Evaluation of Water Management Programs and Alternatives for Springflow Protection of Endangered Species at Comal and San Marcos Springs

Prepared for:

Edwards Aquifer
Recovery Implementation Program
(EARIP)

Prepared by:

Todd Engineers

HDR Engineering, Inc.

Westward Environmental, Inc.

October 2011

Evaluation of Water Management Programs and Alternatives for Springflow Protection of Endangered Species at Comal and San Marcos Springs

Prepared for:
Edwards Aquifer
Recovery Implementation Program
(EARIP)

Prepared by:

Todd Engineers

HDR
HDR Engineering, Inc.

Westward
Environmental, Inc.

STATE OF TEXAS
SAMUEL KENT VAUGH
63487
REGISTERED
PROFESSIONAL ENGINEER

STATE OF TEXAS
LARRY F. LAND
31380
REGISTERED
PROFESSIONAL ENGINEER

October 2011

Table of Contents

Section **Page**

Table of Contents (Continued)

Section **Page**

List of Figures

List of Figures (Continued)

Figure **Page**

List of Tables

List of Tables (Continued)

Executive Summary

ES-1 Introduction

The Edwards Aquifer Recovery Implementation Program (EARIP) is a collaborative, consensus-based, regional stakeholder process that is tasked with the development of a plan to protect federally-listed endangered species, while managing Texas' Edwards Aquifer for the benefit of all. The primary threat to these species is the intermittent loss of habitat from reduced spring flows that is caused by naturally fluctuating rainfall patterns and regional pumping. The Edwards Aquifer is a unique karst aquifer, is the primary source of drinking water for more than 2 million people, and serves the domestic, agricultural, industrial, and recreational needs of the area. It also is the source of the two largest springs in Texas: Comal and San Marcos.

This report has been prepared under the direction of the EARIP Steering Committee and Program Manager and focuses on the technical evaluations of alternatives to provide springflow protection during droughts. HDR Engineering, Inc. (HDR), along with Todd Engineers and Westward Environmental, Inc., prepared this report on the bases of our participation in discussions with Stakeholders and the Program Manager and the performance of technical evaluations under the direction of the Program Manager. As preliminary results were developed and presented, often in the form of slide presentations, the Stakeholders revised or added new alternatives and programs and requested follow-up technical evaluations. This process continued until the Stakeholders informally agreed on a phased approach in implementing a Habitat Conservation Plan (HCP). Stakeholders informally adopted the Bottom-Up Program for springflow protection.

Improvements in groundwater and surface water conditions that are attributed to management programs need to be compared against a standard set of conditions in order to quantify the relative benefits of each program. This standard, or baseline, represents groundwater and springflow conditions that would occur absent the management programs being considered. This type of analysis isolates the impacts of a program from the normal variability in natural hydrologic conditions.

For this study, a baseline scenario was developed using the U.S. Geological Survey's MODFLOW groundwater model (MODFLOW) and incorporating the current allowable permitted pumping and Critical Period Management (CPM) rules for the model period of record (1947-2000).

ES-2 Bottom-Up Program

The Bottom-Up Program consists of four water management alternatives, including: (1) Voluntary Irrigation Suspension Program Option (VISPO), (2) Municipal Water Conservation, (3) SAWS ASR with Trade-Off Option, and (4) Stage V CPM Reductions. These alternatives individually cannot provide the required springflow protection, but together in an incremental and cumulative manner can provide significant springflow protection during the Initial Adaptive Management Phase. The activities are arranged in the selective cumulative (Stacked) manner as shown in Figure ES-1.

Figure ES-1. Schematic Showing Stacking of Alternatives in Bottom-Up Program

ES-2.1 Voluntary Irrigation Suspension Program Option

The operational concept of VISPO is to establish an agreement between holders of Edwards pumping permits (mostly irrigation) and the EARIP so that owners of the permits are willing to curtail or eliminate authorized pumping when drought conditions seem to threaten springflow protection. The agreement would pay the permit holders a "standby fee" each year for participating in VISPO plus an "implementation fee" for actual curtailment when a drought condition is triggered. At this time, five and ten year agreements are under consideration.

ES-2.2 Municipal Water Conservation

Municipal water conservation (Conservation) is based on a draft *Voluntary Dedicated Water Supply Program* that was developed by a Conservation Work Group, that explored water conservation potential for small water communities and water systems and the agricultural sector. Most opportunities for conservation are believed to include: residential uses of "exempt" wells, "lost water" through municipal infrastructure deficiencies, industrial and commercial processes, rural and small community residential plumbing technologies, excessive landscape watering, use of gray water, and use of condensate and rain water harvesting for landscape.

ES-2.3 SAWS ASR with Trade-Off Option

The San Antonio Water System (SAWS) Aquifer Storage & Recovery (ASR) facilities in south Bexar County are used for storage, recovery, and transport of Edwards water. The water is obtained by leasing Edwards irrigation permits and stored in SAWS ASR. When needed for springflow protection, the water is recovered and delivered into SAWS water distribution system, thereby serving as an off-set or trade-off for SAWS not to pump their authorized Edwards permits by an equal amount.

ES-2.4 Stage V

In the event that implementation of the first three alternatives (layers) of the Bottom-Up Program is not sufficient for springflow protection, an additional CPM stage (Stage V) is added as an "emergency" measure.

ES-2.5 Springflow Protection from the Bottom-Up Program

The calculated springflow protection at Comal and San Marcos Springs from the Bottom-Up Program is measured by results from the MODFLOW simulations. The scenarios included baseline conditions and the successive stacking of four layers of alternatives. As implied, the baseline scenario represents conditions with full Initial Regular Permit (IRP) pumping constrained only by CPM rules. Successively, follow-up scenarios added one layer at a time in the Bottom-Up Program. Incrementally, one could determine the level of improvement in springflow protection for a given alternative by comparing results from a given layer with the results of the previous layer. It's important to note that performance of an alternative in the stacked layer approach would be different if simulations had been done as a stand-alone alternative or, possibly, in a different sequence.

The selected measures or indicators of springflow protection for Comal and San Marcos Springs are MODFLOW simulated hydrographs, number of months below preselected springflow thresholds, and selected springflow statistics. The periods of particular interest are the drought of record (1947-1957) and the full MODFLOW simulation period (1947-2000).

Representative measures of springflow protection are minimum monthly springflow, minimum 6-month moving average springflow, and long-term average springflow. These statistics are presented for the 1947-2000 period in Table ES-1 for Comal and San Marcos Springs. As shown in this summary, the minimum monthly average springflows for Comal and San Marcos Springs are 27 cfs and 51 cfs, respectively, for the full Bottom-Up Program. The minimum 6-month moving average springflows for Comal and San Marcos Springs are 39 cfs and 53 cfs, respectively. The long-term average springflows are 196 cfs at Comal and 155 cfs at San Marcos.

Table ES-1.
Selected Springflow Statistics in Cubic Feet per Second (1947-2000)

Spring	Statistic	Baseline (348K+)	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
Comal	Minimum Month	0	0	0	15	27
	Minimum 6-Month Moving Average	0	0	0	31	39
	Long-Term Average	178	182	186	195	196
San Marcos	Minimum Month	2	16	19	49	51
	Minimum 6-Month Moving Average	12	25	29	53	53
	Long-Term Average	153	153	154	154	155

ES-2.6 Estimated Cost

A summary of estimated costs for the Bottom-Up Program, not including administrative and management costs, is provided in Table ES-2 for layers 1-3 and Table ES-3 for layer 4. The greatest annual cost is for Edwards water leases, which average $12,395,000 per year over 1947-2000 conditions. The total annual cost is estimated to be $15,475,000. The most costly layers are VISPO and SAWS ASR. It's important to note that these program components also have the greatest impact on springflow protection.

Table ES-2.
Estimated Costs for Layers 1-3 of Bottom-Up Program

Program Component	Investment	Annual (54-Year Average)			
		Edwards Water Leases	Depreciation	O&M	Total
Layer 1: VISPO (10-Year Option)	N/A	$4,172,000	N/A	N/A	$4,172,000
Layer 2: Municipal Conservation (10-Year Program)	$19,730,000	$1,973,000	N/A	N/A	$1,973,000
Layer 3: SAWS ASR	N/A	$6,250,000	Waived	$3,080,000	$9,330,000
Total (Layers 1-3)	**$19,730,000**	**$12,395,000**	**$0**	**$3,080,000**	**$15,475,000**

Table ES-3.
Range of Estimated Costs for Layer 4 of Bottom-Up Program

Alternative (from 2011 Region L Water Plan)	Unit Cost (acft/yr)	Annual Cost
Irrigation Water Conservation	$140	$3,836,000
Municipal Water Conservation	$600	$16,440,000
Near-Term Water Management Strategies for SAWS	$1,300	$35,620,000
Long-Term Water Management Strategies for SAWS	$2,300	$63,020,000
Drought Management	$150 to $15,000+	$4,110,000 to $411,000,000+
Note: Annual cost is based on acquiring 27,400 acft/yr.		

1 Introduction

The Edwards Aquifer Recovery Implementation Program (EARIP) is a collaborative, consensus-based, regional stakeholder process that is tasked with the development of a plan to protect federally-listed endangered species, while managing Texas' Edwards Aquifer for the benefit of all. The Edwards Aquifer is a unique karst aquifer, is the primary source of drinking water for more than 2 million people, and serves the domestic, agricultural, industrial, and recreational needs of the area. It also is the source of the two largest springs in Texas: Comal and San Marcos (Figure 1-1). These springs, which are vital to eight endangered species, feed tributaries to the Guadalupe River that, in turn, provide freshwater inflows to bays and estuaries on the Gulf Coast.

There are eight federally-listed species listed as either threatened or endangered that depend directly on water in, or discharged from, the Edwards Aquifer system. They are the fountain darter, San Marcos salamander, San Marcos gambusia, Texas blind salamander, Peck's cave amphipod, Comal Springs dryopid beetle, Comal Springs riffle beetle, and Texas wild rice. The San Marcos gambusia has not been seen since 1982 and may be extinct.

The primary threat to these species is the intermittent loss of habitat due to reduced spring flows caused by naturally fluctuating rainfall patterns and regional pumping. Other threats include invasive non-native species, recreational activities, predation, direct or indirect habitat destruction or modification by humans, and other factors that decrease water quality.

This report has been prepared under the direction of the EARIP Steering Committee and Program Manager and focuses on technical evaluations of alternatives for providing springflow protection during droughts. Key technical analyses include:

- Incremental comparisons of baseline and springflow protection alternatives;
- Identification and assessment of surface water for recharge enhancement;
- Technical evaluations and costs of projects and programs to measure their effectiveness for springflow protection purposes; and
- Preparation of reports and presentations.

HDR Engineering, Inc. (HDR), Todd Engineers, and Westward Environmental, Inc. have participated in ongoing discussions and meetings with Stakeholders and provided technical analyses on topics identified by the Stakeholders. As preliminary results were developed and presented, often in the form of presentations at meetings, the Stakeholders revised or added new alternatives and programs and requested follow-up technical evaluations. This process continued until the Stakeholders informally agreed on a phased approach in implementing a Habitat Conservation Plan (HCP). The approach begins with an Initial Adaptive Management Phase, which includes actions that are sufficient to avoid jeopardizing the continued existence of the species in the short-term while long-term actions and programs are being developed and, possibly, implemented. For this initial phase, the Stakeholders adopted the Bottom-Up Program for springflow protection. Since the initial concept of the Bottom-Up Program was formulated, it has been refined on the basis of performance in meeting the goals of springflow protection at acceptable costs.

The technical evaluation of the Bottom-Up Program is described in detail in Section 3 of this report. This description is preceded by discussion of the baseline against which all springflow protection alternatives were compared (Section 2); and followed by summaries of the technical evaluations of springflow protection alternatives (Section 4) that were considered prior to ultimate selection of the Bottom-Up Program. Special technical analysis requested by the EARIP Program Manager or were necessary to support technical evaluations of one or more alternatives springflow protection program are summarized in appendices.

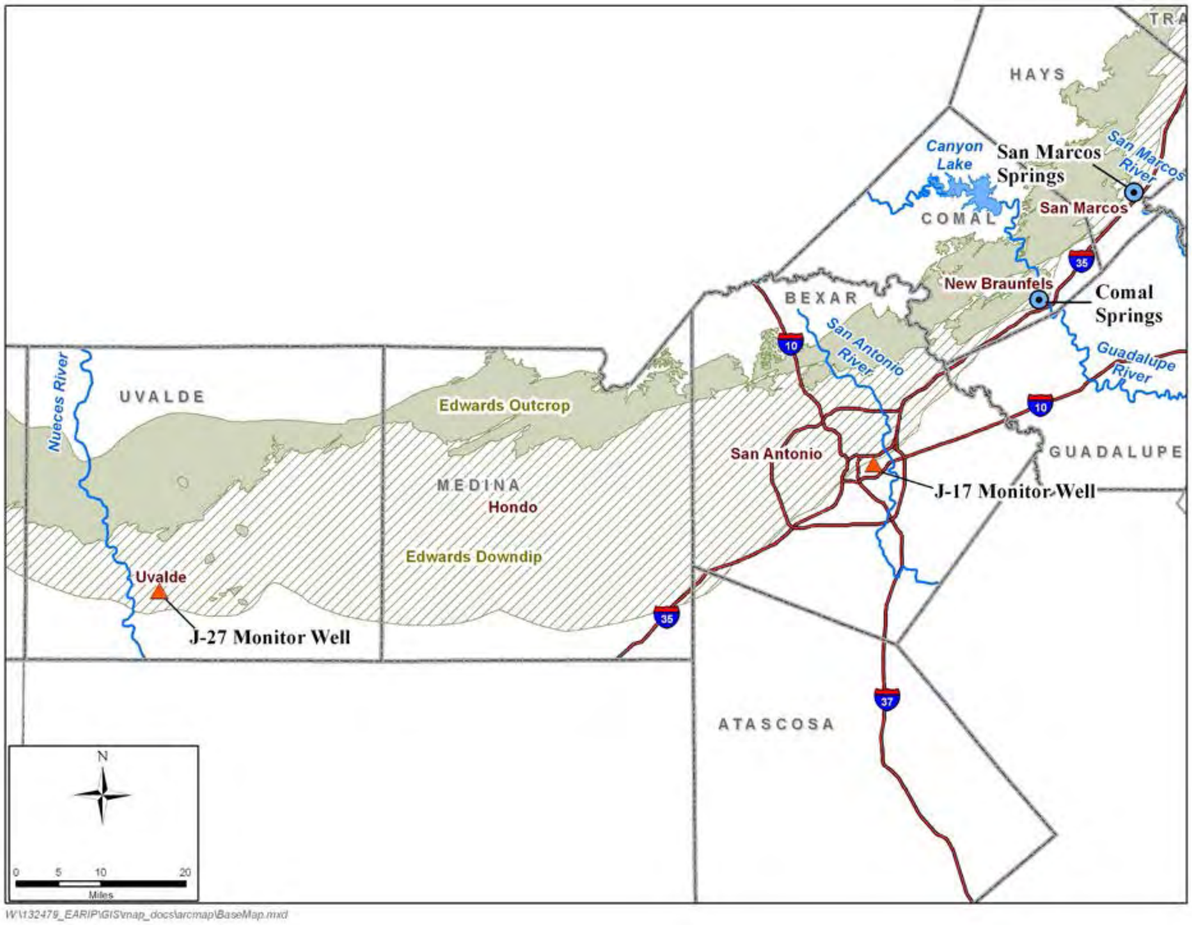


Figure 1-1. Location of Edwards Aquifer, Major Springs, and Key Monitoring Wells

2 Baseline Conditions

Groundwater and surface water conditions resulting from management programs need to be compared against a standard set of conditions in order to quantify the relative benefits of each program. This standard, or baseline, is defined by groundwater and springflow conditions that would occur absent implementation of the EARIP management programs being evaluated. This type of analysis isolates the impacts of a program from the normal variability in natural hydrologic conditions.

For this study, a baseline scenario was developed using the U.S. Geological Survey's MODFLOW groundwater model (MODFLOW)[1] and incorporating allowable permitted pumping and Critical Period Management (CPM) rules pursuant to Senate Bill 3 (SB3) of the 80th Texas Legislature for the model period of record (1947-2000). Development of the baseline pumping scenario and resulting springflows are summarized in this section.

2.1 Modifications to MODFLOW

The baseline scenario reflects recent conditions (including permitted withdrawals) without new springflow protection programs. Baseline development required revision of model input files to reflect total permitted pumping, application of CPM rules, and "firm yield" as defined by 2011 South Central Texas Regional Water Planning Group (Region L), re-affirmed by SB3, and documented in Edwards Aquifer Authority (EAA) rules[2].

Specific model changes included: (1) redefining the pumping in the model to equal the permitted withdrawal amounts, known as Initial Regular Permits (IRPs), of approximately 572,000 acre-feet per year (acft/yr); (2) adjusting geographic distribution and use type based on 2008 pumping within each county; and (3) revising trigger levels at springs and index wells for staged withdrawal reductions. These changes were accomplished with the MODFLOW well file and management modules as described in more detail below.

The structural set up of the model (hydrologic conductivity, faults, drains, etc.) and the original recharge package were not modified to develop baseline conditions. The original

[1] Lindgren, R.J., Dutton, A.R, Hovorka, S.D., Worthington, S.R.H. and Painter, S., 2004, Conceptualization and simulation of the Edwards Aquifer, San Antonio Region, Texas: U.S. Geological Survey Scientific Investigations Report 2004-5277, 143p.

[2] Edwards Aquifer Authority, 2010, http://www.edwardsaquifer.org/display_policies_rules_m.php?pg=rules .

recharge package simulates hydrologic conditions that occurred during the model period (1947-2000), which includes the drought of record (DOR).

2.1.1 Well File Modification

The geographic distribution and amounts of pumping in the original MODFLOW model were based on estimates of actual pumping from 1947 through 2000, the transient period of record for the model. These data from the model show pumping increased from about 170,000 acft/yr in the late 1940s to about 542,400 acft/yr in the late 1980s as illustrated in Figure 2-1.

