composite Consumptive Use Coefficient, Riparian Vegetation, Sierra Vista Sub-basin	2.88	a.f./acre							
145	Composite Consumptive Use Coefficient, Riparian Vegetation, Benson Sub-basin	3.28	a.f./acre							
146	Riparian Corridor Width Equation, First Coefficient	0.018144								
147	Riparian Corridor Width Equation, Second Coefficient	0.932133								
148	SPRNCA Withdrawals from Floodplain Aquifer, Sierra Vista Sub-basin	0	acre-feet							
149	SPRNCA Withdrawals from Regional Aquifer, Sierra Vista Sub-basin	0	acre-feet							
150	SPRNCA Withdrawals from Floodplain Aquifer, Benson Sub-basin	0	acre-feet							
151	SPRNCA Withdrawals from Regional Aquifer, Benson Sub-basin	0	acre-feet							
152										
153										
154	IX. INDUSTRIAL CONSUMPTION									
155	1989 Mining Withdrawals from Regional Aquifer, Sierra Vista Sub-basin	2	acre-feet							
156	1989 Other Industrial Use of Regional Aquifer, Sierra Vista Sub-basin	204.7	acre-feet							
157	Fraction of Mining Usage Recharged to Regional Aquifer, Sierra Vista Sub-basin	0								
158	Fraction of Other Industrial Usage Recharged to Regional Aquifer, Sierra Vista Sub-b.	0.2								
159	1989 Mining Withdrawals from Regional Aquifer, Benson Sub-basin	0	acre-feet							

USF200010524

	A	B	C	D	E	F	G	H	I	J
160	1989 Other Industrial Use of Regional Aquifer, Benson Sub-basin	542	acre-feet							
161	Fraction of Mining Usage Recharged to Regional Aquifer, Benson Sub-basin	0								
162	Fraction of Other Industrial Usage Recharged to Regional Aquifer, Benson Sub-basin	0.3								
163	Projected Annual Rate of Growth of Mining Consumption	0								
164	Projected Annual Rate of Growth of Other Industrial Consumption	0								
165										
166	X. RESERVOIRS AND STOCKPONDS									
167	1990 Area of Runoff-Supplied Impoundments in Sierra Vista Sub-basin	611.2	acres							
168	1990 Area of Runoff-Supplied Impoundments in Benson Sub-basin	341	acres							
169	1990 Area of Ground Water-Supplied Impoundments in Sierra Vista Sub-basin	25.9	acres							
170	1990 Area of Ground Water-Supplied Impoundments in Benson Sub-basin	108.8	acres							
171	Water Retention Rate for Runoff-Supplied Impoundments	0.6								
172	Water Retention Rate for Ground Water-Supplied Impoundments	0.66								
173										
174	XI. OPTIONS									
175	Include Riparian Salvage Acres in Total Initial Riparian Acreage?	0	yes = 1, no = 0							
176	Model System Without Human Depletions?	0	yes = 1, no = 0							
177	Impose Domestic Conservation? (Choose Option 0, 1, 2, or 3)	0	0 = no; 1 = Percent reduction; 2 = Appliance effects; 3 = GPCD limits							
178	Include Fort Huachuca in Conservation Efforts?	0	yes = 1, no = 0							
179	Impose Target Crop Irrigation Requirements?	0	yes = 1, no = 0							
180	Impose Target Irrigation Efficiencies?	0	yes = 1, no = 0							
181	Impose Pumping Tax on Irrigation Use of Ground Water?	0	yes = 1, no = 0							

USF200010525

Appendix C
Projection Equations of the Model, Columns C-O
With Columns A and B Provided for Identifications

USF200010527

	A	B
200	TWENTY-YEAR PROJECTION OF WATER BALANCE AND SOCIOECONOMIC CONDITIONS	
201	Year	
202	Season	
203	I. SOCIOECONOMIC CONDITIONS	
204	Population of City of Sierra Vista	N.people
205	Population of Sierra Vista-Southeast Suburban Area	N.people
206	Population of Fort Huachuca	N.people
207	Population of Huachuca City	N.people
208	Population of City of Tombstone	N.people
209	Population of City of Bisbee	N.people
210	Population of Town of Naco	N.people
211	Population of Water Service Areas of Rural Sierra Vista Sub-basin	N.people
212	Population of Non-Service Areas of Rural Sierra Vista Sub-basin	N.people
213	Population of City of Benson	N.people
214	Population of Town of St. David	N.people
215	Population of Town of Pomerene	N.people
216	Population of Water Service Areas of Rural Benson Sub-basin	N.people
217	Population of Non-Water Service Areas of Rural Benson Sub-basin	N.people
218	Median Household Income, City of Sierra Vista	dollars
219	Median Household Income, Sierra Vista-Southeast Suburban Area	dollars
220	Median Household Income, Fort Huachuca	dollars
221	Median Household Income, Huachuca City	dollars
222	Median Household Income, City of Tombstone	dollars
223	Median Household Income, City of Bisbee	dollars
224	Median Household Income, Town of Naco	dollars
225	Median Household Income, Rural Water Service Areas, Sierra Vista Sub-basin	dollars
226	Median Household Income, Rural Non-Service Areas, Sierra Vista Sub-basin	dollars
227	Median Household Income, City of Benson	dollars
228	Median Household Income, Town of St. David	dollars
229	Median Household Income, Town of Pomerene	dollars
230	Median Household Income, Rural Water Service Areas, Benson Sub-basin	dollars
231	Median Household Income, Rural Non-Service Areas, Benson Sub-basin	dollars
232	Household Consumer Surplus Loss, City of Sierra Vista	dollars
233	Household Consumer Surplus Loss, Sierra Vista-Southeast Suburban Area	dollars
234	Household Consumer Surplus Loss, Huachuca City	dollars
235	Household Consumer Surplus Loss, City of Tombstone	dollars
236	Household Consumer Surplus Loss, City of Bisbee	dollars
237	Household Consumer Surplus Loss, Town of Naco	dollars
238	Household Consumer Surplus Loss, Rural Water Service Areas, Sierra Vista Sub-basin	dollars
239	Household Consumer Surplus Loss, City of Benson	dollars
240	Household Consumer Surplus Loss, Town of St. David	dollars
241	Household Consumer Surplus Loss, Town of Pomerene	dollars
242	Household Consumer Surplus Loss, Rural Water Service Areas, Benson Sub-basin	dollars
243	Fraction of Households with Low-Flow Plumbing, City of Sierra Vista	fraction
244	Fraction of Households with Low-Flow Plumbing, Sierra Vista-SE Suburban Area	fraction
245	Fraction of Households with Low-Flow Plumbing, Fort Huachuca	fraction
246	Fraction of Households with Low-Flow Plumbing, Huachuca City	fraction
247	Fraction of Households with Low-Flow Plumbing, City of Tombstone	fraction
248	Fraction of Households with Low-Flow Plumbing, City of Bisbee	fraction
249	Fraction of Households with Low-Flow Plumbing, Town of Naco	fraction
250	Fraction of Households with Low-Flow Plumbing, Rural Sierra Vista Sub-basin	fraction
251	Fraction of Households with Low-Flow Plumbing, City of Benson	fraction
252	Fraction of Households with Low-Flow Plumbing, Town of St. David	fraction
253	Fraction of Households with Low-Flow Plumbing, Town of Pomerene	fraction
254	Fraction of Households with Low-Flow Plumbing, Rural Benson Sub-basin	fraction
255		
256	II. GROSS HYDROLOGICAL AND ECOLOGICAL STATUS INDICATORS	
257	Storage in Floodplain Aquifer, Sierra Vista Sub-basin	acre-feet
258	Storage in Regional Aquifer, Sierra Vista Sub-basin	acre-feet
259	Storage in Floodplain Aquifer, Benson Sub-basin	acre-feet
260	Storage in Regional Aquifer, Benson Sub-basin	acre-feet
261	Potential Area of Riparian Vegetation in Sierra Vista Sub-basin	acres
262	Potential Area of Riparian Vegetation in Benson Sub-basin	acres
263	Average River Stage in Sierra Vista Sub-basin	feet
264	Average River Stage in Benson Sub-basin	feet
265	Average River-Aquifer Head Difference, Sierra Vista Sub-basin	feet
266	Average River-Aquifer Head Difference, Benson Sub-basin	feet
267	Period-End Elev. of Floodplain Water Table Above Riverbed, Sierra Vista Sub-basin	feet
268	Period-End Elev. of Reg. Aq. Water Table Boundary Above Riverbed, Sierra Vista Sub-basin	feet
269	Period-End Elev. of Floodplain Water Table Above Riverbed, Benson Sub-basin	feet
270	Period-End Elev. of Reg. Aq. Water Table Boundary Above Riverbed, Benson Sub-basin	feet
271		
272	III. INFLOWS TO SIERRA VISTA SUB-BASIN	
273	Natural Inputs to Surface Waters in Sierra Vista Sub-basin	acre-feet
274	Natural Inputs to Floodplain Aquifer in Sierra Vista Sub-basin	acre-feet
275	Natural Inputs to Regional Aquifer in Sierra Vista Sub-basin	acre-feet
276	Imported Water Stored in Floodplain Aquifer in Sierra Vista Sub-basin	acre-feet

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277	Imported Water Stored in Regional Aquifer in Sierra Vista Sub-basin	acre-feet
278		
279	IV. SIERRA VISTA SUB-BASIN LOSSES TO STORAGE	
280	City of Sierra Vista Use of Regional Aquifer	acre-feet
281	Sierra Vista-Southeast Suburban Area Use of Regional Aquifer	acre-feet
282	Fort Huachuca Use of Regional Aquifer	acre-feet
283	Huachuca City Use of Regional Aquifer	acre-feet
284	City of Tombstone Use of Regional Aquifer	acre-feet
285	City of Bisbee Use of Regional Aquifer	acre-feet
286	Town of Naco Use of Regional Aquifer	acre-feet
287	Rural Sierra Vista Sub-basin Water-Service Areas, Use of Regional Aquifer	acre-feet
288	Rural Sierra Vista Sub-basin Non-Service Areas, Use of Regional Aquifer	acre-feet
289	Irrigation Use of Groundwater in Sierra Vista Sub-basin	acre-feet
290	Mining Industrial Use of Regional Aquifer in Sierra Vista Sub-basin	acre-feet
291	Other Industrial Use of Regional Aquifer in Sierra Vista Sub-basin	acre-feet
292	Evaporation from Runoff-Supplied Stockponds & Reservoirs, Sierra Vista Sub-basin	acre-feet
293	Evaporation from GW-Supplied Stockponds & Reservoirs, Sierra Vista Sub	acre-feet
294	Phreatophyte Consumption from Floodplain Aquifer in Sierra Vista Sub-basin	acre-feet
295	Channel Evaporation from Riverbed in Sierra Vista Sub-basin	acre-feet
296	RNCA Withdrawals from Floodplain Aquifer in Sierra Vista Sub-basin	acre-feet
297	RNCA Withdrawals from Regional Aquifer in Sierra Vista Sub-basin	acre-feet
298	Export from Floodplain Aquifer in Sierra Vista Sub-basin	acre-feet
299	Export from Regional Aquifer in Sierra Vista Sub-basin	acre-feet
300	Floodplain Aquifer Underflow to Benson Sub-basin	acre-feet
301	Regional Aquifer Underflow to Benson Sub-basin	acre-feet
302	Potential Discharge from Floodplain Aquifer to River in Sierra Vista Sub-basin	acre-feet
303	Available Discharge from Floodplain Aquifer to River in Sierra Vista Sub-basin	acre-feet
304	River Discharge Volume from Sierra Vista Sub-basin	acre-feet
305		
306	V. SIERRA VISTA SUB-BASIN RECHARGE AND RETURNS TO STORAGE	
307	Recharge from Regional to Floodplain Aquifer in Sierra Vista Sub-basin	acre-feet
308	Recharge to Regional Aquifer from City of Sierra Vista	acre-feet
309	Recharge to Regional Aquifer from Sierra Vista Southeast Suburbs	acre-feet
310	Recharge to Regional Aquifer from Fort Huachuca	acre-feet
311	Recharge to Regional Aquifer from Huachuca City	acre-feet
312	Recharge to Regional Aquifer from City of Tombstone	acre-feet
313	Recharge to Regional Aquifer from City of Bisbee	acre-feet
314	Recharge to Regional Aquifer from Town of Naco	acre-feet
315	Recharge to Regional Aquifer from Rural Water-Service Areas	acre-feet
316	Recharge to Regional Aquifer from Rural Non-Service Areas	acre-feet
317	Irrigation Return to Floodplain Aquifer in Sierra Vista Sub-basin	acre-feet
318	Mining Industrial Return to Regional Aquifer in Sierra Vista Sub-basin	acre-feet
319	Other Industrial Return to Regional Aquifer in Sierra Vista Sub-basin	acre-feet
320	SPRNCA Diversion of Groundwater into River in Sierra Vista Sub-basin	acre-feet
321	Recharge to Floodplain Aq. from On-River Impoundment in Sub-basin	acre-feet
322		
323	VI. INFLOWS TO BENSON SUB-BASIN	
324	Natural Inputs to Surface Waters in Benson Sub-basin	acre-feet
325	Natural Inputs to Floodplain Aquifer in Benson Sub-basin	acre-feet
326	Natural Inputs to Regional Aquifer in Benson Sub-basin	acre-feet
327	Imported Water Stored in Floodplain Aquifer in Benson Sub-basin	acre-feet
328	Imported Water Stored in Regional Aquifer in Benson Sub-basin	acre-feet
329		
330	VII. BENSON SUB-BASIN LOSSES TO STORAGE	
331	City of Benson Use of Regional Aquifer	acre-feet
332	Town of St. David Use of Regional Aquifer	acre-feet
333	Town of Pomerene Use of Regional Aquifer	acre-feet
334	Rural Benson Sub-basin Water-Service Areas, Use of Regional Aquifer	acre-feet
335	Rural Benson Sub-basin Non-Service Areas, Use of Regional Aquifer	acre-feet
336	St. David Irrigation District Diversions of Surface Water	acre-feet
337	Pomerene Water Users Association Diversions of Surface Water	acre-feet
338	Total Irrigation Use of Groundwater in Benson Sub-basin	acre-feet
339	Mining Industrial Use of Regional Aquifer in Benson Sub-basin	acre-feet
340	Other Industrial Use of Regional Aquifer in Benson Sub-basin	acre-feet
341	Evap. from Runoff-Supplied Stockponds & Reservoirs, Benson Sub-basin	acre-feet
342	Evaporation from GW-Supplied Stockponds & Reservoirs, Benson Sub	acre-feet
343	Phreatophyte Consumption from Floodplain Aquifer in Benson Sub-basin	acre-feet
344	Channel Evaporation from Riverbed in Benson Sub-basin	acre-feet
345	SPRNCA Withdrawals from Floodplain Aquifer in Benson Sub-basin	acre-feet
346	SPRNCA Withdrawals from Regional Aquifer in Benson Sub-basin	acre-feet
347	Export from Floodplain Aquifer in Benson Sub-basin	acre-feet
348	Export from Regional Aquifer in Benson Sub-basin	acre-feet
349	Floodplain Aquifer Underflow to Lower San Pedro Basin	acre-feet
350	Regional Aquifer Underflow to Lower San Pedro Basin	acre-feet
351	Potential Discharge from Floodplain Aquifer to River in Benson Sub-basin	acre-feet
352	Available Discharge from Floodplain Aquifer to River in Benson Sub-basin	acre-feet
353	River Discharge Volume from Benson Sub-basin	acre-feet

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354		
355	VIII. BENSON SUB-BASIN RECHARGE AND RETURNS TO STORAGE	
356	Recharge from Regional to Floodplain Aquifer in Benson Sub-basin	acre-feet
357	Recharge to Regional Aquifer from City of Benson	acre-feet
358	Recharge to Regional Aquifer from St. David	acre-feet
359	Recharge to Regional Aquifer from Town of Pomerene	acre-feet
360	Recharge to Regional Aquifer from Rural Water-Service Areas	acre-feet
361	Recharge to Regional Aquifer from Rural Non-Service Areas	acre-feet
362	Irrigation Return to Floodplain Aquifer in Benson Sub-basin	acre-feet
363	Mining Industrial Return to Regional Aquifer in Benson Sub-basin	acre-feet
364	Other Industrial Return to Regional Aquifer in Benson Sub-basin	acre-feet
365	SPRNCA Diversion of Groundwater into River in Benson Sub-basin	acre-feet
366		
367	IX. ANNUAL HYDROLOGICAL CHANGES	
368	Annual Change in Floodplain Aquifer Storage in Sierra Vista Sub-basin	acre-feet
369	Annual Change in Regional Aquifer Storage in Sierra Vista Sub-basin	acre-feet
370	Annual Change in Floodplain Aquifer Storage in Benson Sub-basin	acre-feet
371	Annual Change in Regional Aquifer Storage in Benson Sub-basin	acre-feet
372	Annual Change in Floodplain Aquifer Depth to Water Table in Sierra Vista Sub-basin	feet
373	Annual Change in Regional Aquifer Depth to Water Table in Sierra Vista Sub-basin	feet
374	Annual Change in Floodplain Aquifer Depth to Water Table in Benson Sub-basin	feet
375	Annual Change in Regional Aquifer Depth to Water Table in Benson Sub-basin	feet
376	Annual Change in Discharge of River from Sierra Vista Sub-basin	acre-feet
377	Annual Change in Discharge of River from Benson Sub-basin	acre-feet
378	Annual Change in Potential Area of Riparian Vegetation in Sierra Vista Sub-basin	acres
379	Annual Change in Potential Area of Riparian Vegetation in Benson Sub-basin	acres
380	Accumulation of Change in Boundary Elevation of Reg. Aq. Water Table, S.V. Sub-basin	feet
381	Accumulation of Change in Boundary Elevation of Reg. Aq. Water Table, S.V. Sub-basin	feet
382		
383	X. NET SOCIOECONOMIC CHANGES	
384	Total Population in Upper San Pedro River Basin (excluding Babbee)	N.people
385	Total Irrigated Acreage in Sierra Vista Sub-basin	acres
386	Total Irrigated Acreage in Benson Sub-basin	acres

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	C
200	
201	1989
202	end-of-year
203	-------
204	=IF($B$175=1,0,+B82)
205	=IF($B$175=1,0,+C82)
206	=IF($B$175=1,0,+D82)
207	=IF($B$175=1,0,+E82)
208	=IF($B$175=1,0,+F82)
209	=IF($B$175=1,0,+G82)
210	=IF($B$175=1,0,+H82)
211	=IF($B$175=1,0,+I82)
212	=IF($B$175=1,0,+J82)
213	=IF($B$175=1,0,+K82)
214	=IF($B$175=1,0,+L82)
215	=IF($B$175=1,0,+M82)
216	=IF($B$175=1,0,+N82)
217	=IF($B$175=1,0,+O82)
218	=IF(B176=1,0,+B84)
219	=IF(B176=1,0,+C84)
220	=IF(B176=1,0,NA())
221	=IF(B176=1,0,+E84)
222	=IF(B176=1,0,+F84)
223	=IF(B176=1,0,+G84)
224	=IF(B176=1,0,+H84)
225	=IF(B176=1,0,+I84)
226	=IF(B176=1,0,+J84)
227	=IF(B176=1,0,+K84)
228	=IF(B176=1,0,+L84)
229	=IF(B176=1,0,+M84)
230	=IF(B176=1,0,+N84)
231	=IF(B176=1,0,+O84)
232	
233	
234	
235	
236	
237	
238	
239	
240	
241	
242	
243	=IF($B$175=1,0,+B92)
244	=IF($B$175=1,0,+C92)
245	=IF($B$175=1,0,+D92)
246	=IF($B$175=1,0,+E92)
247	=IF($B$175=1,0,+F92)
248	=IF($B$175=1,0,+G92)
249	=IF($B$175=1,0,+H92)
250	=IF($B$175=1,0,((I92*I82)+(J92*J82))/(I92+J82))
251	=IF($B$175=1,0,+K92)
252	=IF($B$175=1,0,L92)
253	=IF($B$175=1,0,M92)
254	=IF($B$175=1,0,((N92*N82)+(O92*O82))/(N82+O82))
255	
256	-------
257	=$B$34
258	=$B$27
259	=$C$34
260	=$C$27
261	=IF($B$174=0,+$B$140+C378,+$B$140+$B$142+C378)
262	=IF($B$174=0,+$B$141+C379,+$B$141+$B$143+C379)
263	=$B$45*((($B$65+C304)/2)^$B$44
264	=IF(C304+C363<0,0.000000000000001,$C$45*(0.5*(C304+C363))^$C$44)
265	=IF(C263>0,IF(IF($B$176=1,B39,B40))+$B$43>0,C263-(IF($B$176=1,B39,B40))),C263+$B$43),IF(IF($B$176=1,B39,B40))>0,0-(IF($B$176=1,B39,B40))),0))
266	=IF(C264>0,IF(IF($B$176=1,C39,C40))+$C$43>0,C264-IF($B$176=1,C39,C40),C264+$C$43),IF(IF($B$176=1,C39,C40)>0,0-IF($B$176=1,C39,C40),0))
267	=IF(B176=1,B39,B40)
268	=IF(B176=1,B29,B30)
269	=IF(B176=1,C39,C40)
270	=IF(B176=1,C29,C30)
271	
272	-------
273	=$B$5+($B$20*($B$12^$B$21)*($B$13^$B$22))
274	=B66
275	=IF($B$176=1,$B$67+$B$28,$B$67+($B$28*(1+$B$68)))
276	=$B$58