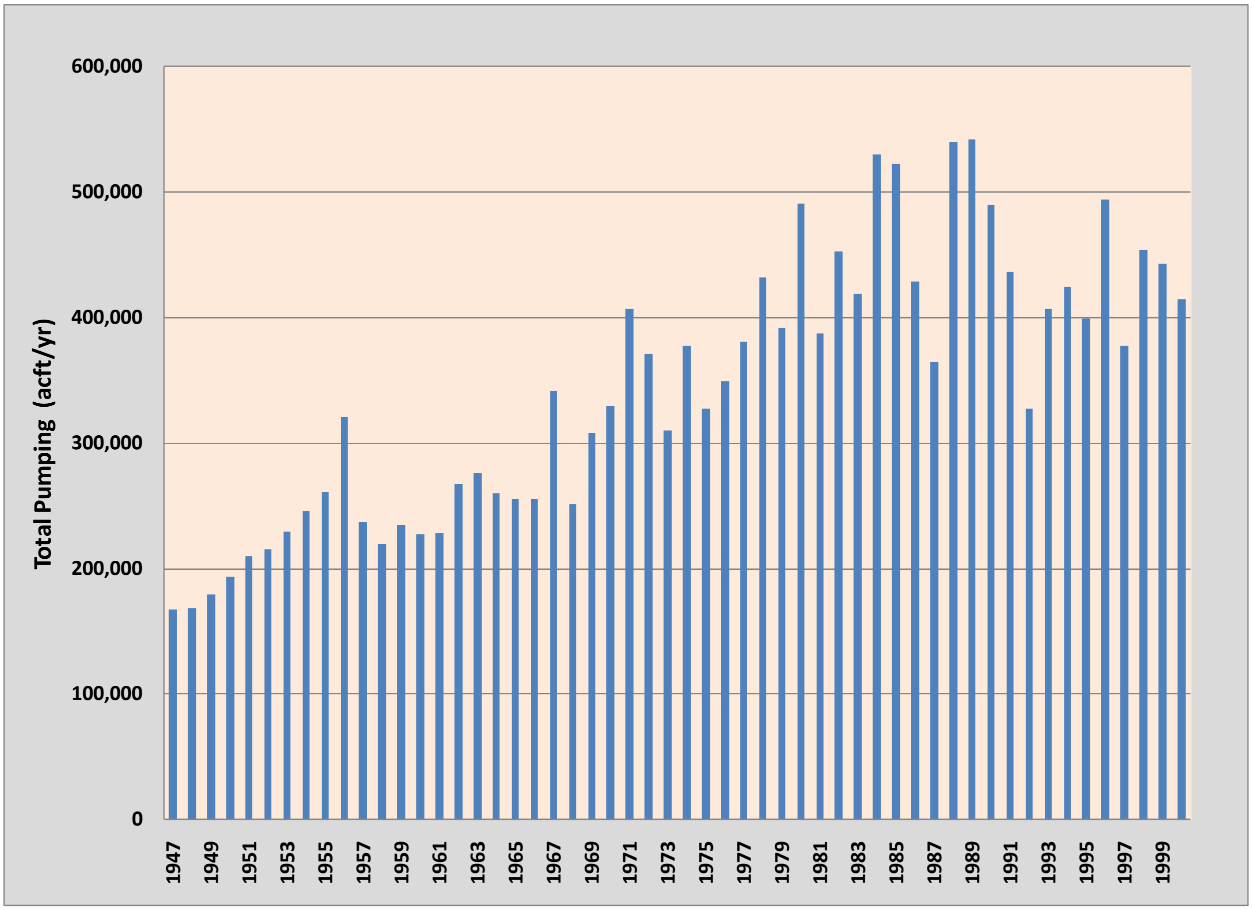


Figure 2-1. Historical Edwards Aquifer Withdrawals

The MODFLOW well file was modified for the baseline scenario to account for significant transfers (by purchase or lease) of initial regular permits from western to eastern counties and/or to change types of use (e.g., from irrigation to municipal). Furthermore, an additional 13,296 acft/yr of domestic pumping was added throughout the model area and 6,907 acft/yr of exempt Federal pumping was added to municipal totals in Bexar and Hays counties, which results in total annual baseline withdrawals of 593,240 acft/yr from the aquifer within the EAA area. For the baseline scenario, this amount of pumping (after transient adjustments for CPM) was repeated each year. Authorized Edwards withdrawals are summarized in Table 2-1.

Section §711.329 of the EAA rules (adopted in June 2010) describes transferring pumping rights from west of Cibolo Creek to east of Cibolo Creek. These rules regarding transfers include assigning a portion of the lease or purchase to a groundwater trust, durations of the lease, and constraints on dates of sale, lease, and well registration. For purposes of this study, purchases and leases of initial regular permits (IRPs) originally west of Cibolo and presently used by entities east of Cibolo were returned to original locations in accordance with these new EAA rules. The net effect of these transfers or returns was no change in total pumping as the permitted pumping was reduced in one county and added to another. A summary of these transfer amounts is included in Table 2-1.

The spatial distribution of the permitted and exempt domestic and livestock pumping within each county is based on a 2005 annual permit distribution by county and use type provided by EAA. For example, the 2008 pumping totals for Bexar County municipal use were distributed among existing Bexar Municipal well locations on the basis of total 2005 permitted pumping at each well. Well locations and color-coded ranges of adjusted annual permitted pumping used in the baseline are shown in Figure 2-2.

Table 2-1.
Authorized Edwards Aquifer Withdrawals in Acre-Feet per Year

County	Purpose of Use	Current Authorized Amount	Cibolo Transfers - Leases	Federal Exemption	Revised Authorized Amount
Atascosa	Irrigation	2,127			2,127
Bexar	Industrial	31,054	0		31,054
Bexar	Irrigation	23,592	23		23,615
Bexar	Municipal	313,522		6,714	320,236
Comal	Industrial	9,381	0		9,381
Comal	Irrigation	808			808
Comal	Municipal	13,722	-750		12,972
Guadalupe	Industrial	546	0		546
Guadalupe	Irrigation	0			0
Guadalupe	Municipal	0	0		0
Hays	Industrial	2,766			2,766
Hays	Irrigation	704	0		704
Hays	Municipal	7,544	0	193	7,737
Medina	Industrial	1,916			1,916
Medina	Irrigation	63,415	422		63,837
Medina	Municipal	9,473			9,473
Uvalde	Industrial	529			529
Uvalde	Irrigation	86,016	306		86,322
Uvalde	Municipal	5,922			5,922
Total Permitted		**573,037**	**0**	**6,907**	**579,944**
Exempt (Domestic and Livestock		13,296			13,296
Total Pumping		**586,333**	**0**	**6,907**	**593,240**

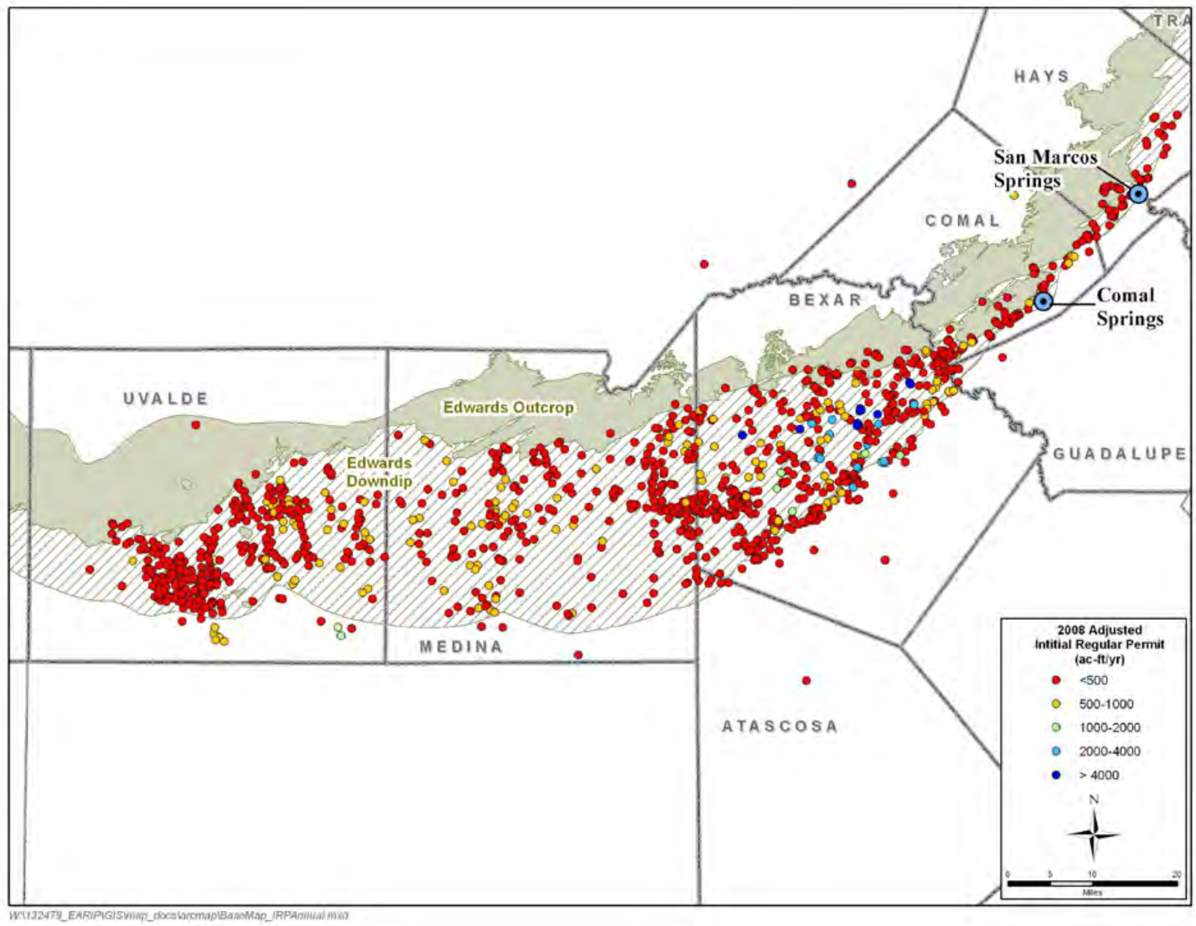


Figure 2-2. Locations of EAA Initial Regular Permits

Because well permits provide for pumping on an annual basis and the model evaluates hydrologic conditions monthly, the annual pumping total for each well was allocated to a monthly use pattern. This monthly allocation is based on an analysis by LBG-Guyton Associates on behalf of EAA that correlated the distribution of monthly pumping to well type. The percentages of annual pumping that are allocated to each month for municipal, industrial, and agricultural wells are listed in Table 2-2. As shown, agricultural use is highest in the late spring/early summer and lower during the winter months. Industrial use is assumed constant from month to month and municipal use typically increases in summer, but not to the degree associated with agricultural use. These patterns were applied to annual pumping totals for wells in the well file. To format the modified well file for use in MODFLOW, a FORTRAN program created for EAA by LBG-Guyton Associates was used.

Table 2-2
Monthly Distribution of Pumping

Month	Pumping by Water Use (Percent of Annual)		
	Municipal	**Industrial**	**Agricultural**
January	6.9	8.3	1.1
February	6.4	8.3	1.5
March	7.5	8.3	2.6
April	8.0	8.3	5.7
May	8.4	8.3	19.0
June	9.1	8.3	29.0
July	11.0	8.3	16.1
August	11.1	8.3	9.9
September	9.0	8.3	4.7
October	8.4	8.3	5.2
November	7.1	8.3	3.8
December	7.1	8.3	1.4
Total	**100.0**	**100.0**	**100.0**

2.1.2 Amended Critical Period Management Rules

The management modules developed by HydroGeoLogic for EAA[3,4] were used to incorporate the CPM rules (Table 2-3). The management modules allow designation of well uses (municipal, industrial, or agricultural), well pools, triggers (associated with springs and/or observation wells), and various management rules, and automatically reduce pumping when triggers are reached in the simulations. Software tools developed by LBG-Guyton Associates and Todd Engineers were used to create the management module files, assign pumping wells to the correct pools and uses, and designate the triggers and management rules in the modules. CPM rules and associated annual withdrawals are summarized in Table 2-4. Although federal pumping is exempt from EAA CPM rules, each facility has their own drought management plan. For purposes of this assessment, federal water use is assumed to be reduced during drought conditions by reduction factors equivalent to EAA CPM.

[3] HydroGeoLogic, Inc., November 2004, Reference Manual for the Groundwater Management Package for MODFLOW-2000: Prepared for Edwards Aquifer Authority.
[4] HydroGeoLogic, Inc., December 2005, User's Manual for the Groundwater Management Package for MODFLOW-2000: Prepared for Edwards Aquifer Authority.

Table 2-3
Critical Period Management Rules

Critical Period Stage	San Antonio Pool				Uvalde Pool	
	Comal Springs (cfs)	San Marcos Springs (cfs)	Index Well J-17 (ft-msl)	Withdrawal Reduction (%)	Index Well J-27 (ft-msl)	Withdrawal Reduction (%)
I	<225	<96	<660	20	NA	NA
II	<200	<80	<650	30	<850	5
III	<150	NA	<640	35	<845	20
IV	<100	NA	<630	40	<842	35

Table 2-4
Withdrawal Reductions under CPM Rules As Amended by SB3

Critical Period Stage	San Antonio Pool		Uvalde Pool		Total Allowable Permitted Pumping (acft/yr)
	Allowable Permitted Pumping (acft/yr)	Withdrawal Reduction (%)	Allowable Permitted Pumping (acft/yr)	Withdrawal Reduction (%)	
Unrestricted	480,570	N/A	92,467	N/A	573,037
I	384,456	20	92,467	N/A	476,923
II	336,399	30	87,844	5	424,243
III	312,370	35	73,974	20	386,344
IV	288,342	40	60,104	35	348,446

2.1.3 Initial Water Levels

In order to apply the new well file and CPM rules, initial water level conditions within the Edwards Aquifer for the baseline had to be developed. In the original MODFLOW model, a steady state run was used to develop initial conditions for the transient model. The steady state run ensures that the hydrologic components of the model are internally in equilibrium. For the baseline scenario, the water level output from the original MODFLOW steady state run was used as input to the transient portion of the model (1947-2000) for the baseline scenario. The steady state run resulted in an initial water level for Index Well J-17 of 668 feet above mean sea level (ft-msl), which is close to the long-term average of 663 ft-msl.

2.1.4 Resolution of Dry Cells in the Model

The additional stress of increased pumping in the baseline scenario results in some dry cells in the model. A dry cell occurs when simulated water levels fall below the bottom of a model cell. Dry cells can cause numerical instability in the model and prevent the inactive cell from accepting additional recharge or continuing to simulate flow.

While there are numerical methods to re-wet dry cells, the original model did not incorporate re-wetting options and allowed the cells to remain dry through the remainder of the transient simulation. Consequently, the original model simulated a total of 56 dry cells at the end of the first half of the model (including the drought of record), thereby reducing recharge somewhat during that time period. Although the cause for those dry cells is not entirely clear, the lack of recharge was accounted for in the calibration of the model for water levels and springflow at key targets (J-17, Comal Springs, etc.). The location of these dry cells indicates potential model inaccuracies in the recharge zone including aquifer parameters such as storativity values. The number and locations of the dry cells are considered acceptable given the overall objectives of the original model. These inaccuracies are discussed in more detail in the model documentation (Lindgren et al., 2004).

Increased pumping for baseline conditions exacerbates the dry cell problem, especially during the drought of record, to a point where a reasonable numerical solution is not possible. Possible causes of the problem could be numerical error and/or over-stressing the northern constant flux boundary from increased pumping. Because the management programs in this project involve enhanced recharge or lower pumping (both resulting in higher water levels), subsequent model runs did not encounter dry cell problems as significant as under baseline conditions.

To resolve the dry cell issue, a MODFLOW module was applied to the simulation to allow dry cells to be "re-wet." The module provides a numerical solution that does not prevent a cell from going dry, but simply allows the cell subsequently to be re-wet with additional recharge. The module is included in MODFLOW 2000[5] as a re-wetting option that allows dry cells to become "wet" if water levels in surrounding cells reach a certain level, but remain dry if surrounding cells do not meet the re-wetting criteria. Because different model inputs result in

[5] Harbaugh. A.W., Banta, E.R., Hill, M.C., and McDonald, M.C., 2000, MODFLOW-2000, The U.S. Geological Survey Modular Ground-Water Model – User guide to modularization concepts and the ground-water flow process: U.S. Geological Survey Open-File Report 00-92.

different cells remaining dry, changes to recharge could vary with each model run. In addition, this package sometimes causes numerical instability due to the iterative and non-linear nature of the solution.

Notwithstanding these issues, the MODFLOW re-wetting package appears to produce valid results for the analyses of management programs presented herein. Significant numerical instability was not observed, and dry cells were re-wet according to program criteria. A check of the model mass balance indicated similar, but slightly higher, recharge amounts in the baseline scenario when compared to the original model. Differences were small and judged to be insignificant. For all model runs, recharge input and output were compared to ensure mass balance.

2.2 Results of Baseline Scenario

The results of the baseline scenario are documented from model output of springflow at Comal and San Marcos Springs and water levels at index wells J-17 (San Antonio Pool) and J-27 (Uvalde Pool) (Figure 1-1). For the San Antonio Pool, critical period stages are triggered by any one of three triggers (Comal Springs, San Marcos Springs, and/or J-17). For the Uvalde Pool, critical period stages are triggered only by J-27.

As shown in Figure 2-3a, Comal Springs flow is below 225 cfs (the trigger for Stage I CPM), for most of the simulation period. More restrictive CPM stages are triggered at flow rates of 200 cfs (Stage II), 150 cfs (Stage III), and 100 cfs (Stage IV), as shown in Table 2-3. A comparison of Comal Springs with San Marcos Springs (Figure 2-3b) illustrates the importance of Comal Springs as the primary springflow trigger for critical periods. Under baseline conditions, Comal Springs flow reaches critical period stages well before San Marcos springflow.

Figures 2-4a and 2-4b show simulated water levels for the baseline scenario at index wells J-17 and J-27, respectively. Similar to Comal Springs, J-17 levels indicate CPM withdrawal reductions during most of the baseline scenario. Baseline results for the Uvalde Pool show Stage IV conditions for the 1950s and 1960s. However, after about 1975, the Uvalde Pool is out of critical period.