USF200010532

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277	= $B$69
278	
279	-------
280	= IF($B$175 = 1,0, + $B$72 + (0.00306888 * $B$85 * ($B$84^$B$106) * ((4 * $B$97 * ($B$96^$B$104)) + ((($B$86^$B$106) * ($B$98 + $B$99 + $B$100 + $B$101))))))
281	= IF($B$175 = 1,0,0.00306888 * $C$85 * ($C$84^$B$106) * (($4 * $C$97 * ($C$96^$B$104)) + ((($C$95^$B$106) * ($C$98 + $C$99 + $C$100 + $C$101))))
282	= IF($B$175 = 1,0, + $D$86)
283	= IF($B$175 = 1,0,0.00306888 * $E$85 * ($E$84^$B$106) * ((4 * $E$97 * ($E$95^$B$104)) + ((($E$95^$B$106) * ($E$98 + $E$99 + $E$100 + $E$101))))
284	= IF($B$175 = 1,0,0.00306888 * $F$85 * ($F$84^$B$106) * ((4 * $F$97 * ($F$95^$B$104)) + ((($F$95^$B$106) * ($F$98 + $F$99 + $F$100 + $F$101))))
285	= IF($B$175 = 1,0,0.00306888 * $G$85 * ($G$84^$B$106) * ((4 * $G$97 * ($G$95^$B$104)) + ((($G$95^$B$106) * ($G$98 + $G$99 + $G$100 + $G$101))))
286	= IF($B$175 = 1,0,0.00306888 * $H$85 * ($H$84^$B$106) * ((4 * $H$97 * ($H$95^$B$104)) + ((($H$95^$B$106) * ($H$98 + $H$99 + $H$100 + $H$101))))
287	= IF($B$175 = 1,0,0.00306888 * $I$85 * ($I$84^$B$106) * ((4 * $I$97 * ($I$95^$B$104)) + ((($I$95^$B$106) * ($I$98 + $I$99 + $I$100 + $I$101))))
288	= IF($B$175 = 1,0, + $J$92 * ($B$111)
289	= C305 * (B123-B126)/B121
290	= IF($B$175 = 1,0, + $B$64)
291	= IF($B$175 = 1,0, + $B$56)
292	= IF($B$175 = 1,0, + $B$66 * $B$70 * ($B$1-$B$14))
293	= IF($B$175 = 1,0, + $B$68 * $B$71 * ($B$1-$B$14))
294	= C261 * ($B$144-$D$15)
295	= ($B$47 * ($B$48-$B$15)) + ((C304^$B$49) * $B$50 * $B$42 * ($B$61-$B$14)/43560)
296	= IF($B$175 = 1,0, + $B$148)
297	= IF($B$175 = 1,0, + $B$149)
298	= IF($B$175 = 1,0, + $B$60)
299	= IF($B$175 = 1,0, + $B$61)
300	= $B$32
301	= $B$26
302	= NA()
303	= C302
304	= $B$38
305	
306	-------
307	= C276-C301
308	0
309	0
310	0
311	0
312	0
313	0
314	0
315	= (C287 * $I$89 * (1-$I$89) * $I$90)
316	= (C288 * $J$89 * (1-$J$89) * $J$90)
317	= (1-IF($B$179 = 1,$B$129,$B$121)) * C289
318	= (C290 * $B$156)
319	= (C291 * $B$157)
320	= C296 + C297
321	0
322	
323	-------
324	= C304 + (C$20 * (C$12^C$21) * (C$13^C$22))
325	= C300
326	= IF($B$175 = 1,C301 + $C$26, + C301 + ($C$26 * (1 + $B$69)))
327	= $B$62
328	= $B$63
329	
330	-------
331	= IF($B$175 = 1,0,0.00306888 * $K$85 * ($K$84^$B$106) * ((4 * $K$97 * ($K$95^$B$104)) + ((($K$95^$B$106) * ($K$98 + $K$99 + $K$100 + $K$101))))
332	= IF($B$175 = 1,0,0.00306888 * $L$85 * ($L$84^$B$106) * ((4 * $L$97 * ($L$95^$B$104)) + ((($L$95^$B$106) * ($L$98 + $L$99 + $L$100 + $L$101))))
333	= IF($B$175 = 1,0,0.00306888 * $M$85 * ($M$84^$B$106) * ((4 * $M$97 * ($M$95^$B$104)) + ((($M$95^$B$106) * ($M$98 + $M$99 + $M$100 + $M$101))))
334	= IF($B$175 = 1,0,0.00306888 * $N$85 * ($N$84^$B$106) * ((4 * $N$97 * ($N$95^$B$104)) + ((($N$95^$B$106) * ($N$98 + $N$99 + $N$100 + $N$101))))
335	= IF($B$175 = 1,0, + $O$85 * ($B$111 * $B$112)
336	= IF($B$175 = 1,0,MIN($B$116 * ($B$124-$B$126)/$B$122,$B$119))
337	= IF($B$175 = 1,0,MIN($B$116 * ($B$124-$B$126)/$B$122-C336,$B$120))
338	= $B$116 * ($B$124-$B$126)/$B$122)-C336-C337
339	= IF($B$175 = 1,0, + $B$58)
340	= IF($B$175 = 1,0, + $B$59)
341	= IF($B$175 = 1,0, + $B$67 * $B$70 * (C51-C14))
342	= IF($B$175 = 1,0, + $B$69 * $B$71 * (C51-C14))
343	= $C$262 * ($B$146-$C$15)
344	= IF(C363 < = 0,($C$47 * ($C$48-$C$15)),($C$47 * ($C$48-$C$15)) + ((C363^$C$49) * $C$50 * $C$42 * ($C$61-$C$14)/43560))
345	= IF($B$175 = 1,0, + $B$60)
346	= IF($B$175 = 1,0, + $B$61)
347	= IF($B$175 = 1,0, + $B$4)
348	= IF($B$175 = 1,0, + $B$6)
349	= C32
350	= C26
351	= NA()
352	= NA()
353	= $C$38

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364	
365	--------
366	=C326-C360
367	0
368	=(C332*$L$688*(1-$L$689)*$L$690)
369	=(C333*$M$688*(1-$M$689)*$M$690)
370	=(C334*$N$688*(1-$N$689)*$N$690)
371	=(C335*$O$688*(1-$O$689)*$O$690)
372	=(1-IF($B$179=1,$B$130,$B$122))*(C336+C337+C338)
373	=C339*$B$160
374	=C340*$B$161
375	=C345+C346
376	
377	--------
378	=C257-$B$34
379	=C258-$B$27
380	=C259-$C$34
381	=C260-$C$27
382	=C368/($B$31*$B$33)
383	=C369/($B$24*$B$26)
384	=C370/($C$31*$C$33)
385	=C371/($C$24*$C$26)
386	0
387	0
388	0
389	0
390	0
391	0
392	
393	--------
394	=SUM(C204:C217)-C208
395	=MAX(0,IF($B$175=1,0,(1+$B$127)*$I$15-IF($B$174=1,$B$142,0)-IF(C378<=0,0,C378)))
396	=MAX(0,IF($B$175=1,0,(1+$B$128)*$I$16-IF($B$174=1,$B$143,0)-IF(C379<=0,0,C379)))

USF20001053 4

	E
200	
201	=C201+1
202	
203	------
204	
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207	
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255	
256	------
257	=MAX(C257*0.95,MIN(C257*1.05,C257+E274+E276+E307+E317+E321-E289-E294-E296-E298-E300-E303))
258	=C258+E275+E277+SUM(E308:E316)+E318+E319-SUM(E280:E288)-E290-E291-E293-E297-E299-E301-E307
259	=MAX(C259*0.95,MIN(C259*1.05,C259+E325+E327-E338-E343-E345-E347-E348+E358-E362+E362))
260	=C260+E325+E328-SUM(E331:E336)-E339-E340-E342-E346-E348-E350-E358+SUM(E367:E361)+E363+E364
261	
262	
263	=IF((4B45*4B416)+E304<0,0.000000000000001,4B446*(2^(4B45*4B416+E304))^4B444)
264	=IF(E304+E363<0,0.000000000000001,4C446*(2^(E304+E363)))^4C444
265	=IF(E263>0,IF(C267+4B443+E372>0,E263-C267-E372,E263+4B443),IF(C267+E372>0,0-C267-E372,0))
266	=IF(E264>0,IF(C269+4C443+E374>0,E264-C269-E374,E264+4C443),IF(C269+E374>0,0-C269-E374,0))
267	=C267+E372
268	
269	=C269+E374
270	
271	
272	------
273	=4B416*(4B45+(4B420*(4B412^4B421)*(4B413^4B422)))
274	=4B46/4
275	=IF(4B4175=1,4B47/4+(4B428/4),4B47/4+((4B429/4)*(1+4B468)))
276	=4B458/4

USF200010535

	E
277	=$B$59/4
278	
279	-------
280	=IF($B$175=1,0,IF($B$176=3,C204*$B$67*0.00112*0.18+$B$72/4,$B$72/4+IF($B$176=2,1-0.125*C243,IF($B$176=1,1-$B$94,1))*0.00306888*(C204/$B$82)*$B$95*(C218^$B$106)*((($B$97*((($B$95+$B$96)^$B$104))+(((($B$95+$B$96)^$B$106)*($B$98))))))
281	=IF($B$176=1,0,IF($B$176=3,C205*$C$67*0.00112*0.18,IF($B$176=2,1-0.125*C244,IF($B$176=1,1-$C$94,1))*0.00306888*(C205/$C$82)*$C$95*(C219^$B$106)*((($C$97*((($C$95+$C$96)^$B$104))+(((($C$95+$C$96)^$B$106)*($C$98))))))
282	=IF($B$176=1,0,IF($B$177=1,IF($B$176=3,C206*$D$67*0.00112*0.18,IF($B$176=2,1-0.125*C245,IF($B$176=1,1-$D$94,1))*0.18*($D$96/$D$82)*C206),0.18*($D$96/$D$82)*C206))
283	=IF($B$175=1,0,IF($B$176=3,C207*$E$67*0.00112*0.18,IF($B$176=2,1-0.125*C246,IF($B$176=1,1-$E$94,1))*0.00306888*(C207/$E$82)*$E$95*(C221^$B$106)*((($E$97*((($E$95+$E$96)^$B$104))+(((($E$95+$E$96)^$B$106)*($E$98))))))
284	=IF($B$175=1,0,IF($B$176=3,C208*$F$67*0.00112*0.18,IF($B$176=2,1-0.125*C247,IF($B$176=1,1-$F$94,1))*0.00306888*(C208/$F$82)*$F$95*(C222^$B$106)*((($F$97*((($F$95+$F$96)^$B$104))+(((($F$95+$F$96)^$B$106)*($F$98))))))
285	=IF($B$175=1,0,IF($B$176=3,C209*$G$67*0.00112*0.18,IF($B$176=2,1-0.125*C248,IF($B$176=1,1-$G$94,1))*0.00306888*(C209/$G$82)*$G$95*(C223^$B$106)*((($G$97*((($G$95+$G$96)^$B$104))+(((($G$95+$G$96)^$B$106)*($G$98))))))
286	=IF($B$175=1,0,IF($B$176=3,C210*$H$67*0.00112*0.18,IF($B$176=2,1-0.125*C249,IF($B$176=1,1-$H$94,1))*0.00306888*(C210/$H$82)*$H$95*(C224^$B$106)*((($H$97*((($H$95+$H$96)^$B$104))+(((($H$95+$H$96)^$B$106)*($H$98))))))
287	=IF($B$175=1,0,IF($B$176=3,C211*$I$67*0.00112*0.18,IF($B$176=2,1-0.125*C250,IF($B$176=1,1-$I$94,1))*0.00306888*(C211/$I$82)*$I$95*(C225^$B$106)*((($I$97*((($I$95+$I$96)^$B$104))+(((($I$95+$I$96)^$B$106)*($I$98))))))
288	=IF($B$175=1,0,IF($B$176=3,C212*$J$67*0.00112*0.18,IF($B$176=2,1-0.125*C250,IF($B$176=1,1-$J$94,1))*0.18*C212*$B$111)))
289	=C395*IF($B$180=1,0.1716*$B$133*(($B$137^$B$136),(IF($B$178=1,$B$131,$B$123)*$B$62)-($B$126*$B$16))/IF($B$179=1,$B$129,$B$121))
290	=(1+$B$162)*C290/4
291	=(1+$B$163)*C291/4
292	=C292*(($B$61*$B$62)-($B$14*$B$16))/($B$61-$B$14)
293	=C293*(($B$61*$B$62)-($B$14*$B$16))/($B$61-$B$14)
294	=C261*(($B$144*$B$62)-($B$15*$B$16))
295	=($B$47*(($B$48*$B$62)-($B$15*$B$16)))+(((4*E304)^$B$49)*$B$50*$B$42*(($B$61*$B$62)-($B$14*$B$16)))/43680)
296	0
297	0
298	=C298/2
299	=C299/2
300	=$B$32/4
301	=$B$26/4
302	=$B$41*-C265*IF(C263<0.035,275,764.806*C263+248.815)
303	=IF(AND(C265>0,E302<-(E273-E295-E292+E320)),-(E273-E295-E292+E320),E302)
304	=IF(E273+E303-E295-E292+E320<0,0,E273+E303-E295-E292+E320)
305	
306	-------
307	=MAX(0,+E275-E301-0.25*($I$274+$I$275+$I$276+$I$317+$I$321-$I$289-$I$294-$I$296-$I$298-$I$300-$I$301-$I$303))
308	=(E280*($B$68*(1-$B$69))*($B$75+$B$90))-($B$170*$B$76*(($B$61*$B$62)-($B$14*$B$16)))
309	=(E281*$C$68*(1-$C$69)*$C$90)
310	=(E282*$D$68*(1-$D$69)*$D$90)
311	=(E283*$E$68*(1-$E$69)*$E$90)
312	=(E284*$F$68*(1-$F$69)*$F$90)
313	=(E285*$G$68*(1-$G$69)*$G$90)
314	=(E286*$H$68*(1-$H$69)*$H$90)
315	=(E287*$I$68*(1-$I$69)*$I$90)
316	=(E288*$J$68*(1-$J$69)*$J$90)
317	=(1-IF($B$179=1,$B$129,$B$121))*E289
318	=(E290*$B$156)
319	=(E291*$B$157)
320	=E296+E297
321	0
322	
323	-------
324	=E304+($C$16*$C$20*($C$12^$C$21)*($C$13^$C$22))
325	=E300
326	=IF($B$175=1,E301+($C$29/4),+E301+(($C$29/4)*(1+$B$69)))
327	=$B$62/4
328	=$B$63/4
329	
330	-------
331	=IF($B$175=1,0,IF($B$176=3,C213*$K$67*0.00112*0.18,IF($B$176=2,1-0.125*C251,IF($B$176=1,1-$K$94,1))*0.00306888*(C213/$K$82)*$K$95*(C227^$B$106)*((($K$97*((($K$95+$K$96)^$B$104))+(((($K$95+$K$96)^$B$106)*($K$98))))))
332	=IF($B$175=1,0,IF($B$176=3,C214*$L$67*0.00112*0.18,IF($B$176=2,1-0.125*C252,IF($B$176=1,1-$L$94,1))*0.00306888*(C214/$L$82)*$L$95*(C228^$B$106)*((($L$97*((($L$95+$L$96)^$B$104))+(((($L$95+$L$96)^$B$106)*($L$98))))))
333	=IF($B$175=1,0,IF($B$176=3,C215*$M$67*0.00112*0.18,IF($B$176=2,1-0.125*C253,IF($B$176=1,1-$M$94,1))*0.00306888*(C215/$M$82)*$M$95*(C229^$B$106)*((($M$97*((($M$95+$M$96)^$B$104))+(((($M$95+$M$96)^$B$106)*($M$98))))))
334	=IF($B$175=1,0,IF($B$176=3,C216*$N$67*0.00112*0.18,IF($B$176=2,1-0.125*C254,IF($B$176=1,1-$N$94,1))*0.00306888*(C216/$N$82)*$N$95*(C230^$B$106)*((($N$97*((($N$95+$N$96)^$B$104))+(((($N$95+$N$96)^$B$106)*($N$98))))))
335	=IF($B$175=1,0,IF($B$176=3,C217*$O$67*0.00112*0.18,IF($B$176=2,1-0.125*C254,IF($B$176=1,1-$O$94,1))*0.18*C217*$B$111)))
336	=MINIC396*(IF($B$178=1,$B$132,$B$124)*$C$52)-($B$126*$C$16))/IF($B$179=1,$B$130,$B$122),IF(E304<(C336*0.5057),IF(E304<=0,0,E304),C336*0.5057))
337	=MINIC396*(IF($B$178=1,$B$132,$B$124)*$C$52)-($B$126*$C$16))/IF($B$179=1,$B$130,$B$122)-E336,IF(E304<(C336*0.5057+C337*0.6652),IF(E304<=C336*0.5057,0,E304-(C336*0.5057)),C337*0.6652))
338	=(C396*IF($B$180=1,0.17*$B$134*(($B$137^$B$136),(IF($B$178=1,$B$132,$B$124)*$C$52)-($B$126*$C$16))/IF($B$179=1,$B$130,$B$122)))-(E336+E337)
339	=(1+$B$162)*C339/4
340	=(1+$B$163)*C340/4
341	=C341*(($C$61*$C$62)-($C$14*$C$16))/($C$61-$C$14)
342	=C342*(($C$61*$C$62)-($C$14*$C$16))/($C$61-$C$14)
343	=C262*(($B$146*$C$62)-($C$15*$C$16))
344	=IF(E363<=0,($C$47*(($C$48*$C$62)-($C$15*$C$16))),($C$47*(($C$48*$C$52)-($C$15*$C$16)))+(((4*E363^$C$49)*$C$50*$C$42*(($C$61*$C$52)-($C$14*$C$18))/43680))
345	0
346	0
347	=C347/2
348	=C348/2
349	=C349/4
350	=C350/4
351	=4C441*-C266*IF(C264<0.0463,225,705.81*C264+193.03)
352	=IF(AND(C266>0,E361<-(E324-E344+E366-E336-E337-E341)),-(E324-E344+E366-E336-E337-E341),E361)
353	=IF(E324+E352-E344+E366-E336-E337-E341<0,0,E324+E352-E344+E366-E336-E337-E341)

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364	
365	--------
366	= MAX(0, + E326-E350-0.25*(¢I325 + ¢I326 + ¢I327 + ¢I362-¢I338-¢I343-¢I345-¢I347-¢I349-¢I350-¢I352))
367	= (E331*¢K¢88*(1-¢K¢89)*¢K¢90)
368	= (E332*¢L¢88*(1-¢L¢89)*¢L¢90)
369	= (E333*¢M¢88*(1-¢M¢89)*¢M¢90)
360	= (E334*¢N¢88*(1-¢N¢89)*¢N¢90)
361	= (E335*¢O¢88*(1-¢O¢89)*¢O¢90)
362	= (1-IF(¢B¢179 = 1,¢B¢130,¢B¢122))*(E336 + E337 + E338)
363	= E339*¢B¢160
364	= E340*¢B¢161
365	= E345 + E346
366	
367	--------
368	= E257-C257
369	= E258-C258
370	= E259-C259
371	= E260-C260
372	= E368/(¢B¢31*¢B¢33)
373	= E369/(¢B¢24*¢B¢26)
374	= E370/(¢C¢31*¢C¢33)
375	= E371/(¢C¢24*¢C¢26)
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USF200010537

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201	= E201
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256	-------
257	= MAX(C257*0.95,MIN(C257*1.05,E257 + F274 + F276 + F307 + F317 + F321-F289-F294-F296-F298-F300-F303))
258	= E258 + F275 + F277 + SUM(F308:F316) + F318 + F319-SUM(F280:F288)-F290-F291-F293-F297-F299-F301-F307
259	= MAX(C259*0.95,MIN(C259*1.05,E259 + F325 + F327-F338-F343-F345-F347-F349 + F356-F352 + F362))
260	= E260 + F326 + F328-SUM(F331:F335)-F339-F340-F342-F346-F348-F350-F356 + SUM(F357:F361) + F363 + F364
261	
262	
263	= IF((¢B¢5*¢B¢17) + F304 < 0,0.000000000000001,¢B¢45*(2*(¢B¢5*¢B¢17 + F304))^¢B¢44)
264	= IF(F304 + F353 < 0,1-E15,¢C¢45*(2*(F304 + F353))^¢C¢44)
265	= IF(F263 > 0,IF(E267 + ¢B¢43 + F372 > 0,F263-E267-F372,F263 + ¢B¢43),IF(E267 + F372 > 0,0-E267-F372,0))
266	= IF(F264 > 0,IF(E269 + ¢C¢43 + F374 > 0,F264-E269-F374,F264 + ¢C¢43),IF(E269 + F374 > 0,0-E269-F374,0))
267	= E267 + F372
268	
269	= E269 + F374
270	
271	
272	-------
273	= ¢B¢17*(¢B¢5 + (¢B¢20*(¢B¢12^¢B¢21)*(¢B¢13^¢B¢22)))
274	= ¢B¢6/4
275	= IF(¢B¢175 = 1,¢B¢7/4 + (¢B¢28/4),¢B¢7/4 + ((¢B¢28/4)*(1 + ¢B¢68)))
276	= ¢B¢58/4

USF200010538

	F
277	= $B659/4
278	
279	-------
280	=IF($B6175 = 1,0,IF($B6176 = 3,C204*$B687*0.00112*0.3 + $B672/4,$B672/4 + (IF($B6176 = 2,1-0.125*C243,IF($B6176 = 1,1-$B694,1))*0.00306888*(C204/$B682)*$B686*(C218^$B6105)*(($B697*(($B696 + $B696)^$B6104)) + (((($B696 + $B696)^$B6105)*($B699)))))
281	=IF($B6175 = 1,0,IF($B6176 = 3,C205*$C687*0.00112*0.3,IF($B6175 = 2,1-0.125*C244,IF($B6176 = 1,1-$C694,1))*0.00306888*(C205/$C682)*$C686*(C219^$B6105)*(($C697*(($C696 + $C696)^$B6104)) + (((($C696 + $C696)^$B6105)*($C699)))))
282	=IF($B6175 = 1,0,IF($B6177 = 1,IF($B6176 = 3,C206*$D687*0.00112*0.3,IF($B6176 = 2,1-0.125*C245,IF($B6176 = 1,1-$D694,1))*0.3*(($D686/$D682)*C206),0.3*(($D686/$D682)*C206)))
283	=IF($B6175 = 1,0,IF($B6176 = 3,C207*$E687*0.00112*0.3,IF($B6176 = 2,1-0.125*C246,IF($B6176 = 1,1-$E694,1))*0.00306888*(C207/$E682)*$E686*(C221^$B6105)*(($E697*(($E696 + $E696)^$B6104)) + (((($E696 + $E696)^$B6105)*($E699)))))
284	=IF($B6175 = 1,0,IF($B6176 = 3,C208*$F687*0.00112*0.3,IF($B6176 = 2,1-0.125*C247,IF($B6176 = 1,1-$F694,1))*0.00306888*(C208/$F682)*$F686*(C222^$B6105)*(($F697*(($F696 + $F696)^$B6104)) + (((($F696 + $F696)^$B6105)*($F699)))))
285	=IF($B6175 = 1,0,IF($B6176 = 3,C209*$G687*0.00112*0.3,IF($B6176 = 2,1-0.125*C248,IF($B6176 = 1,1-$G694,1))*0.00306888*(C209/$G682)*$G686*(C223^$B6105)*(($G697*(($G696 + $G696)^$B6104)) + (((($G696 + $G696)^$B6105)*($G699)))))
286	=IF($B6175 = 1,0,IF($B6176 = 3,C210*$H687*0.00112*0.3,IF($B6176 = 2,1-0.125*C249,IF($B6176 = 1,1-$H694,1))*0.00306888*(C210/$H682)*$H686*(C224^$B6105)*(($H697*(($H696 + $H696)^$B6104)) + (((($H696 + $H696)^$B6105)*($H699)))))
287	=IF($B6175 = 1,0,IF($B6176 = 3,C211*$I687*0.00112*0.3,IF($B6176 = 2,1-0.125*C250,IF($B6176 = 1,1-$I694,1))*0.00306888*(C211/$I682)*$I686*(C225^$B6106)*(($I697*(($I695 + $I696)^$B6104)) + ((($I696 + $I696)^$B6105)*($I699)))))
288	=IF($B6176 = 1,0,IF($B6176 = 3,C212*$J687*0.00112*0.3,IF($B6176 = 2,1-0.125*C250,IF($B6176 = 1,1-$J694,1))*0.3*C212*$B6111))
289	=C366*IF($B6180 = 1,0.3346*$B6133*($B6137^$B6136),(IF($B6178 = 1,$B6131,$B6123)*($B653)-($B6125*$B6117))/IF($B6179 = 1,$B6129,$B6121))
290	=(1 + $B6162)*C290/4
291	=(1 + $B6163)*C291/4
292	=C292*(($B651*$B653)-($B614*$B617))/($B651-$B614)
293	=C293*(($B651*$B653)-($B614*$B617))/($B651-$B614)
294	=C261*(($B6144*$B653)-($B615*$B617))
295	=($B647*(($B648*$B653)-($B616*$B617)) + (((4*F304)^$B649)*$B650*$B642*(($B651*$B653)-($B614*$B617)))/43560)
296	=C296
297	=C297
298	0
299	0
300	=$B632/4
301	=$B625/4
302	=$B641*-E265*IF(E263<0.036,276,764.806*E263+248.815)
303	=IF(AND(E265>0,F302<-(F273-F295-F292+F320)),-(F273-F295-F292+F320),F302)
304	=IF(F273+F303-F295-F292+F320<0.0,F273+F303-F295-F292+F320)
305	
306	-------
307	=MAX(0,+F275-F301-0.25*(I274+I275+I276+I317+I321-I289-I294-I295-I296-I300-I301-I303))
308	=IF280*$B688*(1-$B689)*($B675+$B690))-($B6170*$B676*(($B651*$B653)-($B614*$B617)))
309	=(F281*$C688*(1-$C689)*$C690)
310	=(F282*$D688*(1-$D689)*$D690)
311	=(F283*$E688*(1-$E689)*$E690)
312	=(F284*$F688*(1-$F689)*$F690)
313	=(F285*$G688*(1-$G689)*$G690)
314	=(F286*$H688*(1-$H689)*$H690)
315	=(F287*$I688*(1-$I689)*$I690)
316	=(F288*$J688*(1-$J689)*$J690)
317	=(1-IF($B6179 = 1,$B6129,$B6121))*F289
318	=(F290*$B6156)
319	=(F291*$B6157)
320	=F296+F297
321	0
322	
323	-------
324	=F304+($C617*$C620*($C612^$C621)*($C613^$C622))
325	=F300
326	=IF($B6176 = 1,F301+($C628/4),+F301+(($C628/4)*(1+$B669)))
327	=$B662/4
328	=$B663/4
329	
330	-------
331	=IF($B6175 = 1,0,IF($B6176 = 3,C213*$K687*0.00112*0.3,IF($B6176 = 2,1-0.125*C261,IF($B6176 = 1,1-$K694,1))*0.00306888*(C213/$K682)*$K686*(C227^$B6106)*(($K697*(($K696 + $K696)^$B6104)) + (((($K696 + $K696)^$B6105)*($K699)))))
332	=IF($B6175 = 1,0,IF($B6176 = 3,C214*$L687*0.00112*0.3,IF($B6176 = 2,1-0.126*C262,IF($B6176 = 1,1-$L694,1))*0.00306888*(C214/$L682)*$L686*(C228^$B6106)*(($L697*(($L696 + $L696)^$B6104)) + (((($L696 + $L696)^$B6105)*($L699)))))
333	=IF($B6175 = 1,0,IF($B6176 = 3,C215*$M687*0.00112*0.3,IF($B6176 = 2,1-0.126*C263,IF($B6176 = 1,1-$M694,1))*0.00306888*(C215/$M682)*$M686*(C229^$B6106)*(($M697*(($M696 + $M696)^$B6104)) + (((($M695 + $M696)^$B6105)*($M699)))))
334	=IF($B6175 = 1,0,IF($B6176 = 3,C216*$N687*0.00112*0.3,IF($B6176 = 2,1-0.126*C264,IF($B6176 = 1,1-$N694,1))*0.00306888*(C216/$N682)*$N686*(C230^$B6106)*(($N697*(($N696 + $N696)^$B6104)) + (((($N696 + $N696)^$B6105)*($N699)))))
335	=IF($B6175 = 1,0,IF($B6176 = 3,C217*$O687*0.00112*0.3,IF($B6176 = 2,1-0.126*C264,IF($B6176 = 1,1-$O694,1))*0.3*C217*$B6111))
336	=MIN(C306*(((IF($B6178 = 1,$B6132,$B6124)*($C653)-($B6126*$C617))/IF($B6179 = 1,$B6130,$B6122),IF(F304<(C336*0.177),IF(F304<=0.0,F304),C336*0.177))
337	=MIN(C306*(((IF($B6178 = 1,$B6132,$B6124)*($C653)-($B6126*$C617))/IF($B6179 = 1,$B6130,$B6122)-F336,IF(F304<(C336*0.177+C337*0.1647),IF(F304<=C336*0.177,0,F304-(C336*0.177)),C337*0.1647))
338	=IC306*IF($B6180 = 1,0.3215*$B6134*($B6137^$B6136),(((IF($B6178 = 1,$B6132,$B6124)*($C653)-($B6126*$C617))/IF($B6179 = 1,$B6130,$B6122)))-F336-F337
339	=(1+$B6162)*C339/4
340	=(1+$B6163)*C340/4
341	=C341*(($C651*$C653)-($C614*$C617))/($C651-$C614)
342	=C342*(($C651*$C653)-($C614*$C617))/($C651-$C614)
343	=C262*(($B6146*$C653)-($C615*$C617))
344	=IF(F363<=0,($C647*(($C648*$C653)-($C616*$C617))),($C647*(($C648*$C653)-($C616*$C617))) + (((4*F363^$C649)*$C650*$C642*(($C651*$C653)-($C614*$C617)))/43560))
346	=C346
346	=C346
347	0
348	0
349	=C349/4
350	=C350/4
351	=$C641*-E266*IF(E264<0.0469,226,705.81*E264+199.03)
352	=IF(AND(E266>0,F351<-(F324-F344+F365-F336-F337-F341)),-(F324-F344+F365-F336-F337-F341),F351)
353	=IF(F324+F352-F344+F365-F336-F337-F341<0.0,F324+F352-F344+F365-F336-F337-F341)

USF20001053

	F
354	
355	-------
356	= MAX(0, + F326-F350-0.25*(¢I326 + ¢I326 + ¢I327 + ¢I362-¢I338-¢I343-¢I345-¢I347-¢I349-¢I350-¢I352))
357	= (F331*¢K¢88*(1-¢K¢89)*¢K¢90)
358	= (F332*¢L¢88*(1-¢L¢89)*¢L¢90)
359	= (F333*¢M¢88*(1-¢M¢89)*¢M¢90)
360	= (F334*¢N¢88*(1-¢N¢89)*¢N¢90)
361	= (F335*¢O¢88*(1-¢O¢89)*¢O¢90)
362	= (1-IF(¢B¢179 = 1, ¢B¢130, ¢B¢122))*(F336 + F337 + F338)
363	= F339*¢B¢160
364	= F340*¢B¢161
365	= F345 + F346
366	
367	-------
368	= F267-E267
369	= F268-E268
370	= F269-E269
371	= F260-E260
372	= F368/(¢B¢31*¢B¢33)
373	= F369/(¢B¢24*¢B¢26)
374	= F370/(¢C¢31*¢C¢33)
375	= F371/(¢C¢24*¢C¢26)
376	
377	
378	
379	
380	
381	
382	
383	-------
384	
385	
386	

USF200010540

USF200010541

USF200010542

	G
364	
365	-------
366	=MAX(0, +G326-G350-0.25*(¢I325 + ¢I326 + ¢I327 + ¢I362-¢I338-¢I343-¢I345-¢I347-¢I349-¢I350-¢I352))
367	=(G331*¢K¢88*(1-¢K¢89)*¢K¢90)
368	=(G332*¢L¢88*(1-¢L¢89)*¢L¢90)
369	=(G333*¢M¢88*(1-¢M¢89)*¢M¢90)
360	=(G334*¢N¢88*(1-¢N¢89)*¢N¢90)
361	=(G335*¢O¢88*(1-¢O¢89)*¢O¢90)
362	=(1-IF(¢B¢179 = 1,¢B¢130,¢B¢122))*(G336 + G337 + G338)
363	=G339*¢B¢160
364	=G340*¢B¢161
365	=G345 + G346
366	
367	-------
368	=G257-F257
369	=G258-F258
370	=G259-F259
371	=G260-F260
372	=G368/(¢B¢31*¢B¢33)
373	=G369/(¢B¢24*¢B¢26)
374	=G370/(¢C¢31*¢C¢33)
375	=G371/(¢C¢24*¢C¢26)
376	
377	
378	
379	
380	
381	
382	
383	-------
384	
385	
386	

USF200010543

USF200010544

	H
277	=$B459/4
278	
279	------
280	=IF($B6175=1,0,IF($B6176=3,C204*$B687*0.00112*0.23+$B672/4,$B672/4+(IF($B6176=2,1-0.125*C243,IF($B6176=1,1-$B694,1))*0.00306888*(C204/$B682)*$B695*(C218^$B6106)*(($B697*(($B695+$B696)^$B6104))+((($B696+$B696)^$B6105)*($B6101))))))
281	=IF($B6175=1,0,IF($B6176=3,C205*$C687*0.00112*0.23,IF($B6176=2,1-0.125*C244,IF($B6176=1,1-$C694,1))*0.00306888*(C205/$C682)*$C686*(C219^$B6106)*(($C697*(($C695+$C696)^$B6104))+((($C696+$C696)^$B6105)*($C6101)))))
282	=IF($B6175=1,0,IF($B6177=1,IF($B6176=3,C206*$D687*0.00112*0.23,IF($B6176=2,1-0.125*C245,IF($B6176=1,1-$D694,1))*0.23*(($D686/$D682)*C205),0.23*(($D686/$D682)*C206)))
283	=IF($B6175=1,0,IF($B6176=3,C207*$E687*0.00112*0.23,IF($B6176=2,1-0.125*C246,IF($B6176=1,1-$E694,1))*0.00306888*(C207/$E682)*$E686*(C221^$B6106)*(($E697*(($E695+$E696)^$B6104))+((($E696+$E696)^$B6105)*($E6101)))))
284	=IF($B6175=1,0,IF($B6176=3,C208*$F687*0.00112*0.23,IF($B6176=2,1-0.125*C247,IF($B6176=1,1-$F694,1))*0.00306888*(C208/$F682)*$F686*(C222^$B6106)*(($F697*(($F695+$F696)^$B6104))+((($F696+$F696)^$B6105)*($F6101)))))
285	=IF($B6175=1,0,IF($B6176=3,C209*$G687*0.00112*0.23,IF($B6176=2,1-0.125*C248,IF($B6176=1,1-$G694,1))*0.00306888*(C209/$G682)*$G686*(C223^$B6106)*(($G697*(($G695+$G696)^$B6104))+((($G696+$G696)^$B6105)*($G6101)))))
286	=IF($B6175=1,0,IF($B6176=3,C210*$H687*0.00112*0.23,IF($B6176=2,1-0.125*C249,IF($B6176=1,1-$H694,1))*0.00306888*(C210/$H682)*$H686*(C224^$B6106)*(($H697*(($H695+$H696)^$B6104))+((($H696+$H696)^$B6105)*($H6101)))))
287	=IF($B6175=1,0,IF($B6176=3,C211*$I687*0.00112*0.23,IF($B6176=2,1-0.125*C250,IF($B6176=1,1-$I694,1))*0.00306888*(C211/$I682)*$I686*(C225^$B6106)*(($I697*(($I695+$I696)^$B6104))+((($I696+$I696)^$B6105)*($I6101)))))
288	=IF($B6175=1,0,IF($B6176=3,C212*$J687*0.00112*0.23,IF($B6176=2,1-0.125*C250,IF($B6176=1,1-$J694,1))*0.23*C212*$B6111))
289	=C365*IF($B6180=1,0.2088*$B6133*($B6137^$B6136),(IF($B6178=1,$B6131,$B6123)*$B655)-($B125*$B619))/IF($B6179=1,$B6129,$B6121))
290	=(1+$B6162)*C290/4
291	=(1+$B6163)*C291/4
292	=C292*(($B651*$B655)-($B614*$B619))/($B651-$B614)
293	=C293*(($B651*$B655)-($B614*$B619))/($B651-$B614)
294	=C261*(($B6144*$B655)-($B615*$B619))
295	=($B647*(($B640*$B655)-($B615*$B619)))+(((4*H304)^$B649)*$B650*$B642*(($B651*$B655)-($B614*$B619))/43560)
296	0
297	0
298	=C298/2
299	=F299/2
300	=$B432/4
301	=$B426/4
302	=$B441*G265*IF(G263<0.035,276,764.806*G263+248.815)
303	=IF(AND(G265>0,H302<-(H273-H295-H292+H320)),-(H273-H295-H292+H320),H302)
304	=IF(H273+H303-H295-H292+H320<0,0,H273+H303-H295-H292+H320)
305	
306	------
307	=MAX(0,+H276-H301-0.25*(($I274+$I275+$I276+$I317+$I321-$I289-($I294-$I296-$I298-$I300-$I301-$I303))
308	=(H280*$B688*(1-$B689)*($B676+$B690))-(($B6170*$B676*(($B651*$B655)-($B614*$B619))))
309	=(H281*$C688*(1-$C689)*$C690)
310	=(H282*$D688*(1-$D689)*$D690)
311	=(H283*$E688*(1-$E689)*$E690)
312	=(H284*$F688*(1-$F689)*$F690)
313	=(H285*$G688*(1-$G689)*$G690)
314	=(H286*$H688*(1-$H689)*$H690)
315	=(H287*$I688*(1-$I689)*$I690)
316	=(H288*$J688*(1-$J689)*$J690)
317	=(1-IF($B6179=1,$B6129,$B6121))*H289
318	=(H290*$B6166)
319	=(H291*$B6167)
320	=H296+H297
321	0
322	
323	------
324	=H304+($C619*$C620*($C612^$C621)*($C613^$C622))
325	=H300
326	=IF($B6176=1,H301+($C628/4),+H301+(($C628/4)*(1+$B669)))
327	=$B662/4
328	=$B663/4
329	
330	------
331	=IF($B6175=1,0,IF($B6176=3,C213*$K687*0.00112*0.23,IF($B6176=2,1-0.125*C261,IF($B6176=1,1-$K694,1))*0.00306888*(C213/$K682)*$K686*(C227^$B6106)*(($K697*(($K695+$K696)^$B6104))+((($K696+$K696)^$B6105)*($K6101)))))
332	=IF($B6175=1,0,IF($B6176=3,C214*$L687*0.00112*0.23,IF($B6176=2,1-0.125*C262,IF($B6176=1,1-$L694,1))*0.00306888*(C214/$L682)*$L686*(C228^$B6106)*(($L697*(($L695+$L696)^$B6104))+((($L696+$L696)^$B6105)*($L6101)))))
333	=IF($B6175=1,0,IF($B6176=3,C215*$M687*0.00112*0.23,IF($B6176=2,1-0.125*C263,IF($B6176=1,1-$M694,1))*0.00306888*(C215/$M682)*$M686*(C228^$B6106)*(($M697*(($M695+$M696)^$B6104))+((($M696+$M696)^$B6105)*($M6101)))))
334	=IF($B6175=1,0,IF($B6176=3,C216*$N687*0.00112*0.23,IF($B6176=2,1-0.125*C264,IF($B6176=1,1-$N694,1))*0.00306888*(C216/$N682)*$N686*(C230^$B6106)*(($N697*(($N695+$N696)^$B6104))+((($N696+$N696)^$B6105)*($N6101)))))
335	=IF($B6175=1,0,IF($B6176=3,C217*$O687*0.00112*0.23,IF($B6176=2,1-0.125*C264,IF($B6176=1,1-$O694,1))*0.23*C217*$B6111))
336	=MIN(C366*(((IF($B6178=1,$B6132,$B6124)*$C656)-($B6126*$C619))/IF($B6179=1,$B6130,$B6122)),IF(H304<(C336*0.3117),IF(H304<=0,0,H304),C336*0.3117))
337	=MIN(C365*(((IF($B6178=1,$B6132,$B6124)*$C655)-($B6126*$C619))/IF($B6179=1,$B6130,$B6122)-H336,IF(H304<(C336*0.3117+C337*0.2663),IF(H304<=C336*0.3117,0,H304-(C336*0.3117)),C337*0.2663))
338	=IC366*IF($B6180=1,0.2015*$B6134*($B6137^$B6136),(((IF($B6178=1,$B6132,$B6124)*$C655)-($B6126*$C619))/IF($B6179=1,$B6130,$B6122)))-H336-H337
339	=(1+$B6162)*C339/4
340	=(1+$B6163)*C340/4
341	=C341*(($C651*$C655)-($C614*$C619))/($C651-$C614)
342	=C342*(($C651*$C655)-($C614*$C619))/($C651-$C614)
343	=C262*(($B6145*$C655)-($C615*$C619))
344	=IF(H363<=0,($C647*(($C648*$C655)-($C615*$C619))),($C647*(($C648*$C655)-($C615*$C619)))+(((4*H363)^$C649)*$C650*$C642*(($C651*$C655)-($C614*$C619))/43560))
345	0
346	0
347	=F347/2
348	=F348/2
349	=C349/4
350	=C350/4
351	=$C641*G266*IF(G264<0.0463,226.706.81*G264+193.03)
352	=IF(AND(G266>0,H351<-(H324-H344+H365-H336-H337-H341)),-(H324-H344+H365-H336-H337-H341),H351)
353	=IF(H324+H352-H344+H365-H336-H337-H341<0,0,H324+H352-H344+H365-H336-H337-H341)