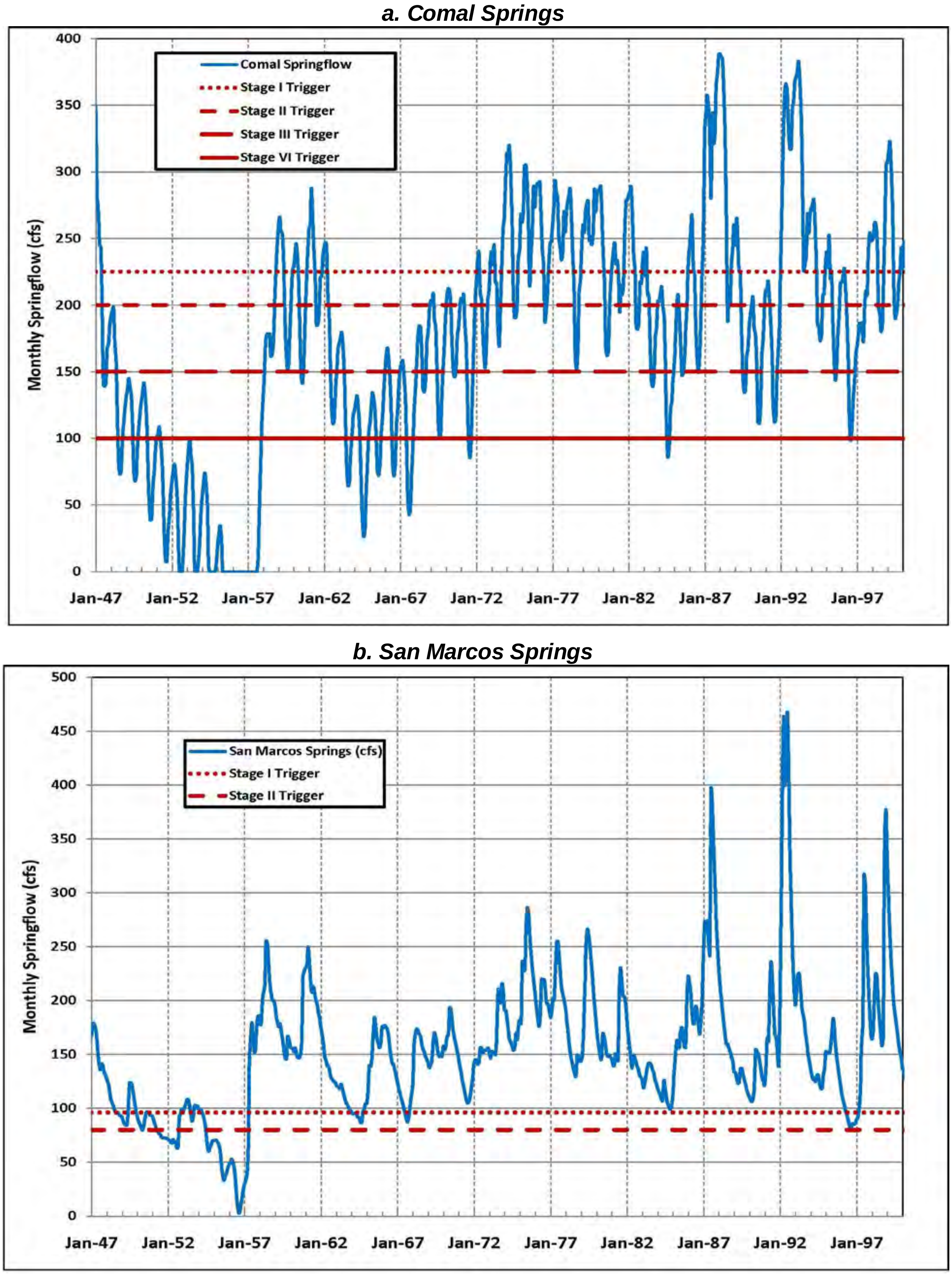
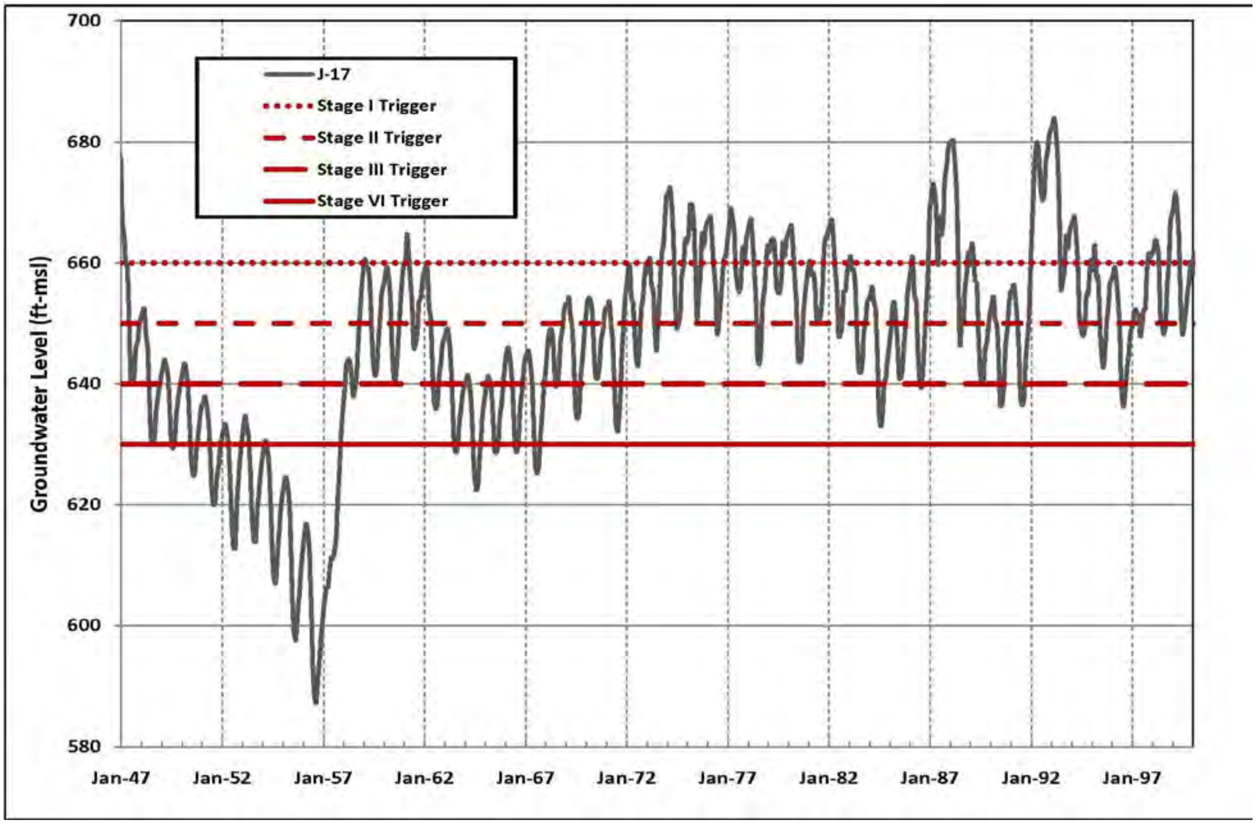


Figure 2-3. Baseline Springflow

a. J-17



b. J-27

Figure 2-4. Baseline Water Levels at Index Wells

As shown in Table 2-5, CPM Stage IV is in effect for a total of about 10 years for the San Antonio Pool and about 22 years for the Uvalde Pool in the first half of the model simulation period (1947-1973). Stage IV is only triggered for 3 months in the San Antonio Pool and not triggered at all in the Uvalde Pool during the second half of the model simulation period (1974-2000).

Table 2-5
Number of Months in Critical Period Under Baseline Conditions

Critical Period Stage	Number of Months					
	1947-1973		1974-2000		1947-2000	
	San Antonio Pool	Uvalde Pool	San Antonio Pool	Uvalde Pool	San Antonio Pool	Uvalde Pool
Unrestricted	14	33	116	324	130	357
I	48	N/A	97	N/A	145	N/A
II	67	14	79	0	146	14
III	76	19	29	0	105	19
IV	119	258	3	0	122	258
TOTAL	324	324	324	324	648	648

3 Bottom-Up Program

The Bottom-Up Program consists of four water management alternatives that individually cannot provide the required springflow protection, but collectively in an incremental and cumulative manner can provide significant springflow protection during the Initial Adaptive Management Phase. The activities are arranged in the selective cumulative (stacked) manner as shown in Figure 3-1.

Figure 3-1. Schematic of Stacking of Alternatives in Bottom-Up Program

3.1 Water Management Alternatives

The Bottom-Up Program consists of four water management alternatives, including: (1) Voluntary Irrigation Suspension Program Option; (2) Municipal Water Conservation; (3) SAWS ASR with Trade-Off Option; and (4) Stage V CPM Emergency Reductions.

3.1.1 Voluntary Irrigation Suspension Program Option (VISPO)

The operational concept of VISPO is to establish agreements between permit holders (mostly irrigators) and the EARIP so that they are willing to suspend authorized pumping when drought conditions threaten springflow protection. The agreement would pay the permit holders a “standby fee” each year for participating in VISPO plus an “implementation fee” for actual curtailment when a drought condition is triggered. Currently (2011), five and ten year agreements are under consideration.

Evaluation of the VISPO alternative for springflow protection involved the following technical assumptions:

- VISPO will apply to about 40,000 acft/yr (IRP value) of Edwards withdrawal rights. Geographic distribution among counties is based on expressions of interest as of May 2011, which total 17,227 acft/yr[6]. Participation from any single county, however, is assumed to be limited to 15,000 acft/yr. Hence, the simulated county distribution of IRP participation in VISPO is as follows: 15,000 acft/yr in Uvalde, 15,000 acft/yr in Medina, 8,520 acft/yr in Bexar, 1,045 acft/yr in Atascosa, and 435 acft/yr in Comal.
- The suspensions will be triggered on January 1 of any given year if the water level in J-17 is below 635 ft-msl level on October 1 of the previous year.
- These suspensions for a given county are assumed to be equally distributed across all irrigation wells within that county.
- Simulated pumping reductions associated with VISPO will be consistent with CPM.
- It is assumed that most, if not all, of the Edwards water committed to the VISPO program element will be from the base (or restricted) portions of irrigation IRPs.
- The cost estimate will be based on information from the VISPO Work Group. More specifically, the cost estimate will be based on a combination of 5-year and 10-year lease options. The average annual cost is assumed to equal the average annual cost for five years of the 5-year option and for ten years of the 10-year option. It's assumed that 70 percent of the options would be in 5-year agreements and 30 percent would be in 10-year agreements. The standby fee will be applied each year and the implementation fee will be applied only in years when VISPO is triggered. The long-term annual average cost will be based on the 1947-2000 model simulation period.

3.1.2 Municipal Water Conservation

Municipal water conservation (Conservation) is based on a draft Voluntary Dedicated Water Supply Program that was developed by a Conservation Work Group of the EARIP, which explored water conservation potential for small communities and water systems and the agricultural sector. Most opportunities for conservation were assumed to include: residential uses of "exempt" wells, "lost water" through municipal infrastructure deficiencies, industrial and commercial processes, rural and small community residential plumbing technologies, excessive landscape watering, use of gray water, and use of condensate and rain water harvesting for landscape.

The testing of the Conservation alternative for springflow protection consisted of the following technical assumptions:

- Total pumping reductions will amount to 10,067 acft/yr when the Edwards Aquifer is not in CPM. These reductions are to be accomplished through: toilet retrofit (1,531 acft/yr); replacement of inefficient fixtures (1,286 acft/yr); leak detection and repair (3,750 acft/yr); large-scale retrofit (2,500 acft/yr); and landscape watering savings (1,000 acft/yr).

[6] EAA, May 2, 2011 spreadsheet

- Pumping reductions will be geographically distributed in proportion to municipal IRPs. This is considered a reasonable approximation given that EARIP model assumptions do not accommodate a potential shift from initial urban savings to rural communities over time.
- Pumping will be reduced according to CPM rules.
- Cost estimates for the conservation layer will be calculated using unit rates that were initially provided by the Work Group and updated though discussions.
- In the event that there is insufficient participation by small communities and water systems and the agricultural sector in the implementation phase, the San Antonio Water System (SAWS) has committed to provide an equivalent reduction in their demand on the Edwards.

3.1.3 SAWS ASR with Trade-Off Option

The SAWS Aquifer Storage & Recovery (ASR) facilities are used for storage, recovery, and transport of Edwards water. The water for this alternative is obtained by leasing Edwards irrigation permits and storing this water in the SAWS ASR facilities in south Bexar County. When needed for springflow protection, the water is recovered and delivered into SAWS water distribution system to reduce or off-set (trade-off) SAWS permitted pumping of the Edwards Aquifer by an equal amount.

Technical assumptions for evaluation are based on extensive discussions with SAWS officials and the working documents provided by SAWS and the EARIP ASR Work Group with the following file names:

05-17-11 Attachment 5a SAWS ASR EARIP Exec Summary 051211.pdf

05-17-11 Attachment 5b EARIP SAWS ASR Concept 051211 Final.pdf

05-27-11 SAWS ASR modeling52711.docx

There are some minor inconsistencies and broad generalizations among the three documents and within the Final Concept paper. These inconsistencies can be attributed mainly to illustrative examples and are not to be treated as constraining this layer of the Bottom-Up Program. It is understood that final details may be adjusted as the Habitat Conservation Plan (HCP) and other program documents are developed. As a result, the following Technical Assumptions are not fully consistent with all three documents, but do honor SAWS' concepts as discussed with the SAWS ASR Work Group.

The following technical assumptions were used in evaluation of the SAWS ASR with Pumping Trade-Off Option:

- Irrigation leases and options are obtained on 50,000 acft/yr of Initial Regular Permits (IRPs) for irrigation and other use types. The leases and options will be divided into thirds (tiers). The first third, approximately 16,667 acft/yr, will be leased at all times for "relaxed" filling of SAWS ASR. The middle third of the options will be implemented in the year after the 10-year moving annual average of Edwards recharge is lower than 572,000 acft/yr and is likely to continue to decrease. The last third will be implemented when the 10-year moving recharge average is less than 472,000 acft/yr. When the options are implemented, this water will either be pumped to fill SAWS ASR or not pumped at all. When the SAWS ASR is in recovery mode, the leased water will not be pumped. When the options are not implemented, the irrigation water is assumed to be pumped by the owner of the permit. It's well understood that future droughts will not replicate the historic Drought of Record. With this in mind, the SAWS ASR Advisory Group may convene at any time to address on-going drought situations by reviewing the rolling-average of recharge triggers and other drought indicators, or potentially accelerating the implementation of the options. Decisions will be guided by Adaptive Management.
- Water to fill SAWS ASR may be provided by SAWS from any existing unused Edwards supplies and from leases and options under the Bottom-Up Program. These two sources of water for SAWS ASR provide an additional element of protectiveness for the springs and the endangered species. Simulations for the EARIP, however, assume that all stored Edwards water in excess of initial storage is obtained under leases associated with the SAWS ASR component of the Bottom-Up Program.
- It's assumed that the leases and options with be distributed evenly among all existing irrigation wells.
- Preliminary operational and modeling procedures are for "dynamic sharing" of injection, recovery, and transmission capacities associated with SAWS ASR facilities. In this context, "dynamic sharing" means that the maximum commitment of SAWS ASR recovery and transmission capacity for direct springflow protection is 100 percent during severe drought.
- Once a severe drought appears to threaten springflow protection, as declared by the SAWS ASR Advisory Group, EARIP may use up to 100 percent of the conveyance capacity of existing (2011) SAWS ASR facilities to off-set Edwards Aquifer demand by SAWS when the monthly average groundwater levels at J-17 are below 630 ft-msl. The selected wells with reduced demand (trade-off or off-set) include Maltsberger, Naco, Stahl, and Randolph, which are located in the northeast part of SAWS distribution system.
- The storage and recovery schedules, including the rates of Edwards pumping off-set will be based on preliminary Bottom-Up Program simulations and limited by the storage, recovery, and transmission capacities of existing facilities. The episodic recovery schedule from SAWS ASR presented herein is limited to 46,000 acft/yr and 126,000 acft of water for a major drought.
- Other major SAWS ASR assumptions include:
    - The initial storage is 80,000 acft;
    - The targeted storage capacity is 120,000 acft during normal and wet conditions and 200,000 acft during severe drought conditions;

  - Guidelines for filling will be at an annual average of 20 MGD (22,400 acft/yr) subject to increase as necessary;
  - Topping-off the ASR to stored volumes between 120,000 acft and 200,000 acft will begin when the 10-year moving recharge average is less than 572,000 acft/yr (based on climatic conditions identical to those that occurred during the Drought of Record) or as decided by the SAWS ASR Advisory Group;
  - There are no water losses from SAWS ASR; and
  - Guidelines for the filling schedule were taken from pages 6 and 7 in concept document with a file name of: *05-17-11 Attachment 5b EARIP SAWS ASR Concept 051211 Final.pdf.*
- The recovery rate for stored water from SAWS ASR is limited to the current transmission capacity from SAWS ASR to Seale and Artesia Pump Stations, which is 60 million gallons per day (MGD), or 5,600 acre-feet per month (acft/mo).
- Cost estimates for this program element are based on the 1947-2000 simulation period and definition provided in SAWS' document named: *05-17-11 Attachment 5b EARIP SAWS ASR Concept 051211 Final.pdf.* Since issuance of the referenced document, however, SAWS has agreed to absorb depreciation costs for existing facilities. The remaining cost (operations, maintenance, and power) will be considered EARIP expenses.
- All permitted withdrawals as constrained by CPM or affected by dedication to Bottom-Up Program activities (i.e., VISPO, Conservation, leased water for the SAWS ASR Project, and Stage V) are identified as firm supplies and are pumped in the model in accordance with the baseline established by the EARIP Steering Committee.

3.1.4 CPM Stage V

In the event that implementation of the first three alternatives (layers) of the Bottom-Up Program is not sufficient for springflow protection, an additional CPM stage (Stage V) is added as an "emergency" measure.

The following technical assumptions were used in evaluation of CPM Stage V:

- Permitted pumping during Stage V will be reduced by 44 percent from the IRP values in both the San Antonio and Uvalde Pools. Domestic and livestock pumping are not restricted. Federal pumping, which is unpermitted, is assumed to be reduced in critical period by the same percentages as permitted pumping.
- The percentage reductions are equal for the San Antonio and Uvalde pools. CPM Stage V is considered to be an "emergency" situation and all permit holders would be required to make an equal sacrifice. The reduction factor for the two pools is 44 percent based on the percentage reduction to move from an IRP total of approximately 572,000 acft/yr to a critical period floor of 320,000 acft/yr. The associated reductions in permitted pumping during Stage V (relative to Stage IV) in the San Antonio and Uvalde Pools are 19,200 acft/yr and 8,200 acft/yr, respectively.

- Stage V is in effect in the San Antonio Pool when the water level at J-17 is lower than 625 ft-msl and in the Uvalde Pool when the water level in J-27 is lower than 840 ft-msl. Stage V would not be triggered in the Uvalde Pool when the San Antonio Pool is not triggered.
- A range of potential costs attributable to Stage V are estimated using available information from the 2011 South Central Texas Regional Water Plan. Approximate costs for demand reduction include: conservation, drought management, and replacement water supplies delivered to Bexar County as necessary to produce about 27,400 acft/yr.

3.1.5 Refinement of the Bottom-Up Program

The Bottom-Up Program described in this document and adopted by the EARIP is built on two earlier tests. Major assumptions in these two tests are summarized in Table 3-1.