USF20001054S

	H
354	
355	-------
356	= MAX(0, + H326-H350-0.25*(€I325 + €I326 + €I327 + €I362-€I338-€I343-€I345-€I347-€I349-€I350-€I352))
357	= (H331*€K€88*(1-€K€89)*€K€90)
358	= (H332*€L€88*(1-€L€89)*€L€90)
359	= (H333*€M€88*(1-€M€89)*€M€90)
360	= (H334*€N€88*(1-€N€89)*€N€90)
361	= (H335*€O€88*(1-€O€89)*€O€90)
362	= (1-(F(€B€179 = 1,€B€130,€B€122))*(H336 + H337 + H338)
363	= H339*€B€160
364	= H340*€B€161
365	= H345 + H346
366	
367	-------
368	= H257-G257
369	= H258-G258
370	= H259-G259
371	= H260-G260
372	= H368/(€B€31*€B€33)
373	= H369/(€B€24*€B€26)
374	= H370/(€C€31*€C€33)
375	= H371/(€C€24*€C€26)
376	
377	
378	
379	
380	
381	
382	
383	-------
384	
385	
386	

USF200010546

	1
200	
201	=H201
202	end-of-yr
203	------
204	=IF(I201=$B$106,+C204+$F$109,C204)
205	=C205
206	=IF(I201=$B$106,+C206+$F$107,C206)
207	=C207
208	=C208
209	=C209
210	=C210
211	=C211
212	=C212
213	=C213
214	=C214
215	=C215
216	=C216
217	=C217
218	=IF($B$175=1.0,+C218)
219	=IF($B$175=1.0,+C219)
220	=NA()
221	=IF($B$175=1.0,+C221)
222	=IF($B$175=1.0,+C222)
223	=IF($B$175=1.0,+C223)
224	=IF($B$175=1.0,+C224)
225	=IF($B$175=1.0,+C225)
226	=IF($B$175=1.0,+C226)
227	=IF($B$175=1.0,+C227)
228	=IF($B$175=1.0,+C228)
229	=IF($B$175=1.0,+C229)
230	=IF($B$175=1.0,+C230)
231	=IF($B$175=1.0,+C231)
232	=IF($B$96=$B$95,IF(I206<C206-0.00306866,I206+$F$107,IF(I206>C206+0.00306866,I206-$F$107,C206)),IF(I206<C206-0.00306866,I206+$F$107,IF(I206>C206+0.00306866,I206-$F$107,C206)))
233	=IF(C206<$E$196,IF(I206<C206-0.00306866,I206+$F$107,IF(I206>C206+0.00306866,I206-$F$107,C206)),IF(I206<C206-0.00306866,I206+$F$107,IF(I206>C206+0.00306866,I206-$F$107,C206)))
234	=IF(C206>$E$196,IF(I206<C206-0.00306866,I206+$F$107,IF(I206>C206+0.00306866,I206-$F$107,C206)),IF(I206<C206-0.00306866,I206+$F$107,IF(I206>C206+0.00306866,I206-$F$107,C206)))
235	=IF(I206<$E$196-0.00306866,I206+$F$107,IF(I206>$E$196+0.00306866,I206-$F$107,$E$196))
236	=IF(I206>$E$196+0.00306866,I206-$F$107,IF(I206<$E$196-0.00306866,I206+$F$107,$E$196))
237	=IF(I206<$E$196,I206+$F$107,IF(I206>$E$196,I206-$F$107,$E$196))
238	=IF(I206>$E$196,I206-$F$107,IF(I206<$E$196,I206+$F$107,$E$196))
239	=IF(I206<$E$196-0.00306866,I206+$F$107,IF(I206>$E$196+0.00306866,I206-$F$107,$E$196))
240	=IF(I206>$E$196+0.00306866,I206-$F$107,IF(I206<$E$196-0.00306866,I206+$F$107,$E$196))
241	=IF(I206<$E$196,I206+$F$107,IF(I206>$E$196,I206-$F$107,$E$196))
242	=IF(I206>$E$196,I206-$F$107,IF(I206<$E$196,I206+$F$107,$E$196))
243	=IF($B$175=1.0,IF(I204<C204-0.00306866,I204+$F$107,IF(I204>C204+0.00306866,I204-$F$107,C204)),IF(I204<C204-0.00306866,I204+$F$107,IF(I204>C204+0.00306866,I204-$F$107,C204)))
244	=IF($B$175=1.0,IF(I205<C205-0.00306866,I205+$F$107,IF(I205>C205+0.00306866,I205-$F$107,C205)),IF(I205<C205-0.00306866,I205+$F$107,IF(I205>C205+0.00306866,I205-$F$107,C205)))
245	=IF($B$175=1.0,IF(I206<C206-0.00306866,I206+$F$107,IF(I206>C206+0.00306866,I206-$F$107,C206)),IF(I206<C206-0.00306866,I206+$F$107,IF(I206>C206+0.00306866,I206-$F$107,C206)))
246	=IF($B$175=1.0,IF(I207<C207-0.00306866,I207+$F$107,IF(I207>C207+0.00306866,I207-$F$107,C207)),IF(I207<C207-0.00306866,I207+$F$107,IF(I207>C207+0.00306866,I207-$F$107,C207)))
247	=IF($B$175=1.0,IF(I208<C208-0.00306866,I208+$F$107,IF(I208>C208+0.00306866,I208-$F$107,C208)),IF(I208<C208-0.00306866,I208+$F$107,IF(I208>C208+0.00306866,I208-$F$107,C208)))
248	=IF($B$175=1.0,IF(I209<C209-0.00306866,I209+$F$107,IF(I209>C209+0.00306866,I209-$F$107,C209)),IF(I209<C209-0.00306866,I209+$F$107,IF(I209>C209+0.00306866,I209-$F$107,C209)))
249	=IF($B$175=1.0,IF(I210<C210-0.00306866,I210+$F$107,IF(I210>C210+0.00306866,I210-$F$107,C210)),IF(I210<C210-0.00306866,I210+$F$107,IF(I210>C210+0.00306866,I210-$F$107,C210)))
250	=IF($B$175=1.0,IF(I212+I211-C212-C211<0,(I212+I211-C212-C211)*(1-C260)+(C212+C211)*C260,I212+I211-C212-C211),(I212-C212+I211-C211)*(1-C260)+(C212+C211)*C260)
251	=IF($B$175=1.0,IF(I213-C213<0,(I213-C213)*(1-C261)+(C213)*C261,I213-C213),(I213-C213)*(1-C261)+(C213)*C261)
252	=IF($B$175=1.0,IF(I214-C214<0,(I214-C214)*(1-C262)+(C214)*C262,I214-C214),(I214-C214)*(1-C262)+(C214)*C262)
253	=IF($B$175=1.0,IF(I215-C215<0,(I215-C215)*(1-C263)+(C215)*C263,I215-C215),(I215-C215)*(1-C263)+(C215)*C263)
254	=IF($B$175=1.0,IF(I216+I217-C216-C217<0,(I216+I217)*(1-C264)+(C216+C217)*C264,I216+I217-C216-C217),(I216-C216+I217-C217)*(1-C264)+(C216+C217)*C264)
255	------
256	------
257	=H257
258	=H258
259	=H259
260	=H260
261	=C261+C378
262	=C262+C379
263	=AVERAGE(E263:H263)
264	=AVERAGE(E264:H264)
265	=AVERAGE(E265:H265)
266	=AVERAGE(E266:H266)
267	=IC267+I372
268	=IC268+I380
269	=IC269+I374
270	=IC270+I381
271	
272	------
273	=SUM(E273:H273)
274	=SUM(E274:H274)
275	=SUM(E275:H275)
276	=SUM(E276:H276)

USF200010547

277	=SUM(E277:H277)
278	
279	------
280	=SUM(E260:H260)
281	=SUM(E281:H281)
282	=SUM(E282:H282)
283	=SUM(E283:H283)
284	=SUM(E284:H284)
285	=SUM(E285:H285)
286	=SUM(E286:H286)
287	=SUM(E287:H287)
288	=SUM(E288:H288)
289	=SUM(E289:H289)
290	=SUM(E290:H290)
291	=SUM(E291:H291)
292	=SUM(E292:H292)
293	=SUM(E293:H293)
294	=SUM(E294:H294)
295	=SUM(E295:H295)
296	=SUM(E296:H296)
297	=SUM(E297:H297)
298	=SUM(E298:H298)
299	=SUM(E299:H299)
300	=SUM(E300:H300)
301	=SUM(E301:H301)
302	=SUM(E302:H302)
303	=SUM(E303:H303)
304	=SUM(E304:H304)
305	
306	------
307	=SUM(E307:H307)
308	=SUM(E308:H308)
309	=SUM(E309:H309)
310	=SUM(E310:H310)
311	=SUM(E311:H311)
312	=SUM(E312:H312)
313	=SUM(E313:H313)
314	=SUM(E314:H314)
315	=SUM(E315:H315)
316	=SUM(E316:H316)
317	=SUM(E317:H317)
318	=SUM(E318:H318)
319	=SUM(E319:H319)
124	=SUM(E320:H320)
321	=SUM(E321:H321)
322	
323	------
324	=SUM(E324:H324)
325	=SUM(E325:H325)
326	=SUM(E326:H326)
327	=SUM(E327:H327)
328	=SUM(E328:H328)
329	
330	------
331	=SUM(E331:H331)
332	=SUM(E332:H332)
333	=SUM(E333:H333)
334	=SUM(E334:H334)
335	=SUM(E335:H335)
336	=SUM(E336:H336)
337	=SUM(E337:H337)
338	=SUM(E338:H338)
339	=SUM(E339:H339)
340	=SUM(E340:H340)
341	=SUM(E341:H341)
342	=SUM(E342:H342)
343	=SUM(E343:H343)
344	=SUM(E344:H344)
345	=SUM(E345:H345)
346	=SUM(E346:H346)
347	=SUM(E347:H347)
348	=SUM(E348:H348)
349	=SUM(E349:H349)
350	=SUM(E350:H350)
361	=SUM(E361:H361)
362	=SUM(E362:H362)
363	=SUM(E363:H363)

USF200010548

354	
355	-------
356	= SUM(E356:H356)
357	= SUM(E357:H357)
358	= SUM(E358:H358)
359	= SUM(E359:H359)
360	= SUM(E360:H360)
361	= SUM(E361:H361)
362	= SUM(E362:H362)
363	= SUM(E363:H363)
364	= SUM(E364:H364)
365	= SUM(E365:H365)
366	
367	-------
368	= SUM(E368:H368)
369	= SUM(E369:H369)
370	= SUM(E370:H370)
371	= SUM(E371:H371)
372	= SUM(E372:H372)
373	= SUM(E373:H373)
374	= SUM(E374:H374)
375	= SUM(E375:H375)
376	= I304-C304
377	= I353-C353
378	0
379	0
380	= C380 + (I373/100)
381	= C381 + (I373/100)
382	
383	-------
384	= SUM(I204:I217)-I209
385	= MAX(0,IF(6B6175 = 1,0,(1 + 6B6127)*C385-IF(I378< =0,0,I378)))
386	= MAX(0,IF(6B6175 = 1,0,(1 + 6B6128)*C386-IF(I379< =0,0,I379)))

USF200010549

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201	=I201+1
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256	-------
257	=MAX(I267*0.96,MIN(I267*1.06,I267+K274+K276+K307+K317+K321-K289-K294-K296-K298-K300-K303))
258	=I268+K276+K277+SUM(K308:K316)+K318+K319-SUM(K260:K288)-K290-K291-K293-K297-K299-K301-K307
259	=MAX(I269*0.96,MIN(I269*1.06,I259+K326+K327-K336-K343-K345-K347-K349+K356-K362+K362))
260	=I260+K326+K328-SUM(K331:K335)-K339-K340-K342-K346-K348-K350-K366+SUM(K357:K361)+K363+K364
261	
262	
263	=IF((6B46*6B616)+K304<0,0.000000000000001,6B46*(2*(6B46*6B616+K304)))*6B644
264	=IF(K304+K363<0,0.000000000000001,6C646*(2*(K304+K363)))*6C644
265	=IF(K263>0,IF(I267+6B643+K372>0,K263-I267-K372,K263+6B643),IF(I267+K372>0,0-I267-K372,0))
266	=IF(K264>0,IF(I269+6C643+K374>0,K264-I269-K374,K264+6C643),IF(I269+K374>0,0-I269-K374,0))
267	=I267+K372
268	
269	=I269+K374
270	
271	
272	-------
273	=6B616*(6B46+(6B620*(6B612^6B621)*(6B613^6B622)))
274	=6B46/4
275	=IF(6B6175=1,6B67/4+(6B628/4),6B67/4+((6B628/4)*(1+6B668)))
276	=6B656/4

USF200010550

	K
277	=$B$59/4
278	
279	--------
280	=IF($B$175=1,0,IF($B$176=3,I204*$B$87*0.00112*0.18+$B$72/4,$B$72/4+(IF($B$176=2,1-0.126*I243,IF($B$176=1,1-$B$94,1))*0.00306888*((I204/$B$82)*$B$85*((I218^$B$106)*(($B$97*(($B$95+$B$96)^$B$104))+((($B$95+$B$96)^$B$105)*($B$98))))))))
281	=IF($B$175=1,0,IF($B$176=3,I205*$C$87*0.00112*0.18,IF($B$176=2,1-0.126*I244,IF($B$176=1,1-$C$94,1))*0.00306888*((I205/$C$82)*$C$85*((I219^$B$106)*(($C$97*(($C$95+$C$96)^$B$104))+((($C$95+$C$96)^$B$105)*($C$98)))))))
282	=IF($B$175=1,0,IF($B$177=1,IF($B$176=3,I206*$D$87*0.00112*0.18,IF($B$176=2,1-0.126*I246,IF($B$176=1,1-$D$94,1))*0.18*($D$86/$D$82)*I206),0.18*($D$86/$D$82)*I206))
283	=IF($B$175=1,0,IF($B$176=3,I207*$E$87*0.00112*0.18,IF($B$176=2,1-0.126*I246,IF($B$176=1,1-$E$94,1))*0.00306888*((I207/$E$82)*$E$85*((I221^$B$106)*(($E$97*(($E$95+$E$96)^$B$104))+((($E$95+$E$96)^$B$105)*($E$98)))))))
284	=IF($B$175=1,0,IF($B$176=3,I208*$F$87*0.00112*0.18,IF($B$176=2,1-0.126*I247,IF($B$176=1,1-$F$94,1))*0.00306888*((I208/$F$82)*$F$85*((I222^$B$106)*(($F$97*(($F$95+$F$96)^$B$104))+((($F$95+$F$96)^$B$105)*($F$98)))))))
285	=IF($B$175=1,0,IF($B$176=3,I209*$G$87*0.00112*0.18,IF($B$176=2,1-0.126*I248,IF($B$176=1,1-$G$94,1))*0.00306888*((I209/$G$82)*$G$85*((I223^$B$106)*(($G$97*(($G$95+$G$96)^$B$104))+((($G$95+$G$96)^$B$105)*($G$98)))))))
286	=IF($B$175=1,0,IF($B$176=3,I210*$H$87*0.00112*0.18,IF($B$176=2,1-0.126*I249,IF($B$176=1,1-$H$94,1))*0.00306888*((I210/$H$82)*$H$85*((I224^$B$106)*(($H$97*(($H$95+$H$96)^$B$104))+((($H$95+$H$96)^$B$105)*($H$98)))))))
287	=IF($B$175=1,0,IF($B$176=3,I211*$I$87*0.00112*0.18,IF($B$176=2,1-0.126*I250,IF($B$176=1,1-$I$94,1))*0.00306888*((I211/$I$82)*$I$85*((I226^$B$106)*(($I$97*(($I$95+$I$96)^$B$104))+((($I$95+$I$96)^$B$105)*($I$98)))))))
288	=IF($B$175=1,0,IF($B$176=3,I212*$J$87*0.00112*0.18,IF($B$176=2,1-0.126*I250,IF($B$176=1,1-$J$94,1))*0.18*I212*$B$111))
289	=I386*IF($B$180=1,0.1716*$B$133*($B$137^$B$136),((IF($B$178=1,$B$131,$B$123)*$B$52)-($B125*$B$16))/IF($B$179=1,$B$129,$B$121))
290	=(1+$B$162)*I290/4
291	=(1+$B$163)*I291/4
292	=I292*(($B$51*$B$52)-($B$14*$B$16))/($B$51-$B$14)
293	=I293*(($B$51*$B$52)-($B$14*$B$16))/($B$51-$B$14)
294	=I261*(($B$144*$B$52)-($B$15*$B$16))
296	=($B$47*(($B$48*$B$52)-($B$15*$B$16)))+(((4*K304)^$B$49)*$B$50*$B$42*(($B$51*$B$52)-($B$14*$B$16))/43560)
296	0
297	0
298	=I298/2
299	=I299/2
300	=$B$32/4
301	=$B$25/4
302	=$B$41*-I265*IF(I263<0.036,276,764.806*I263+248.816)
303	=IF(AND(H265>0,K302<-(K273-K295-K292+K320)),-(K273-K295-K292+K320),K302)
304	=IF(K273+K303-K295-K292+K320<0,0,K273+K303-K295-K292+K320)
306	
306	--------
307	=MAX(0,0.25*(($B$36*(I268-I267))+E307+E307+E307))
308	=(K280*$B$88*(1-$B$89)*($B$75+$B$90))-($B$170*$B$76*(($B$51*$B$52)-($B$14*$B$16)))
309	=(K281*$C$88*(1-$C$89)*$C$90)
310	=(K282*$D$88*(1-$D$89)*$D$90)
311	=(K283*$E$88*(1-$E$89)*$E$90)
312	=(K284*$F$88*(1-$F$89)*$F$90)
313	=(K285*$G$88*(1-$G$89)*$G$90)
314	=(K286*$H$88*(1-$H$89)*$H$90)
315	=(K287*$I$88*(1-$I$89)*$I$90)
316	=(K288*$J$88*(1-$J$89)*$J$90)
317	=(1-IF($B$179=1,$B$129,$B$121))*K289
318	=(K290*$B$156)
319	=(K291*$B$157)
320	=K296+K297
321	0
322	
323	--------
324	=K304+($C$16*$C$20*($C$12^$C$21)*($C$13^$C$22))
325	=K300
326	=IF($B$175=1,K301+($C$28/4),+K301+(($C$28/4)*(1+$B$69)))
327	=$B$62/4
328	=$B$63/4
329	
330	--------
331	=IF($B$176=1,0,IF($B$176=3,I213*$K$87*0.00112*0.18,IF($B$176=2,1-0.126*I251,IF($B$176=1,1-$K$94,1))*0.00306888*((I213/$K$82)*$K$85*((I227^$B$106)*(($K$97*(($K$95+$K$96)^$B$104))+((($K$95+$K$96)^$B$105)*($K$98)))))))
332	=IF($B$175=1,0,IF($B$176=3,I214*$L$87*0.00112*0.18,IF($B$176=2,1-0.126*I252,IF($B$176=1,1-$L$94,1))*0.00306888*((I214/$L$82)*$L$85*((I228^$B$106)*(($L$97*(($L$95+$L$96)^$B$104))+((($L$95+$L$96)^$B$105)*($L$98)))))))
333	=IF($B$175=1,0,IF($B$176=3,I215*$M$87*0.00112*0.18,IF($B$176=2,1-0.126*I253,IF($B$176=1,1-$M$94,1))*0.00306888*((I215/$M$82)*$M$85*((I229^$B$106)*(($M$97*(($M$95+$M$96)^$B$104))+((($M$95+$M$96)^$B$105)*($M$98)))))))
334	=IF($B$175=1,0,IF($B$176=3,I216*$N$87*0.00112*0.18,IF($B$176=2,1-0.126*I254,IF($B$176=1,1-$N$94,1))*0.00306888*((I216/$N$82)*$N$85*((I230^$B$106)*(($N$97*(($N$95+$N$96)^$B$104))+((($N$95+$N$96)^$B$105)*($N$98)))))))
335	=IF($B$175=1,0,IF($B$176=3,I217*$O$87*0.00112*0.18,IF($B$176=2,1-0.126*I254,IF($B$176=1,1-$O$94,1))*0.18*I217*$B$111))
336	=MIN(I386*((IF($B$178=1,$B$132,$B$124)*$C$52)-($B$126*$C$16))/IF($B$179=1,$B$130,$B$122),IF(K304<(I336*0.5067),IF(K304<=0,0,K304),I336*0.5067))
337	=MIN(I386*((IF($B$178=1,$B$132,$B$124)*$C$52)-($B$126*$C$16))/IF($B$179=1,$B$130,$B$122)-K336,IF(K304<(I336*0.5067+I337*0.5562),IF(K304<=I336*0.5067,0,K304-(I336*0.5067)),I337*0.5562))
338	=(I386*IF($B$180=1,0.17*$B$134*($B$137^$B$136),((IF($B$178=1,$B$132,$B$124)*$C$52)-($B$126*$C$16))/IF($B$179=1,$B$130,$B$122)))-(K336+K337)
339	=(1+$B$162)*I339/4
340	=(1+$B$163)*I340/4
341	=I341*(($C$51*$C$52)-($C$14*$C$16))/($C$51-$C$14)
342	=I342*(($C$51*$C$52)-($C$14*$C$16))/($C$51-$C$14)
343	=I262*(($B$145*$C$52)-($C$15*$C$16))
344	=IF(K363<=0,($C$47*(($C$48*$C$52)-($C$15*$C$16))),($C$47*(($C$48*$C$52)-($C$15*$C$16)))+((4*K363^$C$49)*$C$50*$C$42*(($C$51*$C$52)-($C$14*$C$16))/43560))
345	0
346	0
347	=I347/2
348	=I348/2
349	=I349/4
350	=I350/4
351	=$C$41*-I266*IF(I264<0.0463,225,705.81*I264+193.03)
352	=IF(AND(H266>0,K351<-(K324-K344+K365-K336-K337-K341)),-(K324-K344+K365-K336-K337-K341),K351)
353	=IF(K324+K352-K344+K365-K336-K337-K341<0,0,K324+K352-K344+K365-K336-K337-K341)