Table 3-1
Summary of Technical Assumptions in Two Previously Proposed Bottom-Up Programs

Alternative	Test	
	First	**Second**
VISPO	• Irrigation Suspensions: o Medina Co.: 20,000 acft/yr o Uvalde Co.: 15,000 acft/yr o Bexar Co.: 5,000 acft/yr • Trigger: o September 1 when J-17 is lower than 650 ft-msl • Annual Cost: $10,216,000	• Same as first test
Conservation	• Unchanged	• Unchanged
SAWS ASR	• Lease 50,000 acft/yr • Leases are not pumped except to fill ASR • Recovery begins when flow from Comal Springs is less than 50 cfs • ASR Storage: Starts empty, Full Capacity is 200,000 acft • Recovery Off-Sets SAWS pumping in NE section • Can utilize up to 100% of transmission capacity • Annual Cost: $14,336,000	• Same as first test, except: o ASR Storage: Starts at 40,000, Full Capacity is 150,000 acft o Annual Cost: $10,070,000
Stage V	• Permitted pumping reduction is 44% • Triggers: o San Antonio Pool: J-17 at 625 ft-msl o Uvalde Pool: J-27 at 840 ft-msl	• Same as first test, except: o Both pools are triggered by J-17 at 625 ft-msl

A comparison of the technical assumptions for the tentatively adopted Bottom-Up Program, as described in Section 3.1.4 with the first two iterations shows the greatest changes were in the VISPO and SAWS ASR components of the program. For VISPO, the major changes were implementation triggers and geographic distribution of pumping reductions. For SAWS ASR, the greatest change was implementing the 10-year moving average of Edwards recharge to trigger leasing of permits and filling of ASR.

More details and results of these first two iterations are summarized in presentations posted on the EARIP web site.

3.2 Layers

Springflow protection at Comal and San Marcos Springs from the Bottom-Up Program is assessed on the basis of a series MODFLOW simulations. These simulations include baseline conditions and the successive stacking of four layers. As implied, the baseline represents conditions with full IRP pumping that is constrained only by EAA CPM rules. Successive layers are added one at a time in the Bottom-Up Program. Incrementally, one may estimate the degree of improvement in springflow protection for a layer by comparison with the results for a previous layer. It's important to note that performance of Bottom-Up Program components in the stacked layer approach may be different if components are examined individually or in a different sequence.

The selected measures or indicators of springflow protection for Comal and San Marcos Springs are simulated hydrographs from MODFLOW; numbers of months below preselected springflow thresholds; and minimum monthly springflow, minimum 6-month moving average springflow, and long-term average springflow. The periods of particular interest are 1947-1957 (drought of record) and 1947-2000 (MODFLOW simulation period).

3.2.1 Voluntary Irrigation Suspension Program Option (Layer #1)

Pumping reductions attributable to VISPO are triggered for years when drought conditions are anticipated. Figure 3-2 illustrates years during the MODFLOW simulation period when this option is in standby or implementation mode. As illustrated, the option was implemented and irrigation suspended 15 years during 1947-1973 and 1 year during 1974-2000.

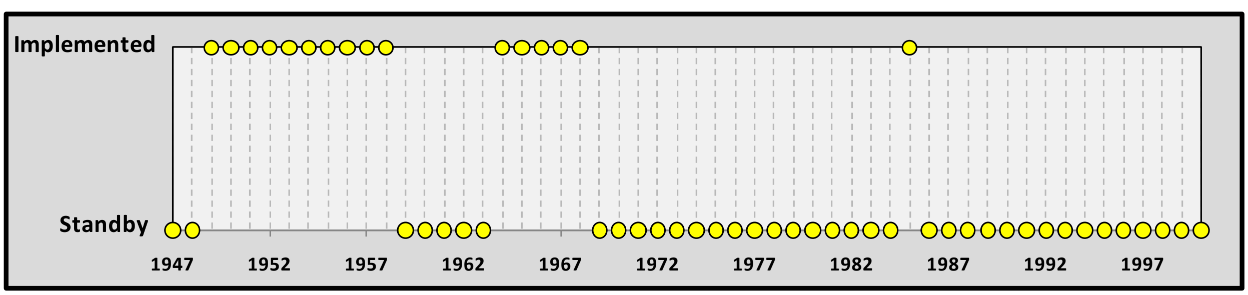


Figure 3-2. Annual Status of VISPO Operations (1947-2000)

The permitted pumping for participants in VISPO is subject to suspension and any simulated pumping reductions are consistent with CPM stage. For example, if suspension was triggered and there were no CPM restrictions for entire year (highly unlikely), the full IRP pumping reductions would be 40,000 acft. On the other hand, if CPM Stage IV were in effect for the entire year that suspension was triggered, the actual reductions in Edwards withdrawals would be 24,750 acft. It's important to note that pumping reductions due to VISPO may allow some increases in other permitted pumping, which can change CPM duration and stage. For example, if baseline pumping (without VISPO) caused the San Antonio Pool to be in Stage IV for eight months in a given year, and reductions in pumping (with VISPO) were sufficient to reduce the duration in Stage IV to four months, the Stage IV restrictions would have been relaxed by four months for all permits in the San Antonio pool.

For the periods 1947-1957 and 1947-2000, VISPO pumping reductions and increases in allowable pumping due to less time in given CPM stages are presented in Table 3-2. This table shows that the average VISPO net pumping reductions were 20,540 acft/yr for the 1947-1957 period. For the 1947-2000 period, VISPO net pumping reductions averaged 10,427 acft/yr. The average VISPO net pumping reductions are less for the 1947-2000 period than the 1947-1957 period because of the intense drought in the latter period.

Table 3-2.
Average Annual Pumping Reductions for Layer #1

Units: acft/year

Condition	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	25,000	15,000	40,000
1947-1957	12,443	8,097	20,540
1947-2000	4,716	3,011	10,427

3.2.2 VISPO + Municipal Water Conservation (Layer #2)

In the adopted Bottom-Up concept, a Municipal Conservation component is added to the VISPO component. The Municipal Conservation component is active each year and the net reductions in pumping are consistent with concurrent CPM stage. The full potential pumping reductions for Layers #1 and #2 total 50,067 acft/yr.

For the periods 1947-1957 and 1947-2000, cumulative net pumping reductions for VISPO and Municipal Conservation (Layer #2) are presented in Table 3-3. This table shows that average pumping reductions through Layer #2 were 26,965 acft/yr for the 1947-1957 period. For the 1947-2000 period, net pumping reductions through Layer #2 averaged 15,390 acft/yr. During the drought of record, the net effect of the Municipal Conservation layer was a pumping reduction of 6,425 acft/yr.

Table 3-3.
Average Annual Pumping Reductions through Layer #2*

Units: acft/year

	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	34,803	15,264	50,067
1947-1957	18,749	8,216	26,965
1947-2000	12,233	3,157	15,390

* Note: Cumulative Adjustments for VISPO and Municipal Conservation

3.2.3 VISPO + Conservation + SAWS ASR with Trade-Off Option (Layer #3)

In Layer #3 of Bottom-Up Program, the SAWS ASR with Trade-Off component is added to the VISPO and Municipal Conservation components. Three key elements of the SAWS ASR with Trade-Off Option include: (1) leasing of IRPs to either fill SAWS ASR or to suspend the permitted pumping, (2) filling SAWS ASR, and (3) recovering stored water for trade-off (off-set) of SAWS permitted pumping at selected pump stations. A schematic of the SAWS ASR with Trade-Off operational concept is presented in Figure 3-3.

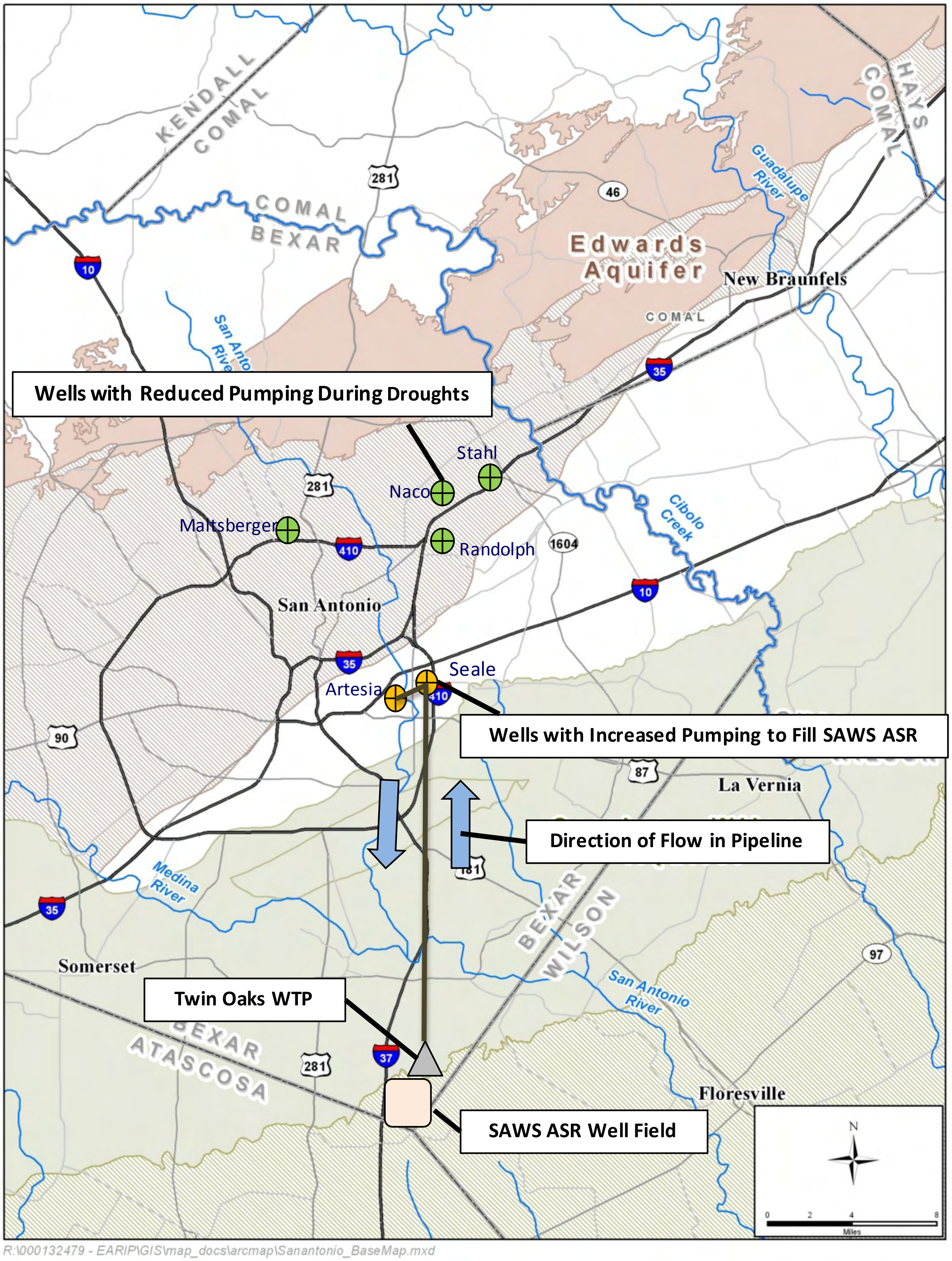


Figure 3-3. SAWS ASR Operational Concept

As formulated by SAWS, the 50,000 acft/yr of IRPs associated with Layer #3 is divided equally into three tiers. The first tier is to be active at all times. Activation of the second and third tiers is based on a 10-year moving average of Edwards recharge. When the 10-year moving average recharge is between 472,000 and 572,000 acft/yr, the second tier of leases are implemented. When the 10-year moving average recharge is less than 472,000, the second and third tiers of leases are implemented. Figure 3-4 illustrates the annual Edwards recharge, the 10-year moving recharge average, and the three tiers. Figure 3-5 illustrates the activation of these tiers during the simulation period. As shown, all three tiers were implemented for 10 years; the first two tiers were implemented for 9 years; and only tier 1 was implemented for the remaining 35 years.

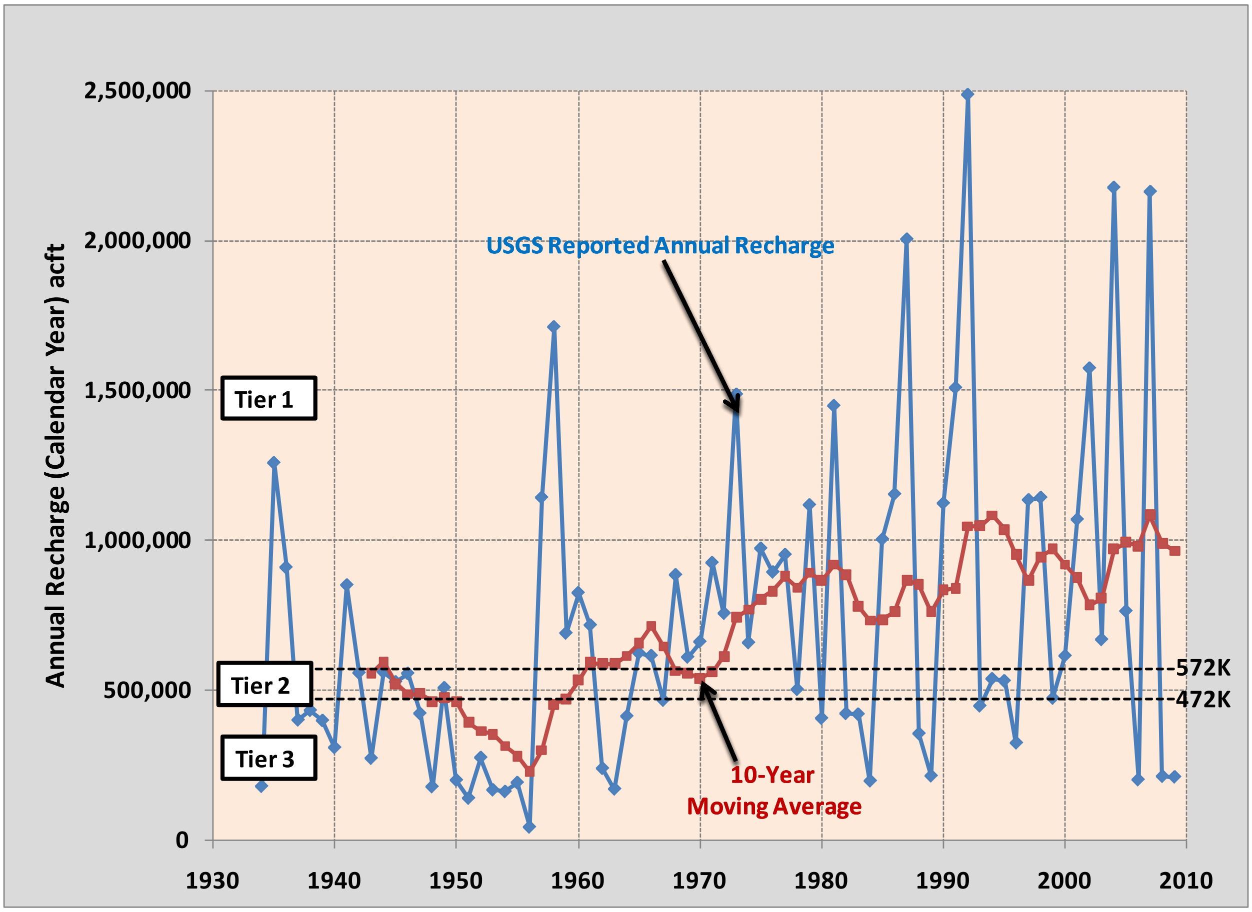


Figure 3-4. Edwards Recharge and Tiers for Operation of SAWS ASR

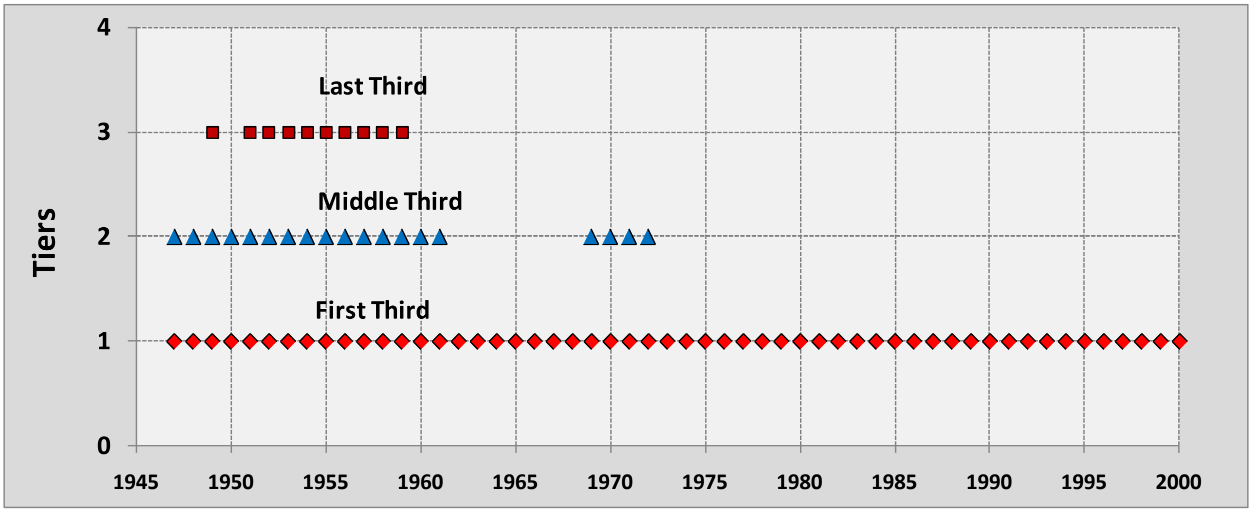


Figure 3-5. Occurrence of Tiers for Operation of SAWS ASR

Filling of SAWS ASR utilizes water that is available from the leases described above. To stay well within the guidelines provided by SAWS, the filling rate was limited to tier 1, which is implemented at all times. If leases from all tiers were utilized for filling, the rates could have been much higher much of the time, which would have greatly shortened the fill and refill times thereby reducing the risk insufficient water in storage at inception of a subsequent drought. The greatest fill rate was 14.9 million gallons per day (MGD). During the fill months for the period 1947-1957, the average filling rate was 11.2 MGD with pumping of this leased water at SAWS Artesia and Seale stations. The capacity of the transmission facilities is limited to about 60 MGD (5,600 acft/mo). The schedule and rate for the filling is shown in Figure 3-6. For operational purposes, the filling is suspended when there is recovery for springflow protection. As discussed earlier, it was assumed that 80,000 acft of water was in SAWS ASR storage at the beginning of the simulation. ASR storage thresholds, as defined by SAWS, were 120,000 acft for tier 1 and 200,000 acft for tiers 2 and 3. Water delivery to SAWS ASR for the 1947-2000 period occurred for 162 months and totaled 120,000 acft. As shown in Figure 3-6, most of the filling occurred from 1947-1965.

Recovering the Edwards stored water from ASR utilizes SAWS existing East-Side pipeline and water transmission facilities. Operationally, the water is delivered back to Artesia and Seale Stations; and SAWS moves this water within their existing distribution system to reduce the total pumping at the Maltsberger, Naco, Stahl, and Randolph stations by an equal amount. The schedule and rate for recovery is shown in Figure 3-6 and is an attempt to optimize springflow protection and minimize the demand for water stored in SAWS ASR. During the 1947-2000 period, about 126,000 acft were recovered for SAWS pumping trade-off. This recovery for springflow protection occurred for 63 months, the vast majority of which were during the 1950s drought.