USF200010551

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364	
365	--------
366	= MAX(0,0.25*((ϵC ϵ36*(I270-I269)) + E356 + E356 + E356))
367	= (K331*ϵK ϵ88*(1-ϵK ϵ89)*ϵK ϵ90)
368	= (K332*ϵL ϵ88*(1-ϵL ϵ89)*ϵL ϵ90)
369	= (K333*ϵM ϵ88*(1-ϵM ϵ89)*ϵM ϵ90)
370	= (K334*ϵN ϵ88*(1-ϵN ϵ89)*ϵN ϵ90)
371	= (K335*ϵO ϵ88*(1-ϵO ϵ89)*ϵO ϵ90)
372	= (1-IF(ϵB ϵ179 = 1,ϵB ϵ130,ϵB ϵ122))*(K336 + K337 + K338)
373	= K339*ϵB ϵ160
374	= K340*ϵB ϵ161
375	= K345 + K346
376	
377	--------
378	= K257-I257
379	= K258-I258
380	= K259-I259
381	= K260-I260
382	= K368/(ϵB ϵ31*ϵB ϵ33)
383	= K369/(ϵB ϵ24*ϵB ϵ26)
384	= K370/(ϵC ϵ31*ϵC ϵ33)
385	= K371/(ϵC ϵ24*ϵC ϵ26)
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USF200010552

USF200010553

	L
277	= $B$59/4
278	
279	------
280	= IF($B$175 = 1,0,IF($B$176 = 3,(I204*$B$97*0.00112*0.3,$B$72/4 + (IF($B$176 = 2,1-0.125*I243,IF($B$176 = 1,1-$B$94,1))*0.00306888*((I204/$B$82)*$B$85*(I219^$B$106)*(($B$97*(($B$96 + $B$96)^$B$104)) + ((($B$96 + $B$96)^$B$106)*($B$99)))))))
281	= IF($B$175 = 1,0,IF($B$176 = 3,I205*$C$97*0.00112*0.3,IF($B$176 = 2,1-0.125*I244,IF($B$176 = 1,1-$C$94,1))*0.00306888*((I205/$C$82)*$C$85*((I219^$B$106)*(($C$97*(($C$95 + $C$96)^$B$104)) + ((($C$95 + $C$96)^$B$106)*($C$99)))))))
282	= IF($B$175 = 1,0,IF($B$177 = 1,IF($B$176 = 3,I206*$D$97*0.00112*0.3,IF($B$176 = 2,1-0.125*I245,IF($B$176 = 1,1-$D$94,1))*0.3*((D$86/$D$82)*I206),0.3*(($D$86/$D$82)*I206)))
283	= IF($B$175 = 1,0,IF($B$176 = 3,I207*$E$97*0.00112*0.3,IF($B$176 = 2,1-0.125*I246,IF($B$176 = 1,1-$E$94,1))*0.00306888*((I207/$E$82)*$E$85*((I221^$B$106)*(($E$97*(($E$95 + $E$96)^$B$104)) + ((($E$95 + $E$96)^$B$106)*($E$99)))))))
284	= IF($B$175 = 1,0,IF($B$176 = 3,I208*$F$97*0.00112*0.3,IF($B$176 = 2,1-0.125*I247,IF($B$176 = 1,1-$F$94,1))*0.00306888*((I208/$F$82)*$F$85*((I222^$B$106)*(($F$97*(($F$95 + $F$96)^$B$104)) + ((($F$95 + $F$96)^$B$106)*($F$99)))))))
285	= IF($B$175 = 1,0,IF($B$176 = 3,I209*$G$97*0.00112*0.3,IF($B$176 = 2,1-0.125*I248,IF($B$176 = 1,1-$G$94,1))*0.00306888*((I209/$G$82)*$G$85*((I223^$B$106)*(($G$97*(($G$95 + $G$96)^$B$104)) + ((($G$95 + $G$96)^$B$106)*($G$99)))))))
286	= IF($B$175 = 1,0,IF($B$176 = 3,I210*$H$97*0.00112*0.3,IF($B$176 = 2,1-0.125*I249,IF($B$176 = 1,1-$H$94,1))*0.00306888*((I210/$H$82)*$H$85*((I224^$B$106)*(($H$97*(($H$95 + $H$96)^$B$104)) + ((($H$95 + $H$96)^$B$106)*($H$99)))))))
287	= IF($B$175 = 1,0,IF($B$176 = 3,I211*$I$97*0.00112*0.3,IF($B$176 = 2,1-0.125*I250,IF($B$176 = 1,1-$I$94,1))*0.00306888*((I211/$I$82)*$I$85*((I225^$B$106)*(($I$97*(($I$95 + $I$96)^$B$104)) + ((($I$95 + $I$96)^$B$106)*($I$99)))))))
288	= IF($B$175 = 1,0,IF($B$176 = 3,I212*$J$97*0.00112*0.3,IF($B$176 = 2,1-0.125*I250,IF($B$176 = 1,1-$J$94,1))*0.3*I212*$B$111))
289	= I365*IF($B$180 = 1,0.3346*$B$139*($B$137^$B$136),(IF($B$178 = 1,$B$131,$B$123)*($B$53)-($B$125*$B$71)))/IF($B$179 = 1,$B$129,$B$121))
290	= (1 + $B$162)*I290/4
291	= (1 + $B$163)*I291/4
292	= I292*(($B$51*$B$53)-($B$14*$B$17))/($B$51-$B$14)
293	= I293*(($B$51*$B$53)-($B$14*$B$17))/($B$51-$B$14)
294	= I261*(($B$144*$B$53)-($B$15*$B$17))
295	= ($B$47*(($B$48*$B$53)-($B$15*$B$17))) + (((4*L304)^$B$49)*$B$50*$B$42*(($B$51*$B$53)-($B$14*$B$17)))/43660)
296	= I296
297	= I297
298	0
299	0
300	= $B$32/4
301	= $B$26/4
302	= $B$41*-K266*IF(K263<0.035,276,764.806*K263 + 248.816)
303	= IF(AND(K265 > 0,L302 < -(L273-L295-L292 + L320)),-(L273-L295-L292 + L320),L302)
304	= IF(L273 + L303-L295-L292 + L320<0,0,L273 + L303-L295-L292 + L320)
305	
306	------
307	= MAX(0.25*(($B$36*(I268-I267)) + F307 + F307 + F307))
308	= (L280*$B$88*(1-$B$89)*($B$75 + $B$90))-($B$170*$B$76*(($B$51*$B$53)-($B$14*$B$17)))
309	= (L281*$C$88*(1-$C$89)*$C$90)
310	= (L282*$D$88*(1-$D$89)*$D$90)
311	= (L283*$E$88*(1-$E$89)*$E$90)
312	= (L284*$F$88*(1-$F$89)*$F$90)
313	= (L285*$G$88*(1-$G$89)*$G$90)
314	= (L286*$H$88*(1-$H$89)*$H$90)
315	= (L287*$I$88*(1-$I$89)*$I$90)
316	= (L288*$J$88*(1-$J$89)*$J$90)
317	= (1-IF($B$179 = 1,$B$129,$B$121))*L289
318	= (L290*$B$156)
319	= (L291*$B$157)
320	= L296 + L297
321	0
322	
323	------
324	= L304 + ($C$17*$C$20*($C$12^$C$21)*($C$13^$C$22))
325	= L300
326	= IF($B$175 = 1,L301 + ($C$28/4), + L301 + (($C$28/4)*(1 + $B$69)))
327	= $B$62/4
328	= $B$63/4
329	
330	------
331	= IF($B$175 = 1,0,IF($B$176 = 3,I213*$K$97*0.00112*0.3,IF($B$176 = 2,1-0.125*I251,IF($B$176 = 1,1-$K$94,1))*0.00306888*((I213/$K$82)*$K$85*((I227^$B$106)*(($K$97*(($K$95 + $K$96)^$B$104)) + ((($K$95 + $K$96)^$B$106)*($K$99)))))))
332	= IF($B$175 = 1,0,IF($B$176 = 3,I214*$L$97*0.00112*0.3,IF($B$176 = 2,1-0.125*I252,IF($B$176 = 1,1-$L$94,1))*0.00306888*((I214/$L$82)*$L$85*((I228^$B$106)*(($L$97*(($L$95 + $L$96)^$B$104)) + ((($L$95 + $L$96)^$B$106)*($L$99)))))))
333	= IF($B$175 = 1,0,IF($B$176 = 3,I215*$M$97*0.00112*0.3,IF($B$176 = 2,1-0.125*I253,IF($B$176 = 1,1-$M$94,1))*0.00306888*((I215/$M$82)*$M$85*((I229^$B$106)*(($M$97*(($M$95 + $M$96)^$B$104)) + ((($M$95 + $M$96)^$B$106)*($M$99)))))))
334	= IF($B$175 = 1,0,IF($B$176 = 3,I216*$N$97*0.00112*0.3,IF($B$176 = 2,1-0.125*I254,IF($B$176 = 1,1-$N$94,1))*0.00306888*((I216/$N$82)*$N$85*((I230^$B$106)*(($N$97*(($N$95 + $N$96)^$B$104)) + ((($N$95 + $N$96)^$B$106)*($N$99)))))))
335	= IF($B$175 = 1,0,IF($B$176 = 3,I217*$O$97*0.00112*0.3,IF($B$176 = 2,1-0.125*I254,IF($B$176 = 1,1-$O$94,1))*0.3*((I217*$B$111)))
336	= MIN((I366*(((IF($B$178 = 1,$B$132,$B$124)*$C$53)-($B$126*$C$17))/IF($B$179 = 1,$B$130,$B$122),IF(L304<((I336*0.177),IF(L304< = 0,0,L304),(I336*0.177))
337	= MIN((I366*(((IF($B$178 = 1,$B$132,$B$124)*$C$53)-($B$126*$C$17))/IF($B$179 = 1,$B$130,$B$122)-L336,IF(L304<((I336*0.177 + I337*0.1647),IF(L304< = I336*0.177,0,L304-(I336*0.177)),(I337*0.1647))
338	= ((I366*IF($B$180 = 1,0.3215*$B$134*($B$137^$B$136),(IF($B$178 = 1,$B$132,$B$124)*$C$53)-($B$126*$C$17))/IF($B$179 = 1,$B$130,$B$122)))-L336-L337
339	= (1 + $B$162)*I339/4
340	= (1 + $B$163)*I340/4
341	= I341*(($C$51*$C$53)-($C$14*$C$17))/($C$51-$C$14)
342	= I342*(($C$51*$C$53)-($C$14*$C$17))/($C$51-$C$14)
343	= I262*(($B$146*$C$53)-($C$15*$C$17))
344	= IF(L363< = 0,($C$47*(($C$48*$C$53)-($C$15*$C$17))),(($C$47*(($C$48*$C$53)-($C$15*$C$17))) + ((4*L363^$C$49)*$C$50*$C$42*(($C$51*$C$53)-($C$14*$C$17))/43660))
345	= I346
346	= I346
347	0
348	0
349	= I349/4
350	= I350/4
351	= $C$41*-K266*IF(K264<0.0463,225,705.81*K264 + 193.03)
352	= IF(AND(K266 > 0,L351 < -(L324-L344 + L365-L336-L337-L341)),-(L324-L344 + L365-L336-L337-L341),L351)
353	= IF(L324 + L352-L344 + L365-L336-L337-L341<0,0,L324 + L352-L344 + L365-L336-L337-L341)

C-27

USF200010554

	L
354	
355	-------
356	= MAX(0,0.25*((¢C¢36*(I270-I269)) + F356 + F356 + F356))
357	= (L331*¢K¢88*(1-¢K¢89)*¢K¢90)
358	= (L332*¢L¢88*(1-¢L¢89)*¢L¢90)
359	= (L333*¢M¢88*(1-¢M¢89)*¢M¢90)
360	= (L334*¢N¢88*(1-¢N¢89)*¢N¢90)
361	= (L335*¢O¢88*(1-¢O¢89)*¢O¢90)
362	= (1-IF(¢B¢179 = 1,¢B¢130,¢B¢122))*(L336 + L337 + L338)
363	= L339*¢B¢160
364	= L340*¢B¢161
365	= L345 + L346
366	
367	-------
368	= L257-K257
369	= L258-K258
370	= L259-K259
371	= L260-K260
372	= L368/(¢B¢31*¢B¢33)
373	= L369/(¢B¢24*¢B¢26)
374	= L370/(¢C¢31*¢C¢33)
375	= L371/(¢C¢24*¢C¢26)
376	
377	
378	
379	
380	
381	
382	
383	-------
384	
385	
386	

USF200010555

USF200010556

	M
277	=$B$69/4
278	
279	-------
280	=IF($B$175=1,0,IF($B$176=3,I204*$D$87*0.00112*0.29,$B$72/4+(IF($B$176=2,1-0.125*I243,IF($B$176=1,1-$B$94,1)))*0.00306888*(I204/($B$82)*$B$95*((I219^$B$105)*(($B$87*(($B$95÷$B$95)^$B$104))+(((($B$95÷$B$95)^$B$105)*($B$100))))))
281	=IF($B$175=1,0,IF($B$176=3,I205*$C$87*0.00112*0.29,IF($B$176=2,1-0.125*I244,IF($B$176=1,1-$C$94,1)))*0.00306888*(I205/$C$82)*$C$95*((I219^$B$105)*(($C$87*(($C$95÷$C$95)^$B$104))+(((($C$95÷$C$95)^$B$105)*($C$100))))))
282	=IF($B$175=1,0,IF($B$177=1,IF($B$176=3,I206*$D$87*0.00112*0.29,IF($B$176=2,1-0.125*I245,IF($B$176=1,1-$D$94,1)))*0.29*($D$86/$D$82)*I206),0.29*($D$86/$D$82)*I206))
283	=IF($B$175=1,0,IF($B$176=3,I207*$E$87*0.00112*0.29,IF($B$176=2,1-0.125*I246,IF($B$176=1,1-$E$94,1)))*0.00306888*(I207/$E$82)*$E$95*((I221^$B$105)*(($E$97*(($E$95÷$E$95)^$B$104))+(((($E$95÷$E$95)^$B$105)*($E$100)))))
284	=IF($B$175=1,0,IF($B$176=3,I208*$F$87*0.00112*0.29,IF($B$176=2,1-0.125*I247,IF($B$176=1,1-$F$94,1)))*0.00306888*(I208/$F$82)*$F$95*((I222^$B$105)*(($F$97*(($F$95÷$F$95)^$B$104))+(((($F$95÷$F$95)^$B$105)*($F$100)))))
285	=IF($B$175=1,0,IF($B$176=3,I209*$G$87*0.00112*0.29,IF($B$176=2,1-0.125*I248,IF($B$176=1,1-$G$94,1)))*0.00306888*(I209/$G$82)*$G$95*((I223^$B$105)*(($G$97*(($G$95÷$G$95)^$B$104))+(((($G$95÷$G$95)^$B$105)*($G$100)))))
286	=IF($B$175=1,0,IF($B$176=3,I210*$H$87*0.00112*0.29,IF($B$176=2,1-0.125*I249,IF($B$176=1,1-$H$94,1)))*0.00306888*(I210/$H$82)*$H$95*((I224^$B$105)*(($H$97*(($H$95÷$H$95)^$B$104))+(((($H$95÷$H$95)^$B$105)*($H$100)))))
287	=IF($B$175=1,0,IF($B$176=3,I211*$I$87*0.00112*0.29,IF($B$176=2,1-0.125*I250,IF($B$176=1,1-$I$94,1)))*0.00306888*(I211/$I$82)*$I$95*((I225^$B$105)*(($I$97*(($I$95÷$I$95)^$B$104))+(((($I$95÷$I$95)^$B$105)*($I$100)))))
288	=IF($B$175=1,0,IF($B$176=3,I212*$J$87*0.00112*0.29,IF($B$176=2,1-0.125*I260,IF($B$176=1,1-$J$94,1)))*0.29*I212*$B$111))
289	=I365*IF($B$180=1,0.2651*$B$133*($B$137^$B$136),(IF($B$178=1,$B$131,$B$123)*($B$64)-($B$125*$B$116)))/IF($B$179=1,$B$129,$B$121))
290	=(1+$B$162)*I290/4
291	=(1+$B$163)*I291/4
292	=I292*(($B$51*$B$54)-($B$14*$B$18))/($B$51-$B$14]
293	=I293*(($B$51*$B$54)-($B$14*$B$18))/($B$51-$B$14]
294	=I261*(($B$144*$B$54)-($B$15*$B$16)]
295	=($B$47*(($B$48*$B$54)-($B$15*$B$16)))+(((4*M304)^$B$49)*$B$50*$B$42*(($B$51*$B$54)-($B$14*$B$18)))/43560)
296	0
297	0
298	0
299	0
300	=$B$32/4
301	=$B$26/4
302	=$B$41*-L265*IF(L263<0.035,275,764.806*L263+248.815]
303	=IF(AND(L265>0,M302<-(M273-M296-M292+M320)),-(M273-M296-M292+M320),M302)
304	=IF(M273+M303-M296-M292+M320<0,0,M273+M303-M296-M292+M320)
305	
306	-------
307	=MAX(0,0.25*(($B$36*(I268-I267))+G307+G307+G307))
308	=(M260*$D$88*(1-$B$89)*($D$75+$B$90))-($B$170*$B$76*(($B$51*$B$54)-($B$14*$B$18)))
309	=(M261*$C$88*(1-$C$89)*$C$90)
310	=(M262*$D$88*(1-$D$89)*$D$90)
311	=(M263*$E$88*(1-$E$89)*$E$90)
312	=(M264*$F$88*(1-$F$89)*$F$90)
313	=(M265*$G$88*(1-$G$89)*$G$90)
314	=(M266*$H$88*(1-$H$89)*$H$90)
315	=(M267*$I$88*(1-$I$89)*$I$90)
316	=(M268*$J$88*(1-$J$89)*$J$90)
317	=(1-IF($B$179=1,$B$129,$B$121))*M289
318	=(M290*$B$166]
319	=(M291*$B$167]
320	=M296+M297
321	0
322	
323	-------
324	=M304+(($C$18*$C$20*(($C$12^$C$21))*(($C$13^$C$22))
325	=M300
326	=IF($B$175=1,M301+($C$26/4),+M301+(($C$26/4)*(1+$B$69)))
327	=$B$82/4
328	=$B$63/4
329	
330	-------
331	=IF($B$175=1,0,IF($B$176=3,I213*$K$87*0.00112*0.29,IF($B$176=2,1-0.125*I251,IF($B$176=1,1-$K$94,1)))*0.00306888*(I213/$K$82)*$K$95*((I227^$B$105)*(($K$97*(($K$95÷$K$95)^$B$104))+(((($K$95÷$K$95)^$B$105)*($K$100)))))
332	=IF($B$175=1,0,IF($B$176=3,I214*$L$87*0.00112*0.29,IF($B$176=2,1-0.125*I252,IF($B$176=1,1-$L$94,1)))*0.00306888*(I214/$L$82)*$L$95*((I228^$B$105)*(($L$97*(($L$95÷$L$95)^$B$104))+(((($L$95÷$L$95)^$B$105)*($L$100)))))
333	=IF($B$175=1,0,IF($B$176=3,I215*$M$87*0.00112*0.29,IF($B$176=2,1-0.125*I253,IF($B$176=1,1-$M$94,1)))*0.00306888*(I215/$M$82)*$M$95*((I229^$B$105)*(($M$97*(($M$95÷$M$95)^$B$104))+(((($M$95÷$M$95)^$B$105)*($M$100)))))
334	=IF($B$175=1,0,IF($B$176=3,I216*$N$87*0.00112*0.29,IF($B$176=2,1-0.125*I254,IF($B$176=1,1-$N$94,1)))*0.00306888*(I216/$N$82)*$N$95*((I230^$B$105)*(($N$97*(($N$95÷$N$95)^$B$104))+(((($N$95÷$N$95)^$B$105)*($N$100)))))
335	=IF($B$175=1,0,IF($B$176=3,I217*$O$87*0.00112*0.29,IF($B$176=2,1-0.125*I254,IF($B$176=1,1-$O$94,1)))*0.29*I217*$B$111))
336	=MIN(I366*(IF($B$179=1,$B$132,$B$124)*$C$54)-($B$126*$C$18)),IF($B$179=1,$B$130,$B$122),IF(M304<(I336*0.0056),IF(M304<=0,0,M304),I336*0.0056))
337	=MIN(I366*(IF($B$179=1,$B$132,$B$124)*$C$54)-($B$126*$C$18)),IF($B$179=1,$B$130,$B$122)-M336,IF(M304<(I336*0.0056+I337*0.0136),IF(M304<=I336*0.0056,0,M304-(I336*0.0056)),I337*0.0136))
338	=(I366*IF($B$180=1,0.307*$B$134*($B$137^$B$136),(IF($B$179=1,$B$132,$B$124)*$C$54)-($B$126*$C$18)))/IF($B$179=1,$B$130,$B$122))-M336-M337
339	=(1+$B$162)*I339/4
340	=(1+$B$163)*I340/4
341	=I341*(($C$51*$C$54)-($C$14*$C$18))/($C$51-$C$14]
342	=I342*(($C$51*$C$54)-($C$14*$C$18))/($C$51-$C$14]
343	=I262*(($B$146*$C$54)-($C$15*$C$16)]
344	=IF(M353<=0,($C$47*(($C$48*$C$54)-($C$15*$C$16))),($C$47*(($C$48*$C$54)-($C$15*$C$16)))+(((4*M353)^$C$49)*$C$50*$C$42*(($C$51*$C$54)-($C$14*$C$18)))/43560))
345	0
346	0
347	0
348	0
349	=I349/4
350	=I350/4
351	=$C$41*-L266*IF(L264<0.0453,225,705.81*L264+193.03)
352	=IF(AND(L266>0,M351<-(M324-M344+M365-M336-M337-M341)),-(M324-M344+M365-M336-M337-M341),M351)
353	=IF(M324+M352-M344+M365-M336-M337-M341<0,0,M324+M352-M344+M365-M336-M337-M341)