Figure 3-7 illustrates the storage balance in SAWS ASR for the 1947-2000 period. As shown, initial storage was 80,000 acft. Storage was capped at about 120,000 acft in the early 1950s and increased to about 127,000 when tiers 2 and 3 were in place. At the end of the drought, about 21,000 acft remained in storage. It was replenished by early 1965. Again, there is an opportunity to replenish ASR storage in a much shorter period of time if the lease water is more fully utilized.

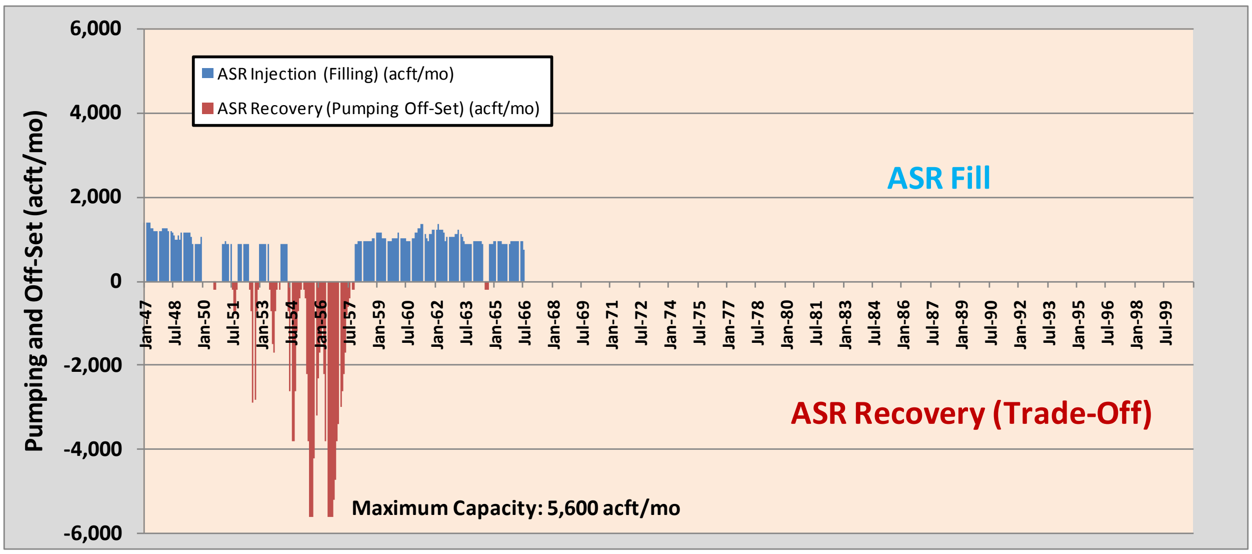


Figure 3-6. Rate and Schedule of SAWS ASR Injection and Recovery (1947-1957)

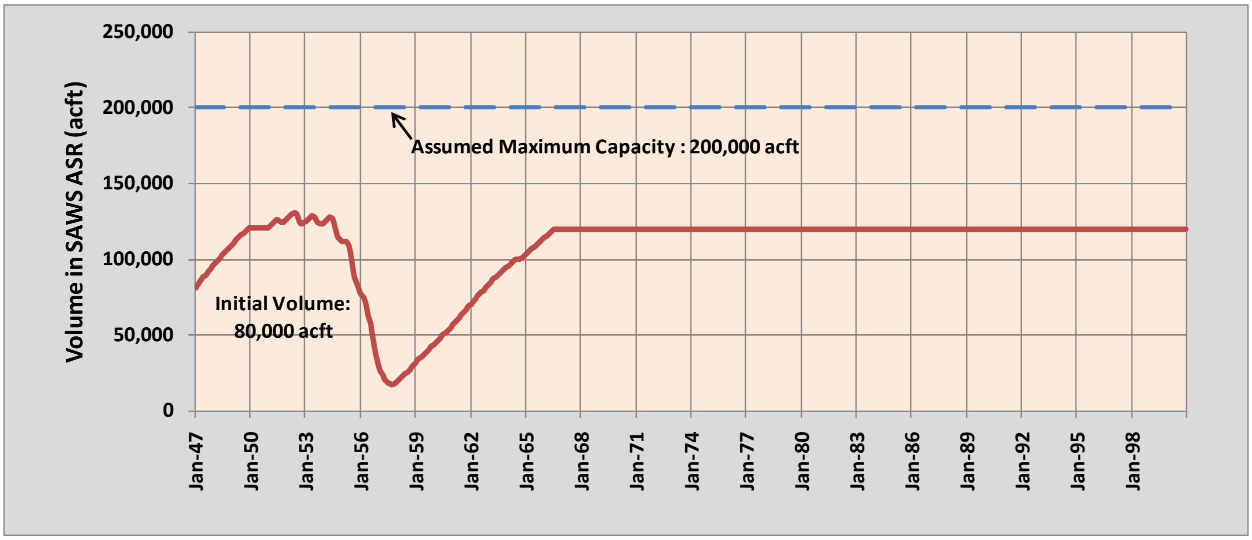


Figure 3-7. Storage of EARIP Water in SAWS ASR

For the periods 1947-1957 and 1947-2000, cumulative net pumping reductions for VISPO, Municipal Conservation, and SAWS ASR (Layer #3) are presented in Table 3-4. This table shows that, for the 1947-1957 period, the average cumulative pumping reduction through Layer #3 was 52,663 acft/yr. For the 1947-2000 period, cumulative pumping reductions through Layer #3 averaged 32,686 acft/yr. During the drought of record period, the net effect of the SAWS ASR alternative was a pumping reduction of 25,698 acft/yr. The occurrences of lease implementation and CPM are strong controlling factors in the pumping reductions.

Table 3-4.
Average Annual Pumping Reductions for Layer #3*

Units: acft/year

	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	59,659	40,408	100,067
1947-1957	28,167	24,496	52,663
1947-2000	18,938	13,748	32,686

* Note: Cumulative Adjustments for VISPO, Conservation and SAWS ASR

3.2.4 VISPO + Conservation + SAWS ASR with Trade-Off Option + Stage V (Layer #4)

In Layer #4 of Bottom-Up Program, CPM Stage V is added to the VISPO, Municipal Conservation, and SAWS ASR with Trade-Off components. Key elements of Stage V are triggering this emergency action primarily off of J-17 water levels and applying an equal 44 percent reduction to permitted wells in both the San Antonio and Uvalde pools. This CPM stage is implemented when J-17 water levels are lower than 625 ft-msl, which is approximately equivalent to 40 cfs at Comal Springs. Based on the Bottom-Up Program and the J-17 results of Layer #3, Stage V was activated for 6 months, of which, two months were in 1955 and four months were in 1956, as illustrated in Figure 3-8.

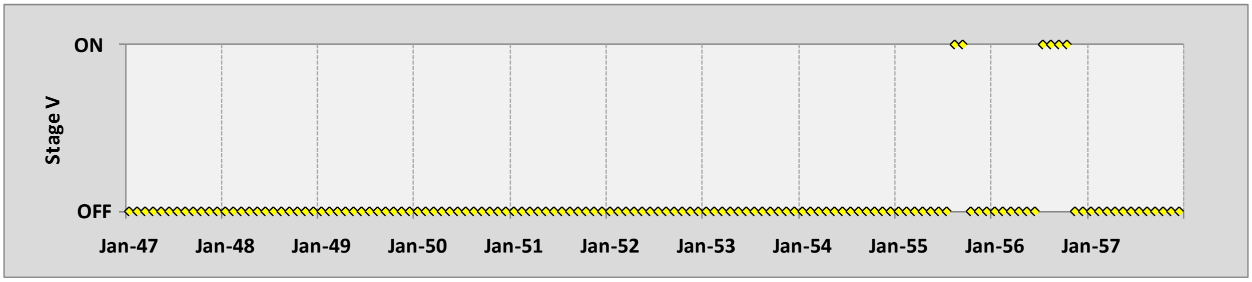


Figure 3-8. Monthly Occurrences of Stage V

For the periods 1947-1957 and 1947-2000, cumulative net pumping reductions for VISPO, Municipal Conservation, SAWS ASR, and Stage V (Layer #4) are presented in Table 3-5. This table shows that, for the 1947-1957 period, the average Layer #4 net pumping reductions were 53,830 acft/yr. For the 1947-2000 period, Layer #4 net pumping reductions averaged 32,923 acft/yr.

Table 3-5.
Average Annual Pumping Reductions for Layer #4

Units: acft/year

	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	78,859	48,608	127,467
1947-1957	29,145	24,685	53,830
1947-2000	19,137	13,786	32,923

3.3 Results

3.3.1 Springflow Hydrographs

Hydrographs from the MODFLOW model simulations are used for a temporal display of the variations in magnitude of springflow. For comparison purposes, hydrographs are presented for five scenarios (baseline and each of the four Bottom-Up Program layers). Study of the hydrographs provides qualitative information on the increase in springflow for each additional layer of the Bottom-Up Program.

MODFLOW calculated springflows for the 1947-1960 period for Comal and San Marcos Springs are presented in Figures 3-9 and 3-10, respectively. Observations upon review of Figures 3-9 and 3-10 focusing on the drought of record include the following: (1) modest improvement in springflow when Municipal Conservation is added; (2) substantial improvements from the VISPO and SAWS ASR components for 1951-1957 at Comal Springs and for 1955-1957 at San

Marcos Springs; and (3) substantial improvement in Comal Springs flow due to implementation of Stage V during the summer of 1956. These hydrographs indicate that the Bottom-Up Program limited the minimum springflows at Comal and San Marcos Springs to about 27 and 51 cfs, respectively. A study of the recovery schedule from SAWS ASR (Figures 3-6 and 3-7) shows that the capacity of the SAWS ASR water transmission facilities (pipelines and pumps) is the limiting factor in the level of springflow protection at Comal Springs. If the capacity of the east-side water transmission system had been greater, additional springflow protection at Comal Springs could have been achieved. However, this enhancement depends on SAWS having the operational capability to move recovered water from the Artesia and Seale pump stations to parts of their distribution system normally served by other SAWS stations that are subject to trade-offs.

MODFLOW calculated springflows for the entire 1947-2000 simulation period for Comal and San Marcos Springs are presented in Figures 3-11 and 3-12, respectively. These hydrographs show that the Bottom-Up Program usually increases springflow by small amounts in periods other than the drought of record. Most of the increases are attributable to adding VISPO and SAWS ASR alternatives, which lead to significantly less Edwards pumping during critical drought conditions. Further study of Figures 3-11 and 3-12 suggests that Comal Springs has a much more direct response to water management alternatives than San Marcos Springs. This is mostly attributable to: (1) a strong hydrogeologic connection between Comal Springs and the main body of the Edwards; and (2) discharge from San Marcos Springs being subject to discharge from Comal Springs and faults located between Comal and San Marcos Springs that function as partial barriers to groundwater flow.

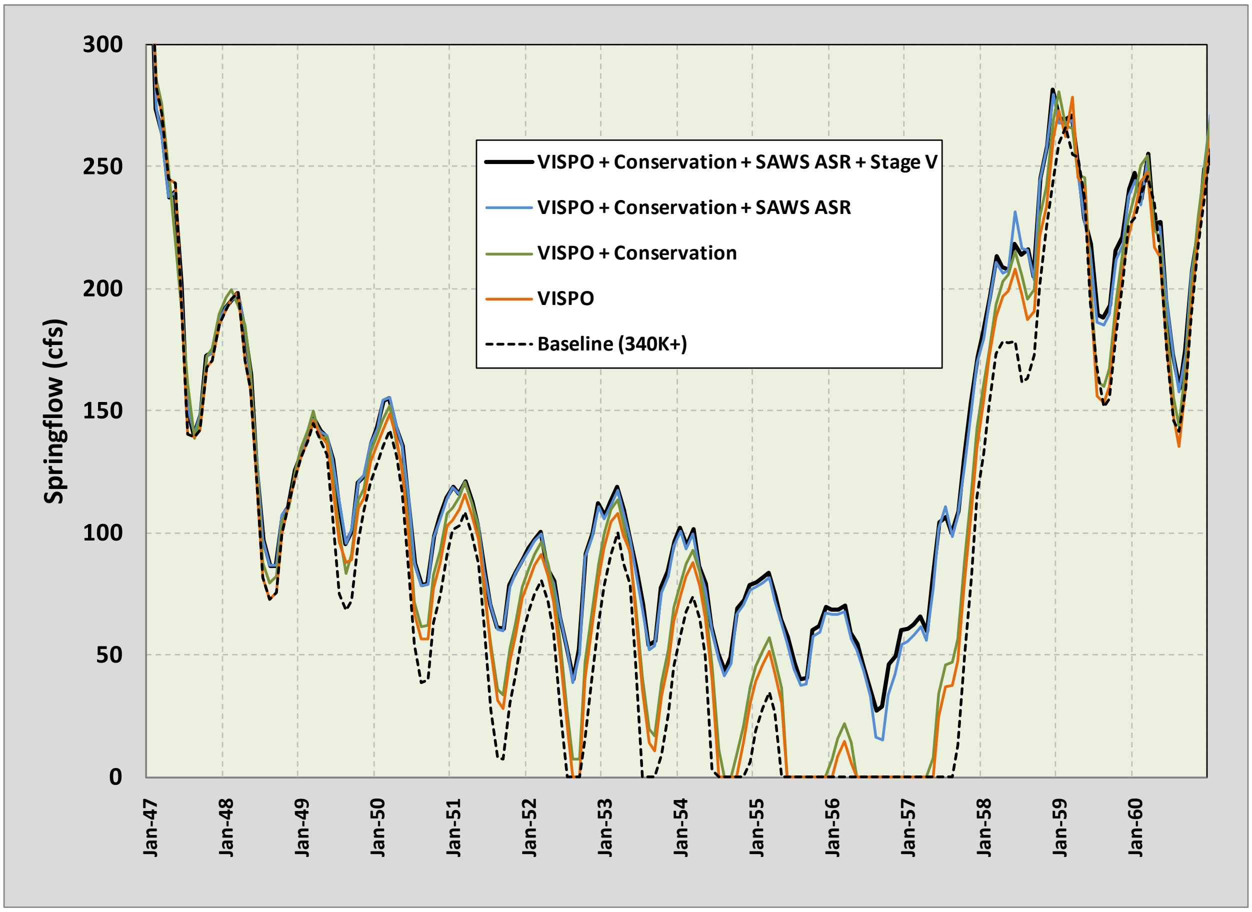


Figure 3-9. Simulated Springflow at Comal Springs (1947-1960)

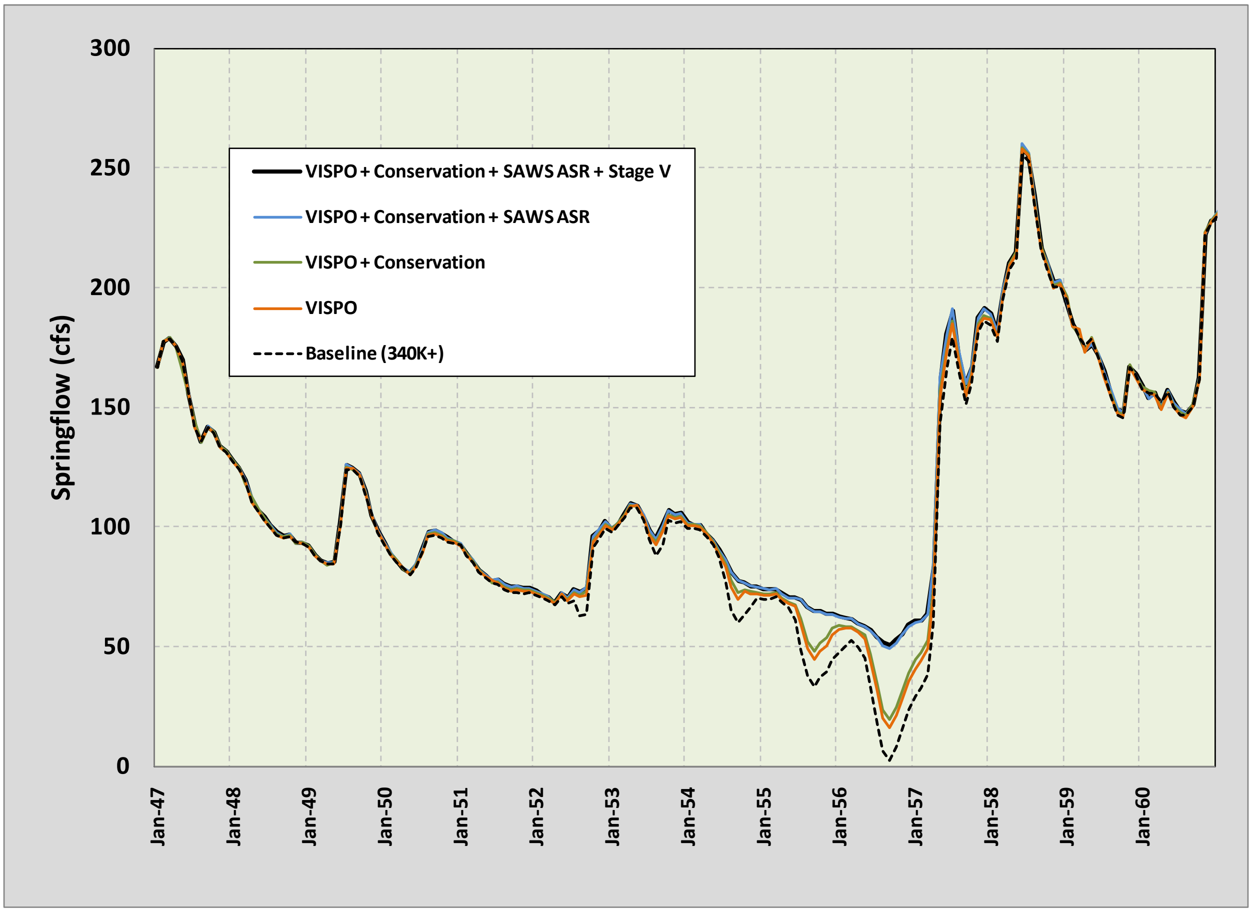


Figure 3-10. Simulated Springflow at San Marcos Springs (1947-1960)