USF2000105557

	M
354	
355	-------
356	= MAX(0,0.25*((€C€36*(I270-I269)) + G356 + G356 + G356))
357	= (M331*€K€88*(1-€K€89)*€K€90)
358	= (M332*€L€88*(1-€L€89)*€L€90)
359	= (M333*€M€88*(1-€M€89)*€M€90)
360	= (M334*€N€88*(1-€N€89)*€N€90)
361	= (M335*€O€88*(1-€O€89)*€O€90)
362	= (1-IF(€B€179 = 1,€B€130,€B€122))*(M336 + M337 + M338)
363	= M339*€B€160
364	= M340*€B€161
365	= M345 + M346
366	
367	-------
368	= M257-L257
369	= M258-L258
370	= M259-L259
371	= M260-L260
372	= M368/(€B€31*€B€33)
373	= M369/(€B€24*€B€26)
374	= M370/(€C€31*€C€33)
375	= M371/(€C€24*€C€26)
376	
377	
378	
379	
380	
381	
382	
383	-------
384	
385	
386	

USF200010558

USF200010559

USF200010560

	N
364	
365	-------
366	=MAX(0,0.25*((¢C¢36*(I270-I269)) + H356 + H356 + H356))
367	=(N331*¢K¢88*(1-¢K¢89)*¢K¢90)
368	=(N332*¢L¢88*(1-¢L¢89)*¢L¢90)
369	=(N333*¢M¢88*(1-¢M¢89)*¢M¢90)
370	=(N334*¢N¢88*(1-¢N¢89)*¢N¢90)
371	=(N335*¢O¢88*(1-¢O¢89)*¢O¢90)
372	=(1-IF(¢B¢179=1,¢B¢130,¢B¢122))*(N336 + N337 + N338)
373	=N339*¢B¢160
374	=N340*¢B¢161
375	=N345 + N346
376	
377	-------
378	=N257-M257
379	=N258-M258
380	=N259-M259
381	=N260-M260
382	=N368/(¢B¢31*¢B¢33)
383	=N369/(¢B¢24*¢B¢26)
384	=N370/(¢C¢31*¢C¢33)
385	=N371/(¢C¢24*¢C¢26)
386	

USF200010561

	0
200	
201	= N201
202	end-of-yr
203	-------
204	= IF(O201 = $B$108,I204*(1 + $B$83) + $F$109,IF(O201 > $B$108,(I204-$F$109)*(1 + $B$83) + $F$109,I204*(1 + $B$83)))
205	= I205*(1 + $C$83)
206	= IF(O201 = $B$108, + I206 + $F$107,I206)
207	= I207*(1 + $E$83)
208	= I208*(1 + $F$83)
209	= I209*(1 + $G$83)
210	= I210*(1 + $H$83)
211	= I211*(1 + $I$83)
212	= I212*(1 + $J$83)
213	= I213*(1 + $K$83)
214	= I214*(1 + $L$83)
215	= I215*(1 + $M$83)
216	= I216*(1 + $N$83)
217	= I217*(1 + $O$83)
218	= IF($B$175 = 1,0, + $C218 + O232)
219	= IF($B$175 = 1,0, + $C219 + O233)
220	= NA()
221	= IF($B$175 = 1,0, + $C221 + O234)
222	= IF($B$175 = 1,0, + $C222 + O236)
223	= IF($B$175 = 1,0, + $C223 + O236)
224	= IF($B$175 = 1,0, + $C224 + O237)
225	= IF($B$175 = 1,0, + $C225 + O238)
226	= IF($B$175 = 1,0, + $C226 + O238)
227	= IF($B$175 = 1,0, + $C227 + O239)
228	= IF($B$175 = 1,0, + $C228 + O240)
229	= IF($B$175 = 1,0, + $C229 + O241)
230	= IF($B$175 = 1,0, + $C230 + O242)
231	= IF($B$175 = 1,0, + $C231 + O242)
232	= ($B$196 + $B$196)*(O280/I204/0.00306888)*($B$82/$B$85)*((((($B$104/(1-$B$104))*(1-(1-M232)^($B$104/(1-$B$104))))-M232)*4*K280/O280) + ((((($B$105/(1-$B$105))*(1-(1-M232)^($B$105/(1-$B$105))))-M232)*(O280-(4*K280))/O280))
233	= ($C$95 + $C$96)*(O281/I205/0.00306888)*($C$82/$C$85)*((((($B$104/(1-$B$104))*(1-(1-M233)^($B$104/(1-$B$104))))-M233)*4*K281/O281) + ((((($B$105/(1-$B$105))*(1-(1-M233)^($B$105/(1-$B$105))))-M233)*(O281-(4*K281))/O281))
234	= ($E$95 + $E$96)*(O283/I207/0.00306888)*($E$82/$E$85)*((((($B$104/(1-$B$104))*(1-(1-M234)^($B$104/(1-$B$104))))-M234)*4*K283/O283) + ((((($B$105/(1-$B$105))*(1-(1-M234)^($B$105/(1-$B$105))))-M234)*(O283-(4*K283))/O283))
235	= ($F$95 + $F$96)*(O284/I208/0.00306888)*($F$82/$F$85)*((((($B$104/(1-$B$104))*(1-(1-M235)^($B$104/(1-$B$104))))-M235)*4*K284/O284) + ((((($B$105/(1-$B$105))*(1-(1-M235)^($B$105/(1-$B$105))))-M235)*(O284-(4*K284))/O284))
236	= ($G$95 + $G$96)*(O285/I209/0.00306888)*($G$82/$G$85)*((((($B$104/(1-$B$104))*(1-(1-M236)^($B$104/(1-$B$104))))-M236)*4*K285/O285) + ((((($B$105/(1-$B$105))*(1-(1-M236)^($B$105/(1-$B$105))))-M236)*(O285-(4*K285))/O285))
237	= ($H$95 + $H$96)*(O286/I210/0.00306888)*($H$82/$H$85)*((((($B$104/(1-$B$104))*(1-(1-M237)^($B$104/(1-$B$104))))-M237)*4*K286/O286) + ((((($B$105/(1-$B$105))*(1-(1-M237)^($B$105/(1-$B$105))))-M237)*(O286-(4*K286))/O286))
238	= ($I$95 + $I$96)*(O287/I211/0.00306888)*($I$82/$I$85)*((((($B$104/(1-$B$104))*(1-(1-M238)^($B$104/(1-$B$104))))-M238)*4*K287/O287) + ((((($B$105/(1-$B$105))*(1-(1-M238)^($B$105/(1-$B$105))))-M238)*(O287-(4*K287))/O287))
239	= ($K$95 + $K$96)*(O331/I213/0.00306888)*($K$82/$K$85)*((((($B$104/(1-$B$104))*(1-(1-M239)^($B$104/(1-$B$104))))-M239)*4*K331/O331) + ((((($B$105/(1-$B$105))*(1-(1-M239)^($B$105/(1-$B$105))))-M239)*(O331-(4*K331))/O331))
240	= ($L$95 + $L$96)*(O332/I214/0.00306888)*($L$82/$L$85)*((((($B$104/(1-$B$104))*(1-(1-M240)^($B$104/(1-$B$104))))-M240)*4*K332/O332) + ((((($B$105/(1-$B$105))*(1-(1-M240)^($B$105/(1-$B$105))))-M240)*(O332-(4*K332))/O332))
241	= ($M$95 + $M$96)*(O333/I215/0.00306888)*($M$82/$M$85)*((((($B$104/(1-$B$104))*(1-(1-M241)^($B$104/(1-$B$104))))-M241)*4*K333/O333) + ((((($B$105/(1-$B$105))*(1-(1-M241)^($B$105/(1-$B$105))))-M241)*(O333-(4*K333))/O333))
242	= ($N$95 + $N$96)*(O334/I216/0.00306888)*($N$82/$N$85)*((((($B$104/(1-$B$104))*(1-(1-M242)^($B$104/(1-$B$104))))-M242)*4*K334/O334) + ((((($B$105/(1-$B$105))*(1-(1-M242)^($B$105/(1-$B$105))))-M242)*(O334-(4*K334))/O334))
243	= IF($B$175 = 1,0,IF(O204-I204 < 0,((O204*I243) + ((1-I243)*I204*($B$93)))/O204,(((I243*I204) + (O204-I204) + ((1-I243)*I204*$B$93))/O204))
244	= IF($B$175 = 1,0,IF(O205-I205 < 0,((O205*I244) + ((1-I244)*I205*$C$93))/O205,(((I244*I205) + (O205-I205) + ((1-I244)*I205*$C$93))/O205))
245	= IF($B$175 = 1,0,IF(O206-I206 < 0,((O206*I245) + ((1-I245)*I206*$D$93))/O206,(((I245*I206) + (O206-I206) + ((1-I245)*I206*$D$93))/O206))
246	= IF($B$175 = 1,0,IF(O207-I207 < 0,((O207*I246) + ((1-I246)*I207*$E$93))/O207,(((I246*I207) + (O207-I207) + ((1-I246)*I207*$E$93))/O207))
247	= IF($B$175 = 1,0,IF(O208-I208 < 0,((O208*I247) + ((1-I247)*I208*$F$93))/O208,(((I247*I208) + (O208-I208) + ((1-I247)*I208*$F$93))/O208))
248	= IF($B$175 = 1,0,IF(O209-I209 < 0,((O209*I248) + ((1-I248)*I209*$G$93))/O209,(((I248*I209) + (O209-I209) + ((1-I248)*I209*$G$93))/O209))
249	= IF($B$175 = 1,0,IF(O210-I210 < 0,((O210*I249) + ((1-I249)*I210*$H$93))/O210,(((I249*I210) + (O210-I210) + ((1-I249)*I210*$H$93))/O210))
250	= IF($B$175 = 1,0,IF(O212 + O211-I212-I211 < 0,(((O212 + O211)*I250) + ((1-I250)*(((I212*$J$93) + (I211*$I$93)))))/O212 + O211,(((I212 + I211)*I250) + (O212-I212 + O211-I211) + (((1-I250)*(((I212*$J$93) + (I211*$I$93)))))/O212 + O211))
251	= IF($B$175 = 1,0,IF(O213-I213 < 0,((O213*I251) + ((1-I251)*I213*$K$93))/O213,(((I251*I213) + (O213-I213) + ((1-I251)*I213*$K$93))/O213))
252	= IF($B$175 = 1,0,IF(O214-I214 < 0,((O214*I252) + ((1-I252)*I214*$L$93))/O214,(((I252*I214) + (O214-I214) + ((1-I252)*I214*$L$93))/O214))
253	= IF($B$175 = 1,0,IF(O216-I215 < 0,((O216*I253) + ((1-I253)*I215*$M$93))/O215,(((I253*I216) + (O215-I215) + ((1-I253)*I215*$M$93))/O215))
254	= IF($B$175 = 1,0,IF(O218 + O217-I218-I217 < 0,(((O216 + O217)*I254) + ((1-I254)*(((I216*$N$93) + (I217*$O$93)))))/O216 + O217,((((I216 + I217)*I254) + (O216-I216 + O217-I217) + (((1-I254)*(((I216*$N$93) + (I217*$O$93)))))/O216 + O217)))
255	
256	-------
257	= N257
258	= N258
259	= N259
260	= N260
261	= (((10^($B$146*SQRT(((I304 + $B$5)*0.00069065))) + $B$147*((O304/2 + $B$5/2)-(I304/2 + $B$5/2)))/(I304/2 + $B$5/2)) + 1)*I261 + I378
262	= (((10^($B$146*SQRT(((I304 + I363)*0.00069065))) + $B$147*((O304/2 + O363/2)-(I304/2 + I363/2)))/(I304/2 + I363/2)) + 1)*I262 + I379
263	= AVERAGE(K263:N263)
264	= AVERAGE(K264:N264)
265	= AVERAGE(K265:N265)
266	= AVERAGE(K266:N266)
267	= I267 + O372
268	= I268 + O380
269	= I269 + O374
270	= I270 + O381
271	
272	-------
273	= SUM(K273:N273)
274	= SUM(K274:N274)
275	= SUM(K275:N275)
276	= SUM(K276:N276)

USF2000105562

	O
277	=SUM(C277:N277)
278	
279	------
280	=SUM(C260:N260)
281	=SUM(C261:N261)
282	=SUM(C262:N262)
283	=SUM(C263:N263)
284	=SUM(C264:N264)
285	=SUM(C265:N265)
286	=SUM(C266:N266)
287	=SUM(C267:N267)
288	=SUM(C268:N268)
289	=SUM(C269:N269)
290	=SUM(C290:N290)
291	=SUM(C291:N291)
292	=SUM(C292:N292)
293	=SUM(C293:N293)
294	=SUM(C294:N294)
295	=SUM(C295:N295)
296	=SUM(C296:N296)
297	=SUM(C297:N297)
298	=SUM(C298:N298)
299	=SUM(C299:N299)
300	=SUM(C300:N300)
301	=SUM(C301:N301)
302	=SUM(C302:N302)
303	=SUM(C303:N303)
304	=SUM(C304:N304)
305	
306	------
307	=SUM(C307:N307)
308	=SUM(C308:N308)
309	=SUM(C309:N309)
310	=SUM(C310:N310)
311	=SUM(C311:N311)
312	=SUM(C312:N312)
313	=SUM(C313:N313)
314	=SUM(C314:N314)
315	=SUM(C315:N315)
316	=SUM(C316:N316)
317	=SUM(C317:N317)
318	=SUM(C318:N318)
319	=SUM(C319:N319)
320	=SUM(C320:N320)
321	=SUM(C321:N321)
322	
323	------
324	=SUM(C324:N324)
325	=SUM(C325:N325)
326	=SUM(C326:N326)
327	=SUM(C327:N327)
328	=SUM(C328:N328)
329	
330	------
331	=SUM(C331:N331)
332	=SUM(C332:N332)
333	=SUM(C333:N333)
334	=SUM(C334:N334)
335	=SUM(C335:N335)
336	=SUM(C336:N336)
337	=SUM(C337:N337)
338	=SUM(C338:N338)
339	=SUM(C339:N339)
340	=SUM(C340:N340)
341	=SUM(C341:N341)
342	=SUM(C342:N342)
343	=SUM(C343:N343)
344	=SUM(C344:N344)
345	=SUM(C345:N345)
346	=SUM(C346:N346)
347	=SUM(C347:N347)
348	=SUM(C348:N348)
349	=SUM(C349:N349)
350	=SUM(C350:N350)
351	=SUM(C351:N351)
352	=SUM(C352:N352)
353	=SUM(C353:N353)

USF200010563

	O
354	
355	-------
356	= SUM(K356:N356)
357	= SUM(K357:N357)
358	= SUM(K358:N358)
359	= SUM(K359:N359)
360	= SUM(K360:N360)
361	= SUM(K361:N361)
362	= SUM(K362:N362)
363	= SUM(K363:N363)
364	= SUM(K364:N364)
365	= SUM(K365:N365)
366	
367	-------
368	= SUM(K368:N368)
369	= SUM(K369:N369)
370	= SUM(K370:N370)
371	= SUM(K371:N371)
372	= SUM(K372:N372)
373	= SUM(K373:N373)
374	= SUM(K374:N374)
375	= SUM(K375:N375)
376	= O304-I304
377	= O353-I353
378	= O261-I261
379	= O262-I262
380	= I380 + (O373/100)
381	= I381 + (O373/100)
382	
383	-------
384	= SUM(O204:O217)-O209
385	= MAX(0,IF(¢B¢175 = 1,0,(1 + ¢B¢127)*I385-IF(O378 < = 0,0,O378)))
386	= MAX(0,IF(¢B¢175 = 1,0,(1 + ¢B¢128)*I386-IF(O379 < = 0,0,O379)))

USF200010564

Appendix D

Projections of Conditions at the End of Twenty Years Under All Combinations of Simulated Scenarios and Policy Options With 1990 Conditions Shown for Comparison

USF200010565

	A	B	C	D	E	F	G	H	I	J	K
1	PROJECTIONS OF WATER BALANCE AND SOCIOECONOMIC CONDITIONS AT THE END OF TWENTY YEARS (WITH 1990 CONDITIONS LISTED FOR COMPARISON)										
2		POLICY	(n/a)	Policy 1	Policy 1	Policy 1	Policy 1	Policy 1	Policy 2-1	Policy 2-2	Policy 2-3
3		SCENARIO	Year-1990	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E	Scenario A	Scenario A	Scenario A
4	I. SOCIOECONOMIC CONDITIONS										
5	Population of City of Sierra Vista	N.people	23773	54338	83221	83221	54338	54338	54338	54338	54338
6	Population of Sierra Vista-Southeast Suburban Area	N.people	1182	1362	2018	2018	1362	1362	1362	1362	1362
7	Population of Fort Huachuca	N.people	9210	9210	12960	12960	9210	9210	9210	9210	9210
8	Population of Huachuca City	N.people	1782	2053	3042	3042	2053	2053	2053	2053	2053
9	Population of City of Tombstone	N.people	1220	681	1024	1024	681	681	681	681	681
10	Population of City of Bisbee	N.people	6288	4860	7258	7258	4860	4860	4860	4860	4860
11	Population of Town of Naco	N.people	496	496	736	736	496	496	496	496	496
12	Population of Water Service Areas of Rural Sierra Vista Sub-basin	N.people	294	293	436	436	293	293	293	293	293
13	Population of Non-Service Areas of Rural Sierra Vista Sub-basin	N.people	10844	10815	16072	16072	10815	10815	10815	10815	10815
14	Population of City of Benson	N.people	3824	3186	4760	4760	3186	3186	3186	3186	3186
15	Population of Town of St. David	N.people	1468	1464	2176	2176	1464	1464	1464	1464	1464
16	Population of Town of Pomerene	N.people	676	674	1002	1002	674	674	674	674	674
17	Population of Water Service Areas of Rural Benson Sub-basin	N.people	1150	1147	1704	1704	1147	1147	1147	1147	1147
18	Population of Non-Water Service Areas of Rural Benson Sub-basin	N.people	1632	1628	2271	2271	1628	1628	1628	1628	1628
19	Median Household Income, City of Sierra Vista	dollars	16740.0	16740.0	16740.0	16740.0	16740.0	16740.0	16716.8	16716.8	16716.8
20	Median Household Income, Sierra Vista-Southeast Suburban Area	dollars	9769.0	9769.0	9769.0	9769.0	9769.0	9769.0	9952.7	9952.7	9952.7
21	Median Household Income, Fort Huachuca	dollars	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
22	Median Household Income, Huachuca City	dollars	13988.0	13988.0	13988.0	13988.0	13988.0	13988.0	13983.0	13983.0	13983.0
23	Median Household Income, City of Tombstone	dollars	9769.0	9769.0	9769.0	9769.0	9769.0	9769.0	9771.0	9771.0	9771.0
24	Median Household Income, City of Bisbee	dollars	10882.0	10882.0	10882.0	10882.0	10882.0	10882.0	10820.8	10820.8	10820.8
25	Median Household Income, Town of Naco	dollars	10882.0	10882.0	10882.0	10882.0	10882.0	10882.0	10883.9	10883.9	10883.9
26	Median Household Income, Rural Water Service Areas, S.V. Sub.	dollars	9769.0	9769.0	9769.0	9769.0	9769.0	9769.0	9799.6	9799.6	9799.6
27	Median Household Income, Rural Non-Service Areas, S.V. Sub.	dollars	9769.0	9769.0	9769.0	9769.0	9769.0	9769.0	9799.6	9799.6	9799.6
28	Median Household Income, City of Benson	dollars	12831.0	12831.0	12831.0	12831.0	12831.0	12831.0	12828.3	12828.3	12828.3
29	Median Household Income, Town of St. David	dollars	12831.0	12831.0	12831.0	12831.0	12831.0	12831.0	12957.4	12957.4	12957.4
30	Median Household Income, Town of Pomerene	dollars	12831.0	12831.0	12831.0	12831.0	12831.0	12831.0	12786.7	12786.7	12786.7
31	Median Household Income, Rural Water Service Areas, Benson Sub.	dollars	9769.0	9769.0	9769.0	9769.0	9769.0	9769.0	9907.8	9907.8	9907.8
32	Median Household Income, Rural Non-Service Areas, Benson Sub-basin	dollars	9769.0	9769.0	9769.0	9769.0	9769.0	9769.0	9907.8	9907.8	9907.8
33	Fraction of Households With Low-Flow Plumbing, City of Sierra Vista	fraction	0.0500	0.8610	0.9027	0.9027	0.8610	0.8610	0.8610	0.8610	0.8610
34	Fraction of Households with Low-Flow Plumbing, S.V.-SE Suburban Area	fraction	0.0500	0.7044	0.8005	0.8005	0.7044	0.7044	0.7044	0.7044	0.7044
35	Fraction of Households with Low-Flow Plumbing, Fort Huachuca	fraction	0.0500	0.6594	0.7580	0.7580	0.6594	0.6594	0.6594	0.6594	0.6594
36	Fraction of Households with Low-Flow Plumbing, Huachuca City	fraction	0.0500	0.7044	0.8005	0.8005	0.7044	0.7044	0.7044	0.7044	0.7044
37	Fraction of Households with Low-Flow Plumbing, City of Tombstone	fraction	0.0500	0.6699	0.6626	0.6626	0.6699	0.6699	0.6699	0.6699	0.6699
38	Fraction of Households with Low-Flow Plumbing, City of Bisbee	fraction	0.0500	0.6641	0.7050	0.7050	0.6641	0.6641	0.6641	0.6641	0.6641
39	Fraction of Households with Low-Flow Plumbing, Town of Naco	fraction	0.0500	0.6595	0.7702	0.7702	0.6595	0.6595	0.6595	0.6595	0.6595
40	Fraction of Households with Low-Flow Plumbing, Rural S.V. Sub-basin	fraction	0.0500	0.6595	0.7702	0.7702	0.6595	0.6595	0.6595	0.6595	0.6595
41	Fraction of Households with Low-Flow Plumbing, City of Benson	fraction	0.0500	0.6627	0.7258	0.7258	0.6627	0.6627	0.6627	0.6627	0.6627
42	Fraction of Households with Low-Flow Plumbing, Town of St. David	fraction	0.0500	0.6595	0.7702	0.7702	0.6595	0.6595	0.6595	0.6595	0.6595
43	Fraction of Households with Low-Flow Plumbing, Town of Pomerene	fraction	0.0500	0.6595	0.7702	0.7702	0.6595	0.6595	0.6595	0.6595	0.6595
44	Fraction of Households with Low-Flow Plumbing, Rural Benson Sub-basin	fraction	0.0500	0.6595	0.7702	0.7702	0.6595	0.6595	0.6595	0.6595	0.6595
45											
46	II. GROSS HYDROLOGICAL AND ECOLOGICAL STATUS INDICATORS										
47	Storage in Floodplain Aquifer, Sierra Vista Sub-basin	acre-feet	159609	157867	153619	157637	156690	156091	158005	158843	159686
48	Storage in Regional Aquifer, Sierra Vista Sub-basin	acre-feet	31737573	31374439	31175662	31297571	31308044	31334186	31405883	31455484	31503681
49	Storage in Floodplain Aquifer, Benson Sub-basin	acre-feet	123681	121111	110280	120832	117054	116044	121294	123183	125286
50	Storage in Regional Aquifer, Benson Sub-basin	acre-feet	27064109	27030182	26536430	27024736	26717212	26888712	27028222	27162923	27273900
51	Potential Area of Riparian Vegetation in Sierra Vista Sub-basin	acres	5894.0	5816.8	5468.3	5810.6	5642.6	5698.0	5822.6	5908.3	5990.0
52	Potential Area of Riparian Vegetation in Benson Sub-basin	acres	6045.0	6015.1	5006.3	6004.1	5441.5	5718.2	6025.4	6213.6	6391.4
53	Average River Stage in Sierra Vista Sub-basin	feet	0.77	0.75	0.66	0.75	0.68	0.73	0.76	0.76	0.77
54	Average River Stage in Benson Sub-basin	feet	0.86	0.84	0.49	0.83	0.66	0.79	0.84	0.87	0.90

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	A	B	C	D	E	F	G	H	I	J	K
55	Average River Baseflow Head Difference, Sierra Vista Sub-basin	feet	-0.55	0.09	1.32	0.18	0.32	0.79	0.04	-0.29	-0.62
56	Average River Baseflow Head Difference, Benson Sub-basin	feet	7.09	8.44	10.16	8.54	10.78	11.04	8.37	7.86	7.31
57	Period-End Elev. of Floodplain Water Table Above Riverbed, S.V. Sub.	feet	1.44	0.78	-0.81	0.69	0.35	0.12	0.84	1.16	1.51
58	Period-End Elev. of Regional Water Table Above Riverbed, S.V. Sub.	feet	3.50	2.41	1.96	2.27	2.21	2.34	2.50	2.65	2.80
59	Period-End Elev. of Floodplain Water Table Above Riverbed, Benson Sub.	feet	-7.72	-8.97	-14.26	-9.09	-10.84	-11.89	-8.88	-7.93	-6.88
60	Period-End Elev. of Regional Water Table Above Riverbed, Benson Sub.	feet	-6.41	-7.50	-7.96	-7.64	-7.71	-7.58	-7.41	-7.26	-7.11
61											
62	III. INFLOWS TO SIERRA VISTA SUB-BASIN										
63	Natural Inputs to Surface Waters in Sierra Vista Sub-basin	acre-feet	40733.7	40733.7	21855.1	40733.7	21855.1	40733.7	40733.7	40733.7	40733.7
64	Natural Inputs to Floodplain Aquifer in Sierra Vista Sub-basin	acre-feet	900.0	900.0	900.0	900.0	900.0	900.0	900.0	900.0	900.0
65	Natural Inputs to Regional Aquifer in Sierra Vista Sub-basin	acre-feet	17540.0	17540.0	17540.0	17540.0	17540.0	17540.0	17540.0	17540.0	17540.0
66	Imported Water Stored in Floodplain Aquifer in S.V. Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
67	Imported Water Stored in Regional Aquifer in S.V. Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
68											
69	IV. SIERRA VISTA SUB-BASIN LOSSES TO STORAGE										
70	City of Sierra Vista Use of Regional Aquifer	acre-feet	4186.9	10563.3	15820.2	15820.2	10563.3	10563.3	8807.4	8807.4	8807.4
71	Sierra Vista-Southeast Suburban Area Use of Regional Aquifer	acre-feet	198.6	144.2	209.5	209.5	144.2	144.2	227.1	227.1	227.1
72	Fort Huachuca Use of Regional Aquifer	acre-feet	2712.0	2712.0	3816.2	3816.2	2712.0	2712.0	2712.0	2712.0	2712.0
73	Huachuca City Use of Regional Aquifer	acre-feet	299.4	364.7	515.4	515.4	364.7	364.7	342.4	342.4	342.4
74	City of Tombstone Use of Regional Aquifer	acre-feet	205.0	115.1	169.6	169.6	115.1	115.1	117.9	117.9	117.9
75	City of Bisbee Use of Regional Aquifer	acre-feet	1056.4	1196.9	1752.0	1752.0	1196.9	1196.9	827.0	827.0	827.0
76	Town of Naco Use of Regional Aquifer	acre-feet	83.3	81.9	119.3	119.3	81.9	81.9	83.1	83.1	83.1
77	Rural S.V. Sub-basin Water-Service Areas, Use of Regional Aquifer	acre-feet	49.4	29.0	42.3	42.3	29.0	29.0	49.3	49.3	49.3
78	Rural S.V. Sub-basin Non-Service Areas, Use of Regional Aquifer	acre-feet	1846.1	1838.8	2679.0	2679.0	1838.8	1838.8	1841.4	1841.4	1841.4
79	Irrigation Use of Groundwater in Sierra Vista Sub-basin	acre-feet	7915.6	12233.2	30557.6	12233.2	14837.8	25193.4	7915.6	3866.3	0.0
80	Mining Industrial Use of Regional Aquifer in Sierra Vista Sub-basin	acre-feet	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
81	Other Industrial Use of Regional Aquifer in Sierra Vista Sub-basin	acre-feet	204.7	204.7	204.7	204.7	204.7	204.7	204.7	204.7	204.7
82	Evaporation from Runoff-Supplied Stockponds & Reservoirs, S.V. Sub.	acre-feet	1649.2	1649.8	1941.1	1649.8	1941.1	1649.8	1649.8	1649.8	1649.8
83	Evaporation from GW-Supplied Stockponds & Reservoirs, S.V. Sub	acre-feet	65.2	65.3	76.8	65.3	76.8	65.3	65.3	65.3	65.3
84	Phreatophyte Consumption from Floodplain Aquifer in S.V. Sub-basin	acre-feet	14440.6	14278.1	15724.8	14266.0	16185.3	14016.6	14290.2	14487.0	14675.1
85	Channel Evaporation from Riverbed in Sierra Vista Sub-basin	acre-feet	1307.2	1282.6	1344.2	1279.7	1396.8	1252.2	1284.7	1296.9	1307.6
86	RNCA Withdrawals from Floodplain Aquifer in Sierra Vista Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
87	RNCA Withdrawals from Regional Aquifer in Sierra Vista Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
88	Export from Floodplain Aquifer in Sierra Vista Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
89	Export from Regional Aquifer in Sierra Vista Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	Floodplain Aquifer Underflow to Benson Sub-basin	acre-feet	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
91	Regional Aquifer Underflow to Benson Sub-basin	acre-feet	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
92	Discharge from Floodplain Aquifer to River in Sierra Vista Sub-basin	acre-feet	1422.6	-848.0	-3199.9	-1228.8	-1453.1	-3411.5	-784.2	441.3	1632.9
93	River Discharge Volume from Sierra Vista Sub-basin	acre-feet	39199.9	36853.2	15369.9	36677.3	17064.1	34420.1	37034.9	38228.1	39409.3
94											
95	V. SIERRA VISTA SUB-BASIN RECHARGE AND RETURNS TO STORAGE										
96	Recharge from Regional to Floodplain Aquifer in S.V. Sub-basin	acre-feet	21931.4	19222.9	28213.7	18905.4	22021.5	23512.3	18433.2	17417.1	16508.2
97	Recharge to Regional Aquifer from City of Sierra Vista	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
98	Recharge to Regional Aquifer from Sierra Vista Southeast Suburbs	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
99	Recharge to Regional Aquifer from Fort Huachuca	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	Recharge to Regional Aquifer from Huachuca City	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
101	Recharge to Regional Aquifer from City of Tombstone	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
102	Recharge to Regional Aquifer from City of Bisbee	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
103	Recharge to Regional Aquifer from Town of Naco	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
104	Recharge to Regional Aquifer from Rural Water-Service Areas	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
105	Recharge to Regional Aquifer from Rural Non-Service Areas	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
106	Irrigation Return to Floodplain Aquifer in Sierra Vista Sub-basin	acre-feet	1187.3	5604.9	13750.9	5604.9	6677.0	11337.0	1187.3	579.8	0.0
107	Mining Industrial Return to Regional Aquifer in S.V. Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
108	Other Industrial Return to Regional Aquifer in S.V. Sub-basin	acre-feet	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9

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109	RNCA Diversion of Groundwater into River in Sierra Vista Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
110	Recharge to Floodplain Aq. from On-River Impoundment in Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
111											
112	VI. INFLOWS TO BENSON SUB-BASIN										
113	Natural Inputs to Surface Waters in Benson Sub-basin	acre-feet	50896.2	48649.5	18692.5	48373.6	20386.6	46216.4	48831.1	50024.4	51205.5
114	Natural Inputs to Floodplain Aquifer in Benson Sub-basin	acre-feet	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
115	Natural Inputs to Regional Aquifer in Benson Sub-basin	acre-feet	12030.0	12030.0	12030.0	12030.0	12030.0	12030.0	12030.0	12030.0	12030.0
116	Imported Water Stored in Floodplain Aquifer in Benson Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
117	Imported Water Stored in Regional Aquifer in Benson Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
118											
119	VII. BENSON SUB-BASIN LOSSES TO STORAGE										
120	City of Benson Use of Regional Aquifer	acre-feet	642.4	553.2	808.7	808.7	553.2	553.2	540.0	540.0	540.0
121	Town of St. David Use of Regional Aquifer	acre-feet	246.6	146.0	211.3	211.3	146.0	146.0	246.0	246.0	246.0
122	Town of Pomerene Use of Regional Aquifer	acre-feet	113.6	176.4	257.0	257.0	176.4	176.4	113.3	113.3	113.3
123	Rural Benson Sub-basin Water-Service Areas, Use of Regional Aquifer	acre-feet	193.2	123.5	179.9	179.9	123.5	123.5	192.7	192.7	192.7
124	Rural Benson Sub-basin Non-Service Areas, Use of Regional Aquifer	acre-feet	260.8	259.8	378.5	378.5	259.8	259.8	260.1	260.1	260.1
125	St. David Irrigation District Diversions of Surface Water	acre-feet	4425.6	4425.6	25.9	4425.6	640.1	3680.5	4425.6	2843.8	0.0
126	Pomerene Water Users Association Diversions of Surface Water	acre-feet	1663.5	1663.5	2.3	1663.5	2.3	308.4	1663.5	0.0	0.0
127	Total Irrigation Use of Groundwater in Benson Sub-basin	acre-feet	12956.6	26034.1	79912.4	26036.2	38174.4	62290.8	12843.0	5975.2	0.0
128	Mining Industrial Use of Regional Aquifer in Benson Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
129	Other Industrial Use of Regional Aquifer in Benson Sub-basin	acre-feet	542.0	542.0	542.0	542.0	542.0	542.0	542.0	542.0	542.0
130	Evap. from Runoff-Supplied Stockponds & Reservoirs, Benson Sub.	acre-feet	903.7	904.1	1071.1	904.1	1071.1	904.1	904.1	904.1	904.1
131	Evaporation from GW-Supplied Stockponds & Reservoirs, Benson Sub	acre-feet	269.1	269.2	319.0	269.2	319.0	269.2	269.2	269.2	269.2
132	Phreatophyte Consumption from Floodplain Aquifer in Benson Sub-basin	acre-feet	17712.1	17664.6	17067.0	17638.6	18417.2	16870.2	17690.2	18208.3	18704.6
133	Channel Evaporation from Riverbed in Benson Sub-basin	acre-feet	1395.3	1448.7	1336.7	1442.7	1380.6	1324.7	1464.1	1529.6	1579.6
134	RNCA Withdrawals from Floodplain Aquifer in Benson Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
135	RNCA Withdrawals from Regional Aquifer in Benson Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
136	Export from Floodplain Aquifer in Benson Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
137	Export from Regional Aquifer in Benson Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
138	Floodplain Aquifer Underflow to Lower San Pedro Basin	acre-feet	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
139	Regional Aquifer Underflow to Lower San Pedro Basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
140	Discharge from Floodplain Aquifer to River in Benson Sub-basin	acre-feet	-17208.2	-16386.0	-12251.1	-16316.2	-10183.6	-18012.7	-16429.7	-16898.8	-18372.9
141	River Discharge Volume from Benson Sub-basin	acre-feet	25498.8	24921.6	5719.2	24721.5	7108.9	21985.8	26054.1	27648.3	30349.0
142											
143	VIII. BENSON SUB-BASIN RECHARGE AND RETURNS TO STORAGE										
144	Recharge from Regional to Floodplain Aquifer in Benson Sub-basin	acre-feet	10498.6	11968.2	44004.3	11958.7	26628.6	27286.0	11961.6	6518.0	0.0
145	Recharge to Regional Aquifer from City of Benson	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
146	Recharge to Regional Aquifer from St. David	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
147	Recharge to Regional Aquifer from Town of Pomerene	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
148	Recharge to Regional Aquifer from Rural Water-Service Areas	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
149	Recharge to Regional Aquifer from Rural Non-Service Areas	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
150	Irrigation Return to Floodplain Aquifer in Benson Sub-basin	acre-feet	2841.9	16011.6	39970.3	16012.7	19408.4	33139.9	2824.8	1337.8	0.0
151	Mining Industrial Return to Regional Aquifer in Benson Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
152	Other Industrial Return to Regional Aquifer in Benson Sub-basin	acre-feet	162.6	162.6	162.6	162.6	162.6	162.6	162.6	162.6	162.6
153	RNCA Diversion of Groundwater into River in Benson Sub-basin	acre-feet	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
154											
155	IX. ANNUAL HYDROLOGICAL CHANGES IN 20TH YEAR										
156	Year-20 Change in Floodplain Aquifer Storage in Sierra Vista Sub-basin	acre-feet	0.0	-174.9	-458.0	-225.2	-211.5	-288.3	-161.1	-139.8	-82.0
157	Year-20 Change in Regional Aquifer Storage in Sierra Vista Sub-basin	acre-feet	-16669.4	-19360.1	-36449.7	-27129.1	-22189.9	-23648.5	-17541.9	-15524.8	-13615.8
158	Year-20 Change in Floodplain Aquifer Storage in Benson Sub-basin	acre-feet	0.0	-215.1	-880.8	-240.5	-249.6	-635.5	-197.2	-197.1	-271.6
159	Year-20 Change in Regional Aquifer Storage in Benson Sub-basin	acre-feet	-573.8	-1844.4	-34479.6	-2414.3	-16555.9	-17133.1	-1932.4	4509.4	10029.2
160	Year-20 Change in Floodplain Aquifer Depth to Water Table in S.V. Sub.	feet	0.00	-0.07	-0.17	-0.08	-0.08	-0.11	-0.06	-0.05	-0.03
161	Year-20 Change in Regional Aquifer Depth to Water Table in S.V. Sub.	feet	-0.42	-0.62	-0.98	-0.73	-0.60	-0.64	-0.47	-0.42	-0.37
162	Year-20 Change in Floodplain Aquifer Depth to Water Table in Benson Sub.	feet	0.00	-0.10	-0.33	-0.12	-0.12	-0.31	-0.10	-0.10	-0.13