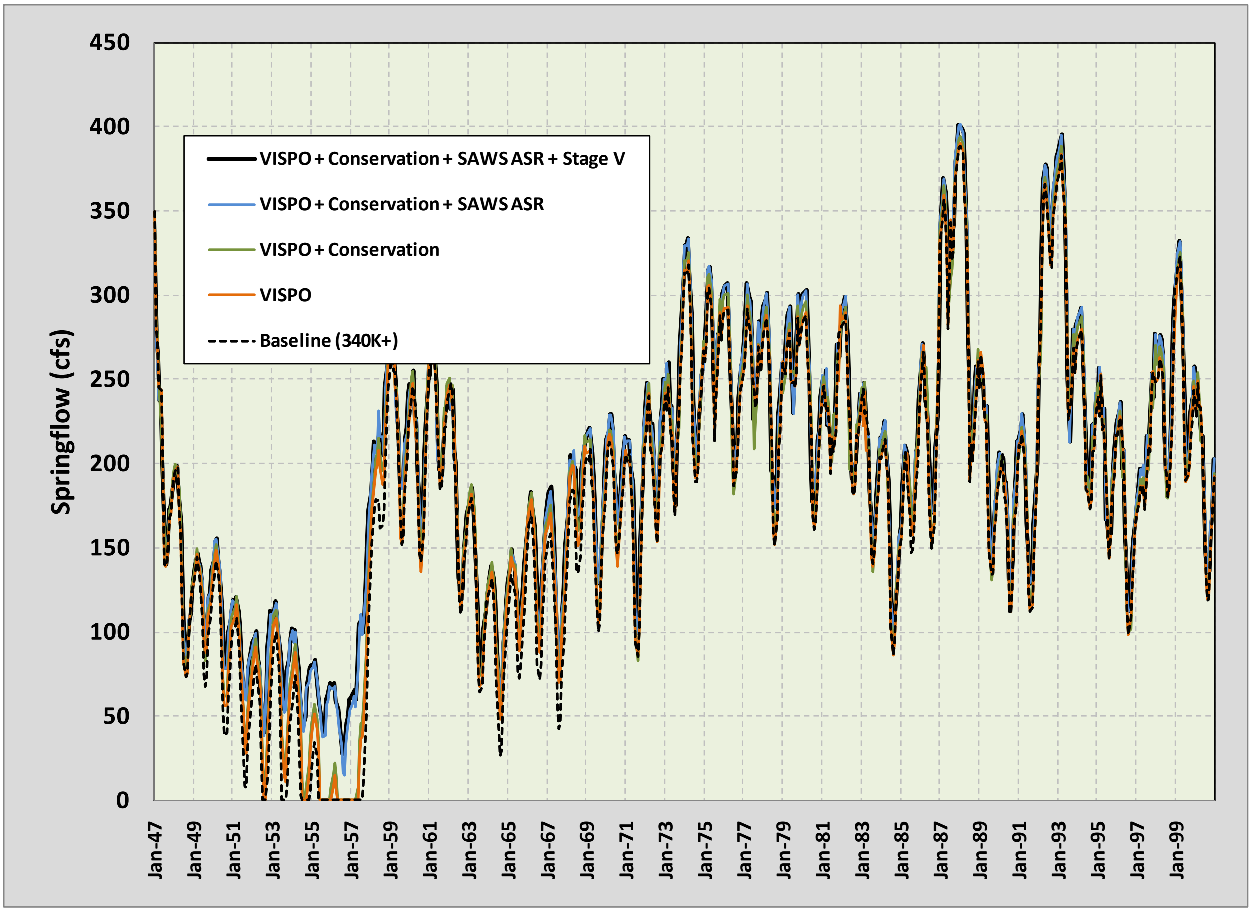


Figure 3-11. Simulated Springflow at Comal Springs (1947-2000)

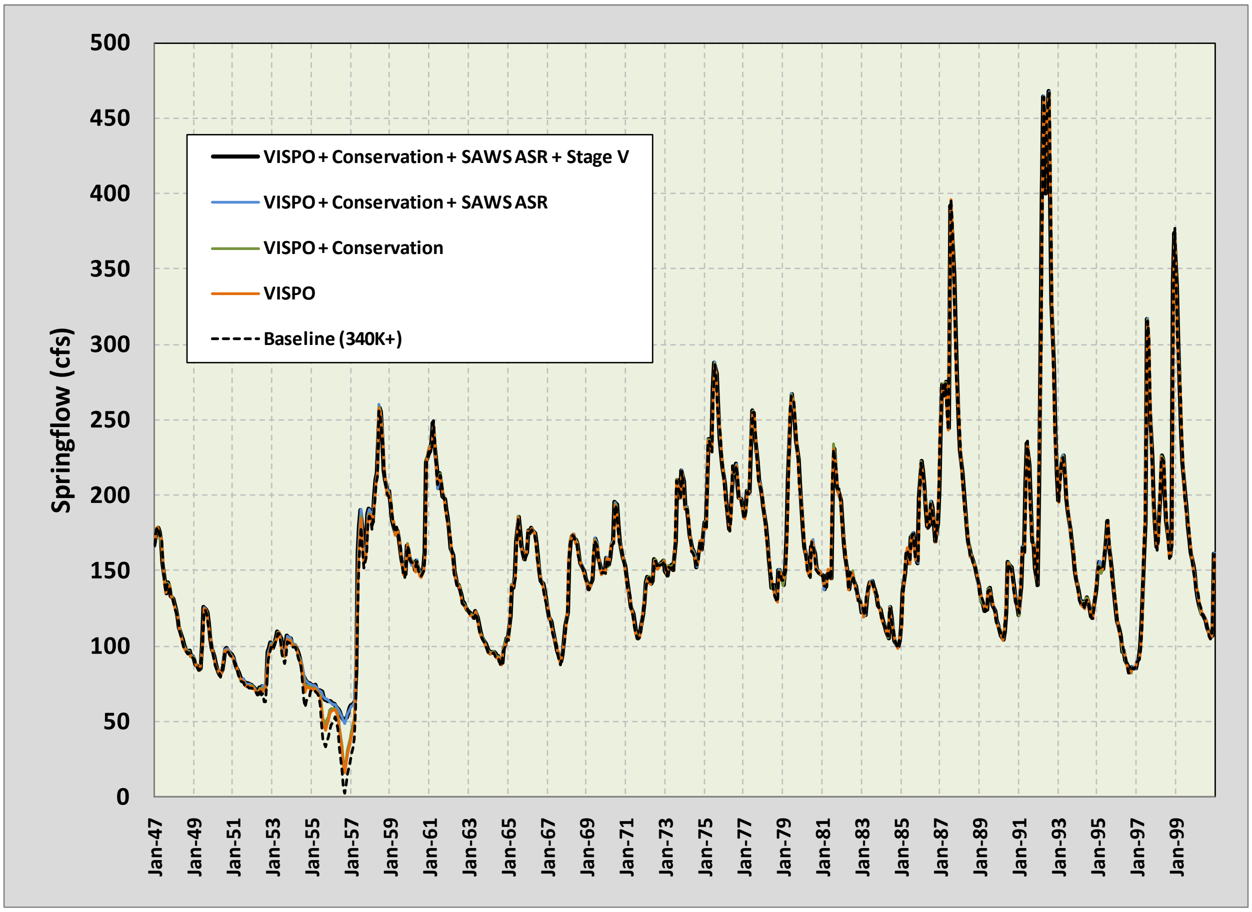


Figure 3-12. Simulated Springflow at San Marcos Springs (1947-2000)

3.3.2 Frequency of Springflow below Thresholds

A measure of considerable importance in the protection of endangered species is the number of months that springflow at Comal Springs and San Marcos Springs is below selected thresholds. Counts of the monthly occurrences for the selected thresholds of springflow are presented in Table 3-6 for the period 1947-2000. Review of these results shows very substantial improvement in springflow protection with VISPO and SAWS ASR. Selected critical thresholds are 45 cfs at Comal Springs and 52 cfs at San Marcos Springs. This table of monthly values from the model shows that there were no months of zero springflow and seven and two months below the thresholds at Comal and San Marcos, respectively, for these critical conditions. Earlier studies of low flow conditions suggest that the minimum daily flow at Comal Springs and San Marcos Springs may be about 15 cfs and 8 cfs, respectively, lower than the monthly value calculated by MODFLOW.

Table 3-6.
Number of Occurrences of Springflow Below Selected Thresholds (1947-2000)

Spring	Threshold (cfs)	Number of Months				
		Baseline	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
Comal	0	38	26	21	0	0
	30	54	36	34	2	2
	45	62	47	41	11	7
	60	73	59	56	27	21
	100	122	112	101	90	84
San Marcos	0	0	0	0	0	0
	25	6	3	3	0	0
	52	20	14	12	3	2
	75	47	47	46	39	39
	100	121	118	116	114	114

3.3.3 Frequency of CPM

Water users in the Edwards are interested in the amount of time that their permits will have CPM restrictions. These results for the period 1947-2000 are summarized for the San Antonio Pool on the basis of J-17 water levels for all CPM stages for the Bottom-Up Program in Table 3-7. These results show that the number of months with no CPM constraints generally increased for each Bottom-Up layer, which, obviously is an improvement over the baseline conditions. However, the amount of time in Stage I increased in an amount that generally offset the improvement for no CPM conditions. In the more severe Stage II to IV CPM restrictions, the number of months generally became less with each successive Bottom-Up layer. Stage V only applies to the last layer of the Bottom-Up Program.

Table 3-7.
Number of Occurrences of CPM in San Antonio Pool (1947-2000)

Stage, as indicated by Comal Springs, except for Stage V	Number of Months				
	Baseline	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
None	205	207	214	226	227
I	71	77	84	96	96
II	151	155	151	140	140
III	99	97	98	96	101
IV	122	112	101	90	78
V	0	0	0	0	6

3.3.4 Springflow Statistics

A few key statistics of importance to biologists in evaluating the performance of springflow protection from the Bottom-Up Program are minimum springflow, minimum 6-month moving average springflow, and long-term average springflow. These statistics are presented for the period 1947-2000 in Table 3-8 for Comal and San Marcos Springs. As shown in this summary, the minimum monthly average springflows for Comal Springs and San Marcos Springs are 27 and 51 cfs, respectively, for the full Bottom-Up Program. The minimum 6-month moving average springflows for Comal Springs and San Marcos Springs are 39 and 53 cfs, respectively. The long-term average springflows are 196 cfs at Comal Springs and 155 cfs at San Marcos Springs.

3.3.5 Impact on Surface Water Rights

In addition to benefiting endangered species at and near Comal and San Marcos Springs, the Bottom-Up Program also provides benefits to environmental flows and holders of water rights in the Comal, Guadalupe, and San Marcos Rivers downstream of the springs. As expected, this benefit is most significant during severe droughts when one or more layers of the Bottom-Up Program are active.

Table 3-8.
Selected Springflow Statistics (1947-2000) in Cubic Feet per Second

Spring	Statistic	Baseline (348K+)	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
Comal	Minimum Month	0	0	0	15	27
	Minimum 6-Month Moving Average	0	0	0	31	39
	Long-Term Average	178	182	186	195	196
San Marcos	Minimum Month	2	16	19	49	51
	Minimum 6-Month Moving Average	12	25	29	53	53
	Long-Term Average	153	153	154	154	155

Benefits to streamflow and water rights are based on hydrologic simulations and water availability calculations performed using the Guadalupe – San Antonio River Basin Water Availability Model (GSA WAM)[7] as modified and refined for use in development of the 2011 South Central Texas Regional Water Plan[8]. The GSA WAM is a monthly time-step computer model used to estimate regulated streamflow and water available for diversion under existing water rights on a priority basis subject to technical assumptions regarding natural, anthropogenic, and legal factors. Changes in streamflow and water availability can be expressed with several statistics. Considering the local setting, the most significant statistics for indicating streamflow changes associated with implementation of the Bottom-Up Program are: (1) minimum month, (2) minimum year, and (3) long-term average. The most representative statistic for indicating changes in water available for diversion or water availability is assumed to be minimum year.

[7] HDR Engineering, Inc., "Water Availability in the Guadalupe – San Antonio River Basin," Texas Natural Resource Conservation Commission (Contract# 9880059200), December 1999.
[8] South Central Texas Regional Water Planning Group, "South Central Texas Regional Water Planning Area, 2011 Regional Water Plan," Texas Water Development Board, San Antonio River Authority, HDR Engineering, Inc., et al., September 2010.

Simulated benefits to streamflows are shown in Table 3-9 for the San Marcos River at Luling, Guadalupe River at Victoria, and freshwater inflow to the Guadalupe Estuary. These benefits are constrained by GSA WAM design and operational procedures. During the most critical month, which is assumed to be August 1956, the monthly average streamflow increased by 40 cfs, 8 cfs, and 0 cfs at Luling, Victoria, and the Estuary, respectively. For the minimum year (1956), streamflow increased by 24 cfs, 41 cfs, and 18 cfs at these three locations, respectively. For the 1947-1989 period, long-term average flows increased by 2 cfs, 16 cfs, and 18 cfs at Luling, Victoria, and the Estuary, respectively. Surface water analyses were performed prior to final simulation of the adopted Bottom-Up Program so non-substantive differences may be apparent in comparison of springflow values in Table 3-9 with others in Section 3.3.

Table 3-9.
Improvement of Streamflows at Selected Locations Due to Bottom-Up Program

	Comal Springs Discharge (cfs)	San Marcos Springs Discharge (cfs)	San Marcos River at Luling Streamflow (cfs)	Guadalupe River at Victoria Streamflow (cfs)	Freshwater Inflow to the Guadalupe Estuary (cfs)
Minimum Month (August 1956) Springflows and Streamflows					
Baseline	0	7	21	27	1
Bottom Up Program	25	51	61	34	1
Increase	25	45	40	8	0
Average during Minimum Year (1956) Springflows and Streamflows					
Baseline	0	29	44	83	76
Bottom Up Program	50	57	68	125	94
Increase	50	27	24	41	18
Annual Average (1947-1989) Springflows and Streamflows					
Baseline	167	146	351	1,550	2,264
Bottom Up Program	189	189	352	1,568	2,280
Increase	22	43	2	18	16

The primary benefits to holders of surface water rights in the Guadalupe - San Antonio River Basin are assumed to be represented by the minimum annual diversion. These benefits are summarized for the top ten beneficiaries or holders of municipal, industrial/steam-electric, irrigation, hydropower, and other water rights in Tables 3-10a-e, respectively. The greatest beneficiary category in terms of reliable water supply is industrial/steam-electric use with four rights each gaining more than 3,200 acft during the minimum year (Table 3-10b). The greatest benefits for municipal and irrigation water rights during this minimum year are increases of 1,725 acft (Table 3-10a) and 1,941 (Table 3-10c) acft, respectively. In summary, the annual benefits to the top ten municipal, industrial/steam-electric, and irrigation water rights total 2,666 acft, 15,608 acft, and 2,530 acft, respectively. Benefits to hydropower water rights are summarized in Table 3-10d and based on unappropriated flow passing the hydropower facility location rather than consumptive use of diverted and/or impounded water. Results in Table 3-10d should not be directly compared to those for all other surface water use types because hydropower is a non-consumptive water use. Benefits to water rights with other purposes (Table 3-10e) are limited.

Table 3-10.
Benefits to Holders of Surface Water Rights for Minimum Year

a. Municipal

Owner	Water Right	Authorized Permitted Diversion (acft/yr)	Use Type	Minimum Annual Diversion (acft/yr)		
				Baseline	Bottom Up Program	Increase
GUADALUPE-BLANCO RIVER AUTH (Canyon)	C2074	90,000	Municipal	87,675	89,400	1,725
SEGUIN MUNICIPAL UTILITIES	C3839	7,000	Municipal	6,454	7,000	546
GUADALUPE-BLANCO RIVER AUTH (Luling)	C3896	1,500	Municipal	99	216	117
GUADALUPE-BLANCO RIVER AUTH (Luling)	C3896	1,300	Municipal	0	86	86
JOHN F BAUGH (CRWA)	C3888	320	Municipal	112	158	46
STATE BANK & TRUST COMPANY (Victoria)	C3895	580	Municipal	37	78	42
COMAL CO FRESH WSD #1	P4491	120	Municipal	23	60	37
W L LIPSCOMB ET AL (Victoria)	C3860	260	Municipal	145	174	29
CITY OF SAN ANTONIO	C2162	100	Municipal	72	100	28
PRESBYTERIAN MO-RANCH ASSEMBLY	C1932	60	Municipal	40	50	10

b. Industrial/Steam-Electric

Owner	Water Right	Authorized Permitted Diversion (acft/yr)	Use Type	Minimum Annual Diversion (acft/yr)		
				Baseline	Bottom Up Program	Increase
CITY OF SAN ANTONIO (CPS, Calaveras)	C2162	36,900	Steam-Electric	32,739	36,900	4,162
CITY OF SAN ANTONIO (CPS, Braunig)	C2161	12,000	Steam-Electric	6,484	10,591	4,106
GBRA - Exelon	C5178	75,000	Steam-Electric	47,642	51,363	3,721
INVISTA (DU PONT)	C3861	33,000	Industrial	26,117	29,365	3,248
MISSION VALLEY TEXTILES, INC	C3829	500	Industrial	289	500	211
SOUTH TEXAS ELECTRIC COOP INC	C3859	1,900	Steam-Electric	456	589	133
STRUCTURAL METALS INC	C3837	34	Industrial	21	34	13
SOUTHWEST TEXAS STATE UNIV	C3866	60	Industrial	22	31	9
CPS ENERGY (CITY OF SAN ANTONIO)--CALAVERAS	C2162	11	Steam-Electric	8	11	3
TOMMIE SMITH BLACKBURN	C1969	15	Industrial	9	11	2

c. Irrigation

Owner	Water Right	Authorized Permitted Diversion (acft/yr)	Use Type	Minimum Annual Diversion (acft/yr)		
				Baseline	Bottom Up Program	Increase
GBRA - Irrigation	C5178	11,000	Irrigation	5,830	7,771	1,941
WILLIAM K ANDERSON ET UX	P5107	518	Irrigation	23	140	118
KING RANCH INC	C3848	1,800	Irrigation	1,694	1,800	106
SEGUIN MUNICIPAL UTILITIES	C3839	200	Irrigation	121	200	79
KENNETH W WHITEWOOD ET UX	C2006	320	Irrigation	51	109	58
HARRY J WRAY	C2025	155	Irrigation	48	100	51
MIGUEL CALZADA URQUIZA ET UX	C3899	1,180	Irrigation	168	215	47
BOENING ENTERPRISES	P3994	1,056	Irrigation	24	70	45
ERWIN KLEMSTEIN	C2050	136	Irrigation	31	75	43
ZARCO FOWARDING, INC	C2052	232	Irrigation	37	79	42

d. Hydropower

Owner	Water Right	Authorized Permitted Diversion (acft/yr)	Use Type	Minimum Annual Diversion (acft/yr)		
				Baseline	Bottom Up Program	Increase
NEW BRAUNFELS UTILITIES	C3824	124,870	Hydroelectric	2,511	38,585	36,074
GUADALUPE-BLANCO R A TP-1	C5488	663,892	Hydroelectric	1,321	24,964	23,643
GUADALUPE-BLANCO R A TP-5	C5488	624,781	Hydroelectric	2,333	25,960	23,626
GUADALUPE-BLANCO R A TP-3	C5488	659,995	Hydroelectric	1,310	24,766	23,456
GUADALUPE-BLANCO R A TP-4	C5488	655,323	Hydroelectric	1,305	24,662	23,358
GUADALUPE-BLANCO R A H-4	C5172	585,599	Hydroelectric	4,608	27,358	22,751
GUADALUPE-BLANCO R A H-5	C5172	574,832	Hydroelectric	4,892	27,292	22,400
SOUTHWEST TEXAS STATE UNIV	C3865	64,370	Hydroelectric	22,137	41,991	19,854
CITY OF GONZALES	C3846	796,363	Hydroelectric	0	1,554	1,554
CUERO HYDROELECTRIC, INC.	C3853	538,560	Hydroelectric	0	1,392	1,392

Note: Minimum Annual Diversion values reported in this table are unappropriated streamflows passing through hydropower facilities and do not include concurrent appropriated streamflows passing through hydropower facilities while in delivery to downstream senior water rights.

e. Other

Owner	Water Right	Authorized Permitted Diversion (acft/yr)	Use Type	Minimum Annual Diversion (acft/yr)		
				Baseline	Bottom Up Program	Increase
TEXAS PARKS & WILDLIFE DEPT	C3869	500	Fish Hatchery	418	500	82
JIM STORY	STORY	400	Unknown	0	20	20
SHELTON RANCH CORPORATION	C2003	10	Mining	6	8	3
DARRELL G LOCHTE ET AL	C1997	20	Mining	10	10	0.1

3.4 Cost Estimates

As discussed earlier, the Bottom-Up Program is a key component of the Initial Adaptive Management Phase. Accordingly, the concept is to postpone decisions regarding the need for engineering solutions to later phases and adopt management alternatives to the extent possible. Using this concept for guidance, none of the selected alternatives in the Bottom-Up Program requires new facilities. Instead, the water management alternatives can be developed under existing EAA rules and with SAWS existing facilities. As a result, the cost basis for the water management alternatives was largely prepared by EARIP work groups. The cost estimates presented herein for the Bottom-Up Program do not include administrative or management costs, which are assumed to be provided by the sponsoring stakeholders and without cost to the EARIP.

3.4.1 Assumptions and Definitions

The costs bases for the VISPO, Municipal Conservation, and SAWS ASR components of the Bottom-Up Program were provided by EARIP Work Groups and processed by HDR. Where Edwards irrigation IRPs are to be procured, the contractual arrangements are assumed to be leases or temporary contracts instead of purchases. A background summary for the cost of each program component follows:

- **VISPO:** The tentative working proposal for the VISPO Work Group is to offer holders of irrigation permits either a 5-year or 10-year option under which EARIP would pay a standby fee and an implementation fee. For a 5-year commitment, the standby fee ($50.00/ acft/yr) would escalate at a rate of 1.5 percent per year for 10 years in the program, and the implementation fee ($150.00/ acft/yr) would escalate at the rate of 3 percent per year. For the 10-year commitment, the standby fee would be $57.50/ acft/yr for the first five years and $70.20/acft/yr for the second five years; and, the implementation fee would be $172.50/ acft/yr for the first five years and $210.60/ acft/yr for the second five years. For purposes of this EARIP report, it is assumed that: (1) 70 percent of the leases are in the 5-year option and 30 percent are in the 10-year option, and (2) the annual fee per acft of water for the 1947-2000 period is the composite average fee for the first ten years for leases under 5-year option and the first 10 years for leases under the 10-year option. The long-term average annual cost is based on an annual calculation that considers the standby each year and the and whether or not the implementation fee as needed.
- **Municipal Conservation:** The Conservation Work Group provided the following guidelines:

  List of elements and their initial cost and annual pumping reductions:

  - High Efficiency Toilets: $12,000,000 (1,531 acft/yr)
  - High Efficiency Water Fixtures: $480,000 (1,286 acft/yr)

- Lost Water (Reducing leaks or lost water in small municipal water systems): $3,750,000 (3,750 acft/yr)
- Large Scale Retrofit (Supporting industries): $2,500,000 (2,500 acft/yr)
- Landscape: $1,000,000. (1,000 acft/yr)

Implementation of the 10-year option is assumed to occur evenly over 10 years.

As envisioned by the Conservation Work Group, these are incentive programs so the costs shown are those potentially borne by the EARIP. Total costs to obtain water savings and pumping reductions may be substantially greater.

- **SAWS ASR with Trade-Off Option:** The concept is to obtain leases and options on 50,000 acft/yr of Initial Regular Permits (IRPs) on Edwards Aquifer irrigation and other permits. The leases and options will be divided into thirds (tiers). The first third, approximating 16,667 acre-feet of permits, will be leased at all times. The middle third and final third of the leases would be implemented during moderate and severe drought conditions, respectively. The first third of the leases (continual) are assumed to cost $125/acft/yr. For the second and third tiers, lease costs have two elements. One is a standby cost, which is assumed to be $40/acft/yr, and would occur each year; and the other is an implementation cost of $150/acft/yr, which would be paid only when the second and third tiers are implemented. The tentative working EARIP-SAWS agreement is that SAWS would: (1) waive costs equivalent to depreciation of a third of the $250,000,000 asset over 30 years on a straight line basis, and (2) be reimbursed $3,080,000 per year for water treatment, power, and other operations and maintenance expenses.
- **Stage V:** The EARIP did not develop guidelines on an appropriate method of estimating these costs. As general information, HDR has presented a range of water supply alternatives that may be considered to replace an equivalent of 27,400 acft/yr on an intermittent basis. The unit costs for these alternatives are from the 2011 South-Central Texas Regional Water Plan. These alternatives and the assumed unit cost include:
  - Irrigation water conservation ($160/acft/yr),
  - Municipal water conservation ($600/acft/yr),
  - Near-term water management strategies for SAWS ($1,300/acft/yr),
  - Long-term water management strategies for SAWS ($2,300/acft/yr), and
  - Drought management ($150/acft/yr to $15,000+/acft/yr).

One concept for implementing the SAWS water management strategies is for the EARIP or others to sponsor a new water supply for SAWS. In exchange, SAWS would temporarily transfer a prorated amount of their Edwards permits or leases to these sponsors (e.g., outlying municipalities).

3.4.2 Summary

A summary of the estimated cost, not including administrative and management costs, is provided in Table 3-11 for layers 1-3 and Table 3-12 for layer 4. The greatest annual cost is for

Edwards water leases, which average $12,395,000 per year over 1947-2000 conditions. The total annual cost is estimated to be $15,475,000. The most costly layers are VISPO and SAWS ASR. It's important to note that these two program components also have the greatest impact on springflow protection.

Table 3-11.
Estimated Costs for Layers 1-3 of Bottom-Up Program

Program Component	Investment	Annual (54-Year Average)			
		Edwards Water Leases	Depreciation	O&M	Total
Layer 1: VISPO (10-Year Option)	N/A	$4,172,000	N/A	N/A	$4,172,000
Layer 2: Municipal Conservation (10-Year Program)	$19,730,000	$1,973,000	N/A	N/A	$1,973,000
Layer 3: SAWS ASR	N/A	$6,250,000	Waived	$3,080,000	$9,330,000
Total (Layers 1-3)	**$19,730,000**	**$12,395,000**	**$0**	**$3,080,000**	**$15,475,000**

Table 3-12.
Range of Estimated Costs for Layer 4 of Bottom-Up Program

Alternative (from 2011 Region L Water Plan)	Unit Cost (acft/yr)	Annual Cost
Irrigation Water Conservation	$140	$3,836,000
Municipal Water Conservation	$600	$16,440,000
Near-Term Water Management Strategies for SAWS	$1,300	$35,620,000
Long-Term Water Management Strategies for SAWS	$2,300	$63,020,000
Drought Management	$150 to $15,000+	$4,110,000 to $411,000,000+
Note: Annual cost is based on acquiring 27,400 acft/yr.		

4 Technical Evaluations of Alternative Programs

The exploratory process leading up to the selection of the Bottom-Up Program consisted of identifying and conducting technical evaluations of five alternative programs, with each having one or more options (also called optimization runs). These alternative programs, descriptions of optimization runs, and very brief descriptions of the concepts are presented in Table 4-1. They are discussed in more detail in the following sections.

Table 4-1.
Listing of Alternative Programs and Optimization Runs

Program Name	Concept	Optimization Runs
Aquifer Storage and Recovery (ASR)	• Pumps leased or purchased Unrestricted Edwards Irrigation Permits. • Stores Edwards water in the Carrizo Aquifer in the vicinity of Cibolo Creek in Wilson County. • Recovers the Edwards water for direct springflow protection during droughts. • Injects the water into the Edwards Aquifer with wells between Cibolo Creek and Comal Springs.	1. Baseline pumping restrictions by CPM set to SB3, which is about a 348,000 acft/yr "floor" in Stage IV. 2. Increase CPM Stage IV pumping restrictions to result in about a 320,000 acft/yr "floor." 3. Increase CPM Stage IV pumping restrictions to result in about a 286,000 acft/yr "floor." Options: a) Lease Irrigation Permits. b) Purchase Irrigation Permits.
Combination	• Concept is similar to the Bottom-Up Program in that alternatives are incrementally stacked in a cumulative process. • As with the Bottom-Up Program, the cumulative results would be different if the four alternatives were analyzed individually and then added together.	1. Enhanced recharge at selected Type II structures. 2. Combination Run #1 plus VISPO. 3. Combination Run #2 plus Land Stewardship. 4. Combination Run #3 plus SAWS ASR.

Table 4-1. (Continued)

Program Name	Concept	Optimization Runs
Recharge and Recirculation (R&R)	• Integrates recharge enhancement from selected Type II structures and unrestricted irrigation permits. • From a well field in Medina County and under selected criteria, pump (recirculate) the permitted water and enhanced recharge water from Type II structures to recharge structures. • When Comal trigger is in effect, cease recirculation, but continue to pump irrigation permits and recharge the water at Hondo and Verde recharge sites. • Enhanced recharge that is missed when trigger is in effect, but remaining in the aquifer, can be recovered and recirculated under selected criteria, including recovery and recirculation having to occur within 2 years of recharge.	1. Comal trigger is set at 150 cfs and Recharge is split 50-50 between Hondo and Verde recharge sites. 2. Comal trigger is set at 100 cfs and Recharge is split 50-50 between Hondo and Verde recharge sites. 3. Comal trigger is set at 100 cfs and Recharge is split 75-25 between Hondo and Verde recharge sites. 4. Comal trigger is set at 30 cfs and Recharge is split 75-25 between Hondo and Verde recharge sites.

Table 4-1. (Concluded)

Trade-Off: Bexar County	• Pumps leased, unrestricted Edwards Irrigation Permits.
	• Stores the water in SAWS ASR facility in South Bexar County.
	• Recovers the water for springflow protection during droughts.
	• Evaluates three ways to provide water for springflow protection:
	  o Trade-off
	  o Direct Recharge
	  o Indirect Recharge
	• Each variant is evaluated with either an ON-OFF switch or episodic recharge pattern.
		1. Trade-Off: Uses SAWS ASR to Offset SAWS Pumping that would otherwise occur
		2. Direct Recharge: Uses SAWS ASR to provide direct recharge of recovered water via an injection well field near Comal Springs
		3. Indirect Recharge: SAWS ASR recovered water is delivered to Artesia and Seale and an equal amount of water is transferred from Naco and Stahl to direct recharge via an injection well field near Comal Springs
		Options:
		a) ON-OFF: SAWS ASR water recovery is either off or at full capacity
		b) Episodic recovery pattern to Optimize water requirements and springflow protection

Trade-Off: Comal and Hays Counties	• Increase CPM pumping reductions for Municipal and Industrial users near New Braunfels and San Marcos and replace the amount of curtailed pumping that is below SB3 pumping reductions with an outside supply. • The framework of this concept utilizes enhanced recharge from selected Type II structures, stores this water in a Carrizo ASR well field, recovers the water during severe drought and delivers this water as a replacement to New Braunfels and San Marcos in exchange for additional CPM restrictions.	1. Approximate balance of ASR storage and off-set water requirements.

The measure of springflow protection for each of the alternatives and options under consideration is summarized by tabulating the number of months that Comal and San Marcos Springs have monthly springflow less than selected thresholds and important springflow statistics for each model run. These results are based on the 1947-1973 simulation period including the drought of record. For comparison purposes, results of the baseline simulation are included. Springflow hydrographs are not included in this report, but are available in HDR presentations on the EARIP web site.

4.1 Springflow Protection Alternatives

4.1.1 Aquifer Storage and Recovery (ASR)

The overall concept of ASR is to store water during times of plenty and to recover stored water in times of shortage.

Major assumptions for the ASR alternative program include:

- The overall baseline pumping in the Edwards is IRPs to the extent available subject to Critical Period Management (CPM). This results in a minimum (nominal) permitted pumping level of approximately 348,000 acft/yr (excluding domestic and livestock and Federal uses) during Stage IV.
- The selected supply of water for storage in ASR is unrestricted Edwards irrigation permits; and, the amount is assumed to be 66,700 acft/yr (approximately equivalent to 40,000 acft/yr during CPM Stage IV), which will be leased from irrigators in Uvalde, Medina, and Bexar Counties. The necessary leases will only be procured and pumped as needed to fill the ASR and to replace minor losses from ASR storage. Leases instead of purchases are selected because the water is only needed temporarily to fill or refill ASR storage.
- The leased irrigation permits will be pumped from Edwards wells in northeastern Bexar County. The allowable pumping will be subject to CPM rules, hence associated withdrawals range from 40,000 to 66,700 acft/yr.
- The pumped water will be stored in the Carrizo Aquifer in Wilson County near Cibolo Creek using conventional ASR facilities.
- Water leases will be on an annual basis.

ASR operational plans are:

- At the beginning of the model simulation, acquired permits are pumped from a northeast Bexar County well field until the estimated amount of water needed to fill storage for springflow protection is achieved. Allowable pumpage is to be consistent with CPM rules.
- Transport pumped Edwards water by pipeline to the Carrizo ASR facilities in Wilson County.
- Store the Edwards water in the ASR facilities until needed. After being filled, a small percentage of Edwards water will continue to be pumped and stored in ASR to overcome any losses and to maintain the Edwards water bubble around the ASR wells.

- When the flow from Comal and San Marcos Springs nears appropriate trigger levels, begin recovering the water from ASR storage and deliver to Edwards recharge facilities near Cibolo Creek. Edwards recharge will be accomplished using injection wells and/or surface recharge structures.
- Experimental MODFLOW simulations show that recharge in the Edwards outcrop in the area between Cibolo Creek and Comal Springs has substantial benefit to San Marcos Springs and limited benefit to Comal Springs. The use of injection wells in the confined portion of the Edwards aquifer targeting a conduit between Cibolo Creek and Comal Springs greatly benefits Comal and has lesser benefits to San Marcos.
- The schedule of recovery of the stored water was developed to nearly optimize the storage of water in ASR while maintaining minimum Comal springflow at rates between 30 and 60 cfs during the drought of record.

The physical facilities associated with the ASR Program (Figure 4-1) include:

- An Edwards well field and raw water collection system is to be located in the general vicinity of Loop 1604 and I-35 in northeast Bexar County.
- An ASR well field will be constructed in the Carrizo Aquifer and is expected to be located in northwest Wilson County and in the vicinity of Cibolo Creek.
- A main pipeline will deliver water from the Edwards well field to the ASR well field for storage during the fill cycle. During the recovery cycle, the direction of flow in part of this main pipeline will be reversed for the delivery of recovered water from ASR to recharge facilities between Cibolo Creek and Comal Springs. One pump station is needed for the fill cycle; and, two pump stations will be required for the recovery cycle.
- Experimental MODFLOW simulations suggest that injection wells will be required for the desired springflow enhancement at Comal Springs. These injection wells are expected to be northeast of Cibolo Creek.

Scale optimization runs include:

- Run #1: Maintain current SB3/EAA CPM pumping restrictions.
- Run #2: Revise Stage IV CPM pumping reductions so that the minimum permitted pumping during severe drought is 320,000 acft/yr.
- Run #3: Revise Stage IV CPM pumping reductions so that the minimum permitted pumping during severe drought is 286,000 acft/yr.
- These three scale optimization runs are made for: (1) purchase of the irrigation permits and (2) leasing of irrigation permits. When the permits are purchased, they are permanently assigned to ASR and are only used to fill ASR storage or to overcome losses. Otherwise, they are not pumped. When the permits are leased, the water is procured on an annual basis as needed (when not needed for ASR, it is assumed to be used by irrigators). As a result, less water is being pumped from the aquifer with the purchase arrangement than with the lease arrangement.