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163	Year-20 Change in Regional Aquifer Depth to Water Table in Benson Sub.	feet	-0.02	-0.06	-1.08	-0.08	-0.52	-0.54	-0.08	0.14	0.31
164	Year-20 Change in Discharge of River from Sierra Vista Sub-basin	acre-feet	-0.1	-236.0	-253.1	-284.1	-223.7	-386.7	-216.8	-190.2	-139.9
165	Year-20 Change in Discharge of River from Benson Sub-basin	acre-feet	-0.2	-166.0	-74.6	-194.7	-53.4	-218.6	-162.9	-128.0	-180.5
166	Year-20 Change in Potential Area of Riparian Vegetation in S.V. Sub.	acres	0.0	-11.0	-37.1	-12.1	-24.0	-22.5	-10.1	-4.7	0.3
167	Year-20 Change in Potential Area of Riparian Vegetation in Benson Sub.	acres	0.0	-13.7	-81.8	-16.9	-49.2	-38.6	-12.2	-0.8	7.7
168											
169	X. NET SOCIOECONOMIC CHANGES										
170	Total Population in Upper San Pedro River Basin (excluding Bisbee)	N.people	57461	87245	131410	131410	87245	87245	87245	87245	87245
171	Total Urban Population in Sierra Vista Sub-basin	N.people	37663	68139	103001	103001	68139	68139	68139	68139	68139
172	Total Rural Population in Sierra Vista Sub-basin	N.people	11138	11108	16607	16607	11108	11108	11108	11108	11108
173	Total Urban Population in Benson Sub-basin	N.people	5968	6323	7927	7927	6323	6323	6323	6323	6323
174	Total Rural Population in Benson Sub-basin	N.people	2682	2675	3975	3975	2675	2675	2675	2675	2675
175	Average Percent Change in Median Household Income in Basin	percent	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0000%	0.0437%	0.0437%	0.0437%
176	Total Irrigated Acreage in Sierra Vista Sub-basin	acres	2697.7	2697.7	5637.0	2697.7	2697.7	5637.0	2697.7	1268.6	0.0
177	Total Irrigated Acreage in Benson Sub-basin	acres	5792.6	5759.4	12347.0	5759.8	5792.6	12337.7	5757.9	2726.9	0.0

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1															
2	Policy 3-1	Policy 3-2	Policy 3-5	Policy 3-10	Policy 4	Policy 5	Policy 2-1	Policy 2-2	Policy 2-3	Policy 3-1	Policy 3-2	Policy 3-5	Policy 3-10	Policy 4	Policy 5
3	Scenario A	Scenario A	Scenario A	Scenario A	Scenario A	Scenario A	Scenario D	Scenario D	Scenario D	Scenario D	Scenario D	Scenario D	Scenario D	Scenario D	Scenario D
4															
5	64338	64338	64338	64338	64338	64338	64338	64338	64338	64338	64338	64338	64338	64338	64338
6	1362	1362	1362	1362	1362	1362	1362	1362	1362	1362	1362	1362	1362	1362	1362
7	9210	9210	9210	9210	9210	9210	9210	9210	9210	9210	9210	9210	9210	9210	9210
8	2053	2053	2053	2053	2053	2053	2053	2053	2053	2053	2053	2053	2053	2053	2053
9	681	681	681	681	681	681	681	681	681	681	681	681	681	681	681
10	4860	4860	4860	4860	4860	4860	4860	4860	4860	4860	4860	4860	4860	4860	4860
11	495	495	495	495	495	495	495	495	495	495	495	495	495	495	495
12	293	293	293	293	293	293	293	293	293	293	293	293	293	293	293
13	10815	10815	10815	10815	10815	10815	10815	10815	10815	10815	10815	10815	10815	10815	10815
14	3185	3185	3185	3185	3185	3185	3185	3185	3185	3185	3185	3185	3185	3185	3185
15	1464	1464	1464	1464	1464	1464	1464	1464	1464	1464	1464	1464	1464	1464	1464
16	674	674	674	674	674	674	674	674	674	674	674	674	674	674	674
17	1147	1147	1147	1147	1147	1147	1147	1147	1147	1147	1147	1147	1147	1147	1147
18	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528	1528
19	16682.4	16638.5	16529.9	16377.8	16740.0	16709.6	16716.8	16716.8	16716.8	16682.4	16638.5	16529.9	16377.8	16740.0	16709.6
20	9730.2	9699.1	9623.0	9518.6	9769.0	9733.6	9952.7	9952.7	9952.7	9730.2	9699.1	9623.0	9518.6	9769.0	9733.6
21	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
22	13930.0	13886.7	13780.7	13634.2	13988.0	13960.8	13983.0	13983.0	13983.0	13930.0	13886.7	13780.7	13634.2	13988.0	13960.8
23	9727.4	9697.0	9622.2	9519.0	9769.0	9754.1	9771.0	9771.0	9771.0	9727.4	9697.0	9622.2	9519.0	9769.0	9754.1
24	10817.5	10766.2	10641.4	10470.4	10882.0	10827.7	10820.8	10820.8	10820.8	10817.5	10766.2	10641.4	10470.4	10882.0	10827.7
25	10841.6	10810.9	10736.1	10632.6	10882.0	10859.8	10883.9	10883.9	10883.9	10841.6	10810.9	10736.1	10632.6	10882.0	10859.8
26	9744.0	9726.2	9682.2	9622.0	9769.0	9764.5	9799.6	9799.6	9799.6	9744.0	9726.2	9682.2	9622.0	9769.0	9764.5
27	9744.0	9726.2	9682.2	9622.0	9769.0	9764.5	9799.6	9799.6	9799.6	9744.0	9726.2	9682.2	9622.0	9769.0	9764.5
28	12770.5	12726.2	12617.5	12467.7	12831.0	12810.2	12828.3	12828.3	12828.3	12770.5	12726.2	12617.5	12467.7	12831.0	12810.2
29	12779.8	12742.3	12650.0	12522.6	12831.0	12812.4	12957.4	12957.4	12957.4	12779.8	12742.3	12650.0	12522.6	12831.0	12812.4
30	12724.0	12646.0	12454.8	12192.8	12831.0	12794.2	12786.7	12786.7	12786.7	12724.0	12646.0	12454.8	12192.8	12831.0	12794.2
31	9731.0	9701.4	9629.8	9531.4	9769.0	9741.4	9907.8	9907.8	9907.8	9731.0	9701.4	9629.8	9531.4	9769.0	9741.4
32	9731.0	9701.4	9629.8	9531.4	9769.0	9741.4	9907.8	9907.8	9907.8	9731.0	9701.4	9629.8	9531.4	9769.0	9741.4
33	0.8510	0.8510	0.8510	0.8510	0.8510	0.8510	0.8510	0.8510	0.8510	0.8510	0.8510	0.8510	0.8510	0.8510	0.8510
34	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044
35	0.6594	0.6594	0.6594	0.6594	0.6594	0.6594	0.6594	0.6594	0.6594	0.6594	0.6594	0.6594	0.6594	0.6594	0.6594
36	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044	0.7044
37	0.6699	0.6699	0.6699	0.6699	0.6699	0.6699	0.6699	0.6699	0.6699	0.6699	0.6699	0.6699	0.6699	0.6699	0.6699
38	0.6641	0.6641	0.6641	0.6641	0.6641	0.6641	0.6641	0.6641	0.6641	0.6641	0.6641	0.6641	0.6641	0.6641	0.6641
39	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595
40	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595
41	0.6627	0.6627	0.6627	0.6627	0.6627	0.6627	0.6627	0.6627	0.6627	0.6627	0.6627	0.6627	0.6627	0.6627	0.6627
42	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595
43	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595
44	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595	0.6595
45															
46															
47	159509	159640	159786	159900	158398	158105	156830	157873	158889	158736	158872	159042	159177	157232	156934
48	31506086	31529364	31559103	31578175	31492104	31430196	31339599	31400758	31461752	31463707	31487162	31517093	31536284	31426134	31383607
49	127229	127523	128020	128222	121864	121667	117283	119844	122826	122201	122551	122729	122882	117774	117347
50	27283364	27286872	27288863	27290692	27067382	27034671	26715504	26910285	27102708	27100667	27107408	27114238	27117937	26755533	26722200
51	5971.8	5980.1	5989.6	5995.3	5839.2	5848.7	5660.6	5789.9	5929.1	5903.6	5915.1	5928.2	5936.0	5673.8	5693.3
52	6488.0	6512.9	6537.6	6551.8	6054.8	6090.5	5455.9	5780.2	6102.5	6057.4	6078.2	6101.8	6115.6	5497.2	5523.0
53	0.77	0.77	0.77	0.77	0.76	0.76	0.58	0.59	0.61	0.61	0.61	0.61	0.61	0.59	0.58
54	0.89	0.89	0.89	0.90	0.86	0.84	0.67	0.62	0.65	0.65	0.65	0.66	0.66	0.69	0.68

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	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
55	-0.55	-0.60	-0.66	-0.69	-0.11	0.00	0.27	-0.12	-0.51	-0.45	-0.51	-0.58	-0.59	0.12	0.23
56	5.92	5.80	5.62	5.54	8.19	8.20	10.72	9.51	8.40	8.36	8.32	8.22	8.15	10.44	10.67
57	1.41	1.46	1.50	1.53	0.99	0.88	0.41	0.78	1.17	1.11	1.18	1.24	1.25	0.55	0.44
58	2.80	2.87	2.95	3.00	2.74	2.57	2.29	2.48	2.68	2.67	2.74	2.82	2.87	2.64	2.36
59	-6.04	-5.79	-5.63	-5.50	-8.62	-8.70	-10.87	-9.58	-8.26	-8.41	-8.31	-8.22	-8.11	-10.59	-10.82
60	-7.11	-7.04	-6.96	-6.91	-7.17	-7.34	-7.62	-7.43	-7.24	-7.24	-7.17	-7.09	-7.04	-7.37	-7.55
61															
62															
63	40733.7	40733.7	40733.7	40733.7	40733.7	40733.7	21855.1	21855.1	21855.1	21855.1	21855.1	21855.1	21855.1	21855.1	21855.1
64	900.0	900.0	900.0	900.0	900.0	900.0	900.0	900.0	900.0	900.0	900.0	900.0	900.0	900.0	900.0
65	17640.0	17640.0	17640.0	17640.0	19084.0	17640.0	17640.0	17640.0	17640.0	17640.0	17640.0	17640.0	17640.0	19084.0	17640.0
66	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
67	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
68															
69															
70	7864.8	6686.3	5169.1	4199.9	10563.3	7965.1	8807.4	8807.4	8807.4	7864.8	6686.3	5169.1	4199.9	10563.3	7965.1
71	119.6	105.4	83.5	67.8	144.2	108.0	227.1	227.1	227.1	119.6	105.4	83.5	67.8	144.2	108.0
72	2712.0	2712.0	2712.0	2712.0	2712.0	2712.0	2712.0	2712.0	2712.0	2712.0	2712.0	2712.0	2712.0	2712.0	2712.0
73	264.5	213.8	163.0	131.1	364.7	266.8	342.4	342.4	342.4	264.5	213.8	163.0	131.1	364.7	266.8
74	76.4	63.2	47.8	38.4	116.1	86.3	117.9	117.9	117.9	76.4	63.2	47.8	38.4	116.1	86.3
75	978.9	856.5	673.7	545.0	1196.9	895.9	827.0	827.0	827.0	978.9	856.5	673.7	545.0	1196.9	895.9
76	61.2	51.9	38.9	32.1	81.9	61.4	83.1	83.1	83.1	61.2	51.9	38.9	32.1	81.9	61.4
77	15.2	12.3	9.2	7.4	29.0	21.8	49.3	49.3	49.3	15.2	12.3	9.2	7.4	29.0	21.8
78	1838.8	1838.8	1838.8	1838.8	1838.8	1379.1	1841.4	1841.4	1841.4	1838.8	1838.8	1838.8	1838.8	1838.8	1379.1
79	1518.2	1184.0	862.9	665.7	12233.2	7905.8	9601.0	4800.5	0.0	1544.0	1205.3	869.0	678.5	14837.9	9601.0
80	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
81	204.7	204.7	204.7	204.7	204.7	204.7	204.7	204.7	204.7	204.7	204.7	204.7	204.7	204.7	204.7
82	1649.8	1649.8	1649.8	1649.8	1649.8	1649.8	1941.1	1941.1	1941.1	1941.1	1941.1	1941.1	1941.1	1941.1	1941.1
83	65.3	65.3	65.3	65.3	65.3	65.3	76.8	76.8	76.8	76.8	76.8	76.8	76.8	76.8	76.8
84	14632.4	14650.6	14671.2	14683.7	14325.2	14349.8	16204.9	16578.4	16951.4	16882.1	16911.6	16945.1	16966.4	16261.4	16319.3
85	1305.9	1307.7	1309.9	1311.2	1290.4	1286.2	1406.0	1443.0	1468.2	1464.8	1467.9	1471.5	1473.2	1423.3	1409.5
86	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
87	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
88	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
89	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
90	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
91	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0	410.0
92	1394.5	1577.8	1799.4	1924.7	-243.7	-629.3	-1289.3	-83.9	1157.0	969.6	1137.2	1331.5	1429.1	-842.3	-1193.7
93	39172.5	39363.9	39573.3	39697.3	37648.7	37168.3	17218.8	18387.1	19602.9	19418.8	19583.3	19774.0	19869.9	17648.4	17310.7
94															
95															
96	16082.3	16113.9	16189.2	16248.0	20029.6	19830.6	22215.2	19764.8	17307.2	17900.7	17918.1	17972.9	18019.9	22765.4	22439.7
97	0.0	0.0	0.0	0.0	4489.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4489.4	0.0
98	0.0	0.0	0.0	0.0	61.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	61.3	0.0
99	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
100	0.0	0.0	0.0	0.0	160.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	160.8	0.0
101	0.0	0.0	0.0	0.0	48.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	48.9	0.0
102	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
103	0.0	0.0	0.0	0.0	34.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	34.8	0.0
104	0.0	0.0	0.0	0.0	14.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14.5	0.0
105	0.0	0.0	0.0	0.0	919.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	919.4	0.0
106	883.2	532.8	383.8	299.6	5604.9	1185.9	1440.1	720.1	0.0	884.8	542.4	391.0	306.3	6877.0	1440.1
107	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
108	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9	40.9

USF200010572

	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
109	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
110	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
111															
112															
113	50968.8	51150.2	51368.6	51493.5	49346.0	48964.6	20541.4	21709.7	22925.5	22741.4	22905.8	23086.6	23192.5	20971.0	20633.3
114	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0	240.0
115	12030.0	12030.0	12030.0	12030.0	13192.0	12030.0	12030.0	12030.0	12030.0	12030.0	12030.0	12030.0	12030.0	13192.0	12030.0
116	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
117	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
118															
119															
120	362.3	299.1	225.9	181.5	553.2	414.7	540.0	540.0	540.0	362.3	299.1	225.9	181.5	553.2	414.7
121	96.5	79.9	60.5	48.6	145.0	108.7	246.0	246.0	246.0	96.5	79.9	60.5	48.6	145.0	108.7
122	115.3	95.1	71.7	57.3	176.4	132.1	113.3	113.3	113.3	115.3	95.1	71.7	57.3	176.4	132.1
123	98.1	84.8	66.0	53.3	123.5	92.5	192.7	192.7	192.7	98.1	84.8	66.0	53.3	123.5	92.5
124	259.8	259.8	259.8	259.8	259.8	194.8	260.1	260.1	260.1	259.8	259.8	259.8	259.8	259.8	194.8
125	4425.6	4425.6	4425.6	4425.6	4425.6	4425.6	780.2	2263.8	0.0	3632.5	3895.6	3880.2	3973.7	1176.3	856.1
126	1563.5	1563.5	1563.5	1563.5	1563.5	1563.5	2.3	0.0	0.0	20.0	27.1	38.8	48.6	2.3	2.3
127	-4846.8	-5218.8	-5531.0	-5679.8	26994.2	12966.6	22051.0	9162.9	0.0	-2331.6	-2897.3	-3426.9	-3690.5	37639.2	21975.0
128	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
129	542.0	542.0	542.0	542.0	542.0	542.0	542.0	542.0	542.0	542.0	542.0	542.0	542.0	542.0	542.0
130	904.1	904.1	904.1	904.1	904.1	904.1	1071.1	1071.1	1071.1	1071.1	1071.1	1071.1	1071.1	1071.1	1071.1
131	269.2	269.2	269.2	269.2	269.2	269.2	319.0	319.0	319.0	319.0	319.0	319.0	319.0	319.0	319.0
132	18973.0	19040.6	19108.2	19144.1	17764.2	16756.4	18468.5	19485.7	20506.6	20360.5	20423.7	20494.2	20536.5	18577.7	18669.8
133	1549.4	1555.2	1559.5	1562.1	1465.3	1462.0	1381.9	1403.7	1425.3	1424.8	1425.8	1427.9	1428.9	1386.0	1382.6
134	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
135	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
136	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
137	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
138	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0	120.0
139	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
140	-13166.1	-13107.9	-12997.9	-12972.9	-16566.1	-16306.6	-10161.1	-9064.0	-11721.0	-8021.5	-7972.5	-7891.9	-7843.9	-10052.7	-10156.1
141	29360.0	29593.8	29818.9	30065.2	26421.4	26302.7	7144.7	7907.0	8708.0	8671.5	8713.6	8766.7	8826.2	7283.5	7186.0
142															
143															
144	0.0	0.0	0.0	0.0	11942.5	11276.1	26598.6	17529.1	8511.8	9092.1	8866.3	8692.0	8604.9	26478.2	26747.2
145	0.0	0.0	0.0	0.0	236.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	236.1	0.0
146	0.0	0.0	0.0	0.0	72.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	72.5	0.0
147	0.0	0.0	0.0	0.0	88.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	88.2	0.0
148	0.0	0.0	0.0	0.0	61.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	61.7	0.0
149	0.0	0.0	0.0	0.0	129.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	129.9	0.0
150	571.2	385.1	229.1	154.7	15991.7	2841.9	3425.0	1712.5	0.0	810.4	412.7	246.1	166.4	19408.4	3425.0
151	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
152	162.6	162.6	162.6	162.6	162.6	162.6	162.6	162.6	162.6	162.6	162.6	162.6	162.6	162.6	162.6
153	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
154															
155															
156	-114.3	-105.7	-105.5	-87.3	-119.6	-151.8	-202.3	-161.4	-141.3	-142.0	-134.1	-119.3	-82.0	-172.0	-181.9
157	-13105.0	-11755.2	-10024.9	-8924.0	-12903.8	-16226.2	-20334.3	-17876.1	-15427.5	-14934.3	-13567.7	-11821.6	-10708.3	-15650.1	-19047.8
158	-232.3	-261.6	-196.7	-182.1	-111.5	-192.0	-208.2	-212.1	47.4	-241.0	-122.1	-129.9	-114.1	-199.8	-218.2
159	10449.3	10562.6	10697.5	10780.9	-89.9	-821.5	-16621.3	-7547.3	1278.3	1360.9	1610.8	1958.9	2118.5	-14600.8	-16348.5
160	-0.04	-0.04	-0.04	-0.03	-0.04	-0.06	-0.08	-0.06	-0.05	-0.05	-0.05	-0.04	-0.03	-0.06	-0.07
161	-0.35	-0.32	-0.27	-0.24	-0.35	-0.44	-0.55	-0.48	-0.42	-0.40	-0.37	-0.32	-0.29	-0.42	-0.51
162	-0.11	-0.13	-0.10	-0.09	-0.05	-0.09	-0.10	-0.10	0.02	-0.12	-0.06	-0.06	-0.06	-0.10	-0.11

USF200010573

	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
163	0.33	0.33	0.34	0.34	0.00	-0.03	-0.52	-0.24	0.04	0.04	0.05	0.06	0.07	-0.46	-0.51
164	-158.1	-145.7	-129.8	-131.1	-164.5	-202.6	-205.7	-195.3	-160.9	-159.4	-140.8	-125.3	-138.9	-168.6	-198.9
165	-179.6	-192.7	-163.7	-164.5	-125.9	-133.8	-55.9	-54.9	-73.2	-48.7	-56.0	-50.9	-50.4	-39.8	-53.3
166	-0.5	0.4	1.4	2.0	-7.7	-8.3	-22.8	-14.3	-5.6	-6.9	-5.7	-4.4	-3.7	-19.4	-20.1
167	12.6	14.5	16.1	18.0	-8.0	-28.0	-47.1	-29.0	-11.1	-12.8	-10.6	-8.1	-6.9	-41.3	-43.0
168															
169															
170	87245	87245	87245	87245	87245	87245	87245	87245	87245	87245	87245	87245	87245	87245	87245
171	68139	68139	68139	68139	68139	68139	68139	68139	68139	68139	68139	68139	68139	68139	68139
172	11108	11108	11108	11108	11108	11108	11108	11108	11108	11108	11108	11108	11108	11108	11108
173	5323	5323	5323	5323	5323	5323	5323	5323	5323	5323	5323	5323	5323	5323	5323
174	2675	2675	2675	2675	2675	2675	2675	2675	2675	2675	2675	2675	2675	2675	2675
175	-0.3470%	-0.6091%	-1.2655%	-2.1660%	0.0000%	-0.1687%	0.0437%	0.0437%	0.0437%	-0.3470%	-0.6091%	-1.2655%	-2.1660%	0.0000%	-0.1687%
176	2619.4	2611.6	2602.2	2496.4	2697.7	2694.5	2697.7	1298.9	0.0	2662.2	2657.1	2650.8	2648.5	2697.7	2697.7
177	5349.6	5324.7	5300.0	5286.8	5762.2	5792.6	5792.6	2896.3	0.0	5730.6	5721.5	5710.7	5703.5	5792.6	5792.6

USF200010574