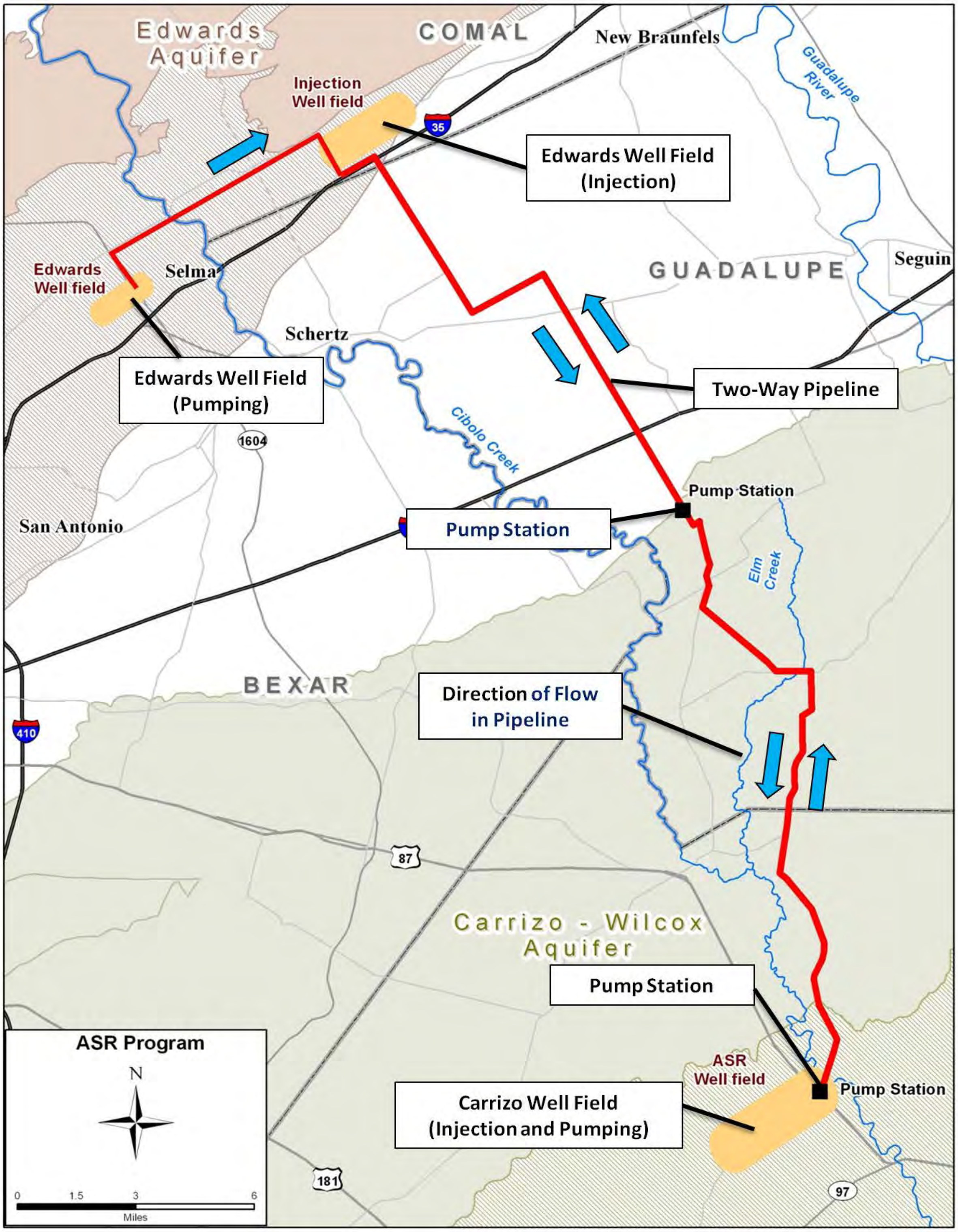


Figure 4-1. Schematic of ASR Program

Results summarizing the number of months when simulated springflows at Comal and San Marcos Springs are below given thresholds for the baseline and Runs #1, #2, and #3 with the irrigation purchase and lease options are presented in Tables 4-2a and 4-2b, respectively. These results suggest the following:

- Comal Springs:
  - Both the purchase and lease irrigation permit options for all three runs can keep the springs flowing during the drought of record. Minimum monthly average flow is greater than 30 cfs only for Run #3 in which Stage IV CPM reductions result in permitted pumping of about 286,000 acft/yr.
  - For the 30 cfs threshold, the springflow results are sensitive to the selected ASR recovery rates and schedule, called episodic recharge. This episodic recharge was developed in a trial and error process of making estimates of the rates and schedule and running MODFLOW. The selected episodic recharge reflects a reasonable level of optimization in consideration of the available water supply, water system limitations, and springflow protection. Minor irregularities in the statistics among the ASR simulations are attributed to the limited effort to optimize the episodic recharge among the various simulations.
  - The purchase of irrigation permits, in comparison to leased permits, noticeably reduces the number of months below given thresholds at 60 cfs and greater.
- San Marcos Springs:
  - The results throughout the range of thresholds show substantial improvement in springflow over the baseline conditions for flow thresholds less than 80 cfs.
  - Little to no improvement in springflow is noted for higher springflow thresholds.

Selected statistical summaries for Comal and San Marcos Springs for the baseline and Runs #1, #2, and #3 with the irrigation purchase and lease arrangements are presented in Tables 4-3a and 4-3b, respectively. These results suggest the following:

- Comal Springs:
  - No flow occurred under the baseline scenario for more than six consecutive months. With the ASR alternative, minimum springflow increased to at least 23 cfs, and minimum 6-month moving average springflow increased to at least 30 cfs.
  - Increasing the reduction percentages in Stage IV in Runs #2 and #3 tended to cause the minimum springsflows to increase.
  - The purchase of irrigation permits, in comparison to leaseing permits, noticeably increases long-term average springflows.
- San Marcos Springs:
  - The results for the minimum and 6-month minimum moving average are substantially improved over baseline conditions.

- Increasing the reduction percentages in Stage IV in Runs #2 and #3 increased the minimum springflows for the minimum and 6-month minimum moving average by about 5 cfs.
- Little to no improvement in springflow is noted for the long-term average.
- The purchase and lease of irrigation water produces almost identical results.

Table 4-2.
Number of Months with Springflow below Selected Thresholds for ASR Program (1947-1973)

a. Purchase of Water Rights

Spring	Threshold (cfs)	Number of Months					
		Baseline (348K)	Baseline (320K)	Baseline (286K)	Run #1- Purchase (348K Base)	Run #2- Purchase (320K Base)	Run #3- Purchase (286K Base)
Comal	0	38	22	10	0	0	0
	30	54	34	18	6	3	0
	60	73	60	37	44	28	20
	90	110	93	74	89	64	55
	120	145	139	135	134	121	111
San Marcos	0	0	0	0	0	0	0
	52	20	12	5	4	3	0
	80	52	51	46	49	48	46
	100	108	103	97	104	102	95
	120	147	146	146	146	146	145

b. Lease of Water Rights

Spring	Threshold (cfs)	Number of Months					
		Baseline (348K)	Baseline (320K)	Baseline (286K)	Run #1- Lease (348K Base)	Run #2- Lease (320K Base)	Run #3- Lease (286K Base)
Comal	0	38	22	10	0	0	0
	30	54	34	18	1	2	0
	60	73	60	37	56	43	25
	90	110	93	74	107	88	69
	120	145	139	135	150	139	134
San Marcos	0	0	0	0	0	0	0
	52	20	12	5	4	2	0
	80	52	51	46	50	48	46
	100	108	103	97	106	101	97
	120	147	146	146	146	146	146

Table 4-3.
Selected Springflow Statistics for ASR Program (1947-1973)

a. Purchase of Water Rights

Springflow for Selected Conditions (1947-1973)							
Spring	Statistic	Springflow (cfs)					
		Baseline (348K)	Baseline (320K)	Baseline (286K)	Run #1- Purchase (348K Base	Run #2- Purchase (320K Base	Run #3- Purchase (286K Base)
Comal	Minimum Month	0	0	0	23	25	40
	Minimum 6-Month Moving Average	0	0	0	30	31	44
	Long-Term Average	126	134	141	142	151	156
San Marcos	Minimum Month	2	19	37	48	50	53
	Minimum 6-Month Moving Average	12	29	45	51	53	56
	Long-Term Average	127	129	131	130	131	131

b. Lease of Water Rights

Springflow for Selected Conditions (1947-1973)							
Spring	Statistic	Springflow (cfs)					
		Baseline (348K)	Baseline (320K)	Baseline (286K)	Run #1- Lease (348K Base	Run #2- Lease (320K Base	Run #3- Lease (286K Base)
Comal	Minimum Month	0	0	0	30	25	38
	Minimum 6-Month Moving Average	0	0	0	35	41	46
	Long-Term Average	126	134	141	132	139	145
San Marcos	Minimum Month	2	19	37	48	50	53
	Minimum 6-Month Moving Average	12	29	45	51	54	56
	Long-Term Average	127	129	131	130	130	131

4.1.2 Combination

The alternative Combination Program consists of four major components, including: (a) Selected Type II Recharge Structures, (b) Voluntary Irrigation Suspension Program Option (VISPO), (c) Land Stewardship in the Guadalupe River watershed upstream of Canyon Reservoir, and (d) SAWS ASR Trade-Off Option with supplies coming from SAWS existing ASR well field in South Bexar County.

Major assumptions for the Combination program include:

- Selected Type II Recharge Structures
    - Frio, Sabinal, Hondo, Verde, San Geronimo, Cibolo, and Salado-Flood Retarding Structures, identified as Program C in the 2011 Region L Water Plan.
    - Mitigation of impacts to Corpus Christi surface water rights in the Nueces River Basin and freshwater inflows to the Nueces Estuary.
    - Honor surface water rights in Guadalupe – San Antonio River Basin.
    - Consensus Criteria for Environmental Flow Needs (CCEFN) used to calculate surface water availability.
- Voluntary Irrigation Suspension Program Option (VISPO)
    - The schedule, rate of irrigation reduction, and costs were provided by the VISPO Work Group.
    - VISPO applies to about 20,000 acft/yr (IRP value) of Edwards pumping rights with 15,000 acft/yr in Medina County and 5,000 acft/yr in Bexar County.
    - Suspensions triggered on January 1 if the water level in J-17 is below 650 ft-msl on September 1 of the previous year.
- Land Stewardship
    - This component is adapted from the 2011 Region L Water Plan *(Section 4C.7 Brush Management (Above Canyon Reservoir)*).
    - The selected scenario for this water management strategy assumes 25 percent land-owner participation. For this level of participation, the Region L analysis shows that the firm yield of Canyon Reservoir may be increased by about 5,600 acft/yr (about 7.7 cfs).
    - Preliminary plans are to store and accrue the additional surface water supplies in Canyon Reservoir for subsequent delivery to the recharge zone for protection of San Marcos Springs.
    - A few months before anticipated critical springflow levels at San Marcos Springs, releases of the stored water will be made to the Guadalupe River for delivery by "bed and banks" (with due accounting for losses) to a tentative diversion point near New Braunfels.
    - From this point, the water would be delivered to York Creek for recharge facilitated in part by existing small reservoirs.
    - Element is intended to provide springflow protection to San Marcos Springs.

- SAWS ASR
  - 30 MGD for up to 200 days during Stage III.
  - 30 MGD for up to 200 days during Stage IV.
  - Total allocation of water stored in SAWS ASR facilities for this program is not to exceed 40,000 acft during a drought.
  - This supply will be used as source water for trade-off with SAWS, which will result in an equivalent reduction in SAWS' permitted Edwards pumping. Thus, it will not be delivered to recharge facilities near the springs for direct springflow protection. Instead, springflow protection will be accomplished through reduced pumping in Bexar County.

The physical facilities (Figure 4-2) include:

- Type II Enhanced Recharge: Construction of dams and other facilities.
- VISPO: None.
- Land Stewardship:
  - A program to be developed and administered with land management practices,
  - Facilities to divert water from Guadalupe River to York Creek for recharge enhancement.
- SAWS South Bexar ASR: No new facilities.

The stacking of the elements in the Combination Program includes:

- Run #1: Selected Type II structures.
- Run #2: Run #1 plus VISPO.
- Run #3: Run #2 plus Land Stewardship.
- Run #4: Run #3 plus SAWS ASR Trade-Off Option.

Results summarizing the number of months when springflows at Comal and San Marcos Springs are below specified thresholds for the baseline and Runs #1-#4 are presented in Table 4-4. These results suggest the following:

- Comal Springs:
  - The cumulative (stacked) runs with all components results in 17 months of no flow, which is down from 38 months in the baseline.
  - As compared to the baseline, the stacked runs produce improvement for all thresholds.
  - Land stewardship provides the least incremental improvements in number of months below springflow thresholds.
- San Marcos Springs:
  - The most significant improvements in springflow are apparent at the 52 cfs threshold.

- Little improvement is noted for springflow thresholds greater than 52 cfs.

Selected statistical summaries for Comal and San Marcos Springs for the baseline and Runs #1-#4 are presented in Table 4-5. These results suggest that:

- Comal Springs:
  - Flows during baseline conditions are zero for the minimum and 6-month minimum moving average for all layers in the stack.
  - The long-term average springflow is improved by up to 23 cfs.
- San Marcos Springs:
  - The results for the minimum and 6-month minimum moving average springflows are substantially improved over baseline conditions.
  - The long-term average springflow is improved by up to 6 cfs.

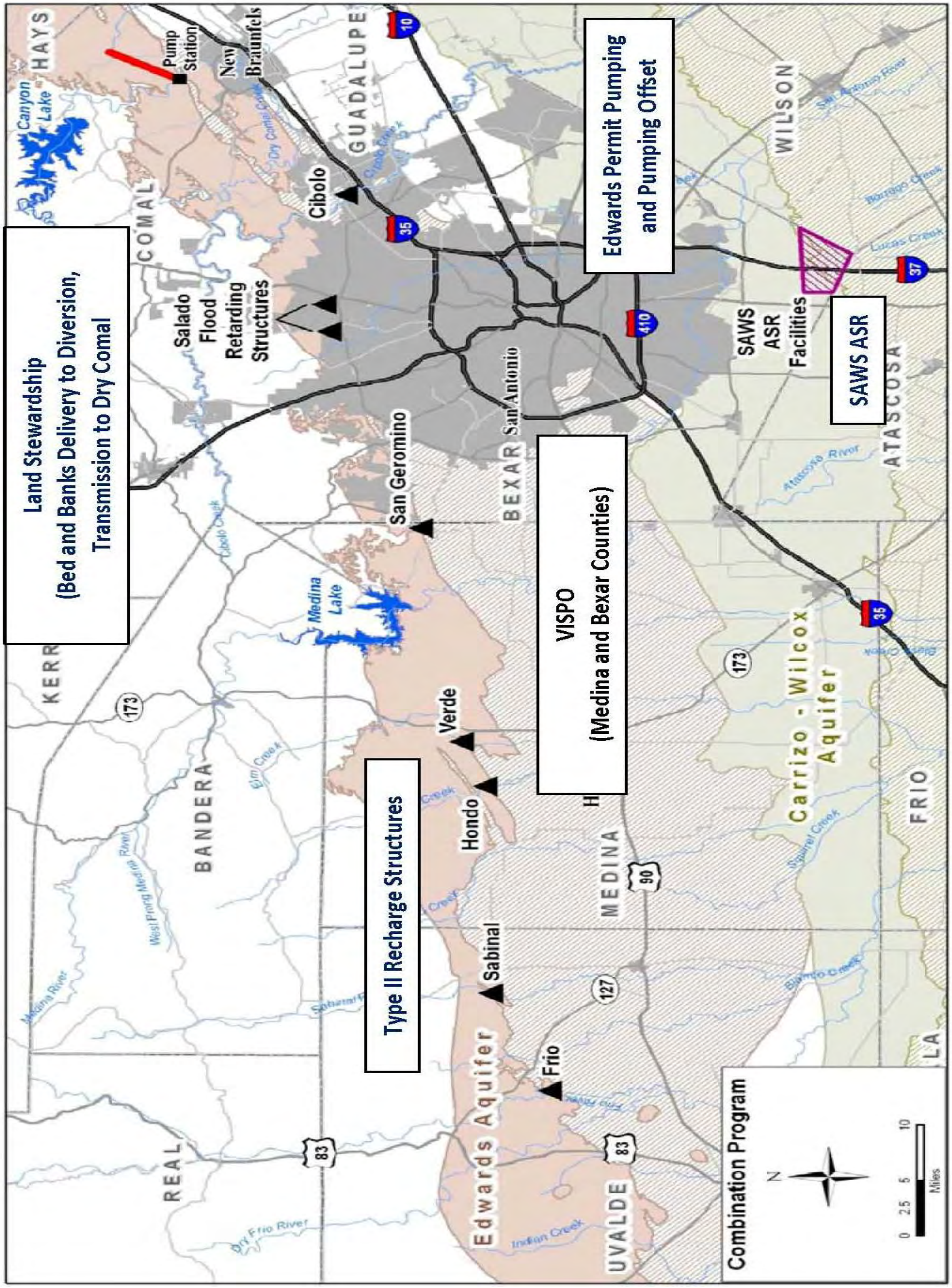


Figure 4-2. Schematic of Combination Program

Table 4-4.
Number of Months with Springflow below Selected Thresholds for Combination Program (1947-1973)

Springflow Duration below Given Thresholds (1947-1973)						
Spring	**Threshold (cfs)**	**Number of Months**				
		Baseline (348K)	**Run #1-Type II Structures**	**Run #2-Type II and VISPO**	**Run #3-Type II, VISPO and Land Stewardship**	**Run #4-Type II, VISPO, Land Stewardship and SAWS ASR**
Comal	0	38	34	26	23	17
	30	54	43	36	35	33
	60	73	66	56	56	51
	90	110	98	87	85	84
	120	145	131	122	122	122
San Marcos	0	0	0	0	0	0
	52	20	17	14	8	6
	80	52	50	50	49	48
	100	108	102	101	99	98
	120	147	143	143	141	141

Table 4-5.
Selected Springflow Statistics for Combination Program (1947-1973)

Springflow for Selected Statistics (1947-1973)							
Spring	Statistic	Springflow (cfs)					
		Baseline (348K)	Run #1- Type II Structures	Run #2- Type II and VISPO	Run #3- Type II, VISPO and Land Stewardship	Run #4- Type II, VISPO, Land Stewardship and SAWS ASR	
Comal	Minimum Month	0	0	0	0	0	
	Minimum 6-Month Moving Average	0	0	0	0	0	
	Long-Term Average	126	141	147	148	149	
San Marcos	Minimum Month	2	6	14	25	27	
	Minimum 6-Month Moving Average	12	16	23	35	37	
	Long-Term Average	127	131	131	132	133	

4.1.3 Recharge and Recirculation (R&R)

During the April 8, 2010 EARIP workshop, a special meeting was scheduled for April 21, 2010 with the purpose of providing some measure of consensus and direction to HDR and Todd Engineers regarding the definition of this alternative. Decisions from this meeting were intended to formulate fundamental assumptions for testing the performance of a preliminary technical evaluation of the R&R alternative. In advance of the April 21, 2010 meeting, Kirk Patterson provided an April 18, 2010 document entitled *RECHARGE & RECIRCULATION BASIC OPTION PACKAGE* for distribution to interested EARIP participants as well as HDR and Todd Engineers. Although there were many different views expressed, the following fundamental assumptions are believed to adhere to the general consensus.

Fundamental assumptions for each of these subject areas include:

- Source Water

- Irrigation Permits.
    - For the purposes of this technical evaluation only, it is assumed that approximately 66,700 acft/yr at full IRP, which is equivalent to about 40,000 acft/yr under Stage IV, irrigation use will not be pumped by irrigators, but will be available for recovery in an eastern Medina County well field and available for recharge and recirculation.
    - No distinction is made between unrestricted and restricted (base) IRPs and base conservation potential is assumed to be part of the above listed values.
    - Bexar, Medina, and Uvalde County irrigation permits will be considered.
    - Cost estimates based on current prices for IRP purchase is $5,500/acft and lease is $125/acft/yr.
- Type 2 Recharge Projects
    - Hondo and Verde sites are included for both natural recharge enhancement and recirculation recharge purposes.
    - Frio and Sabinal sites are included for natural recharge enhancement purposes only.
    - Mitigation of Corpus Christi surface water rights in Nueces River Basin.
    - Surface water rights in Guadalupe – San Antonio River Basin honored.
    - Region L Consensus Criteria for Environmental Flow Needs (CCEFN) used for surface water availability.

- Recharge Recovery
    - Actual permitting of aquifer storage, recharge recovery, and/or R&R projects may involve additional EAA restrictions.
    - Recovery rates based on recently developed factors, as defined in Appendix C.
    - Recovery must occur within 24 months after recharge.

The physical facilities (Figure 4-3) include:

- Well field and collection system in eastern Medina County for recovery of enhanced recharge, unused permits, and recharge credits.
- Pump station and pipeline for transmission of recovered enhanced recharge from well field to recharge sites on Hondo and Verde Creeks.
- Recharge enhancement structures (dams) on Hondo and Verde Creeks and the Frio and Sabinal Rivers.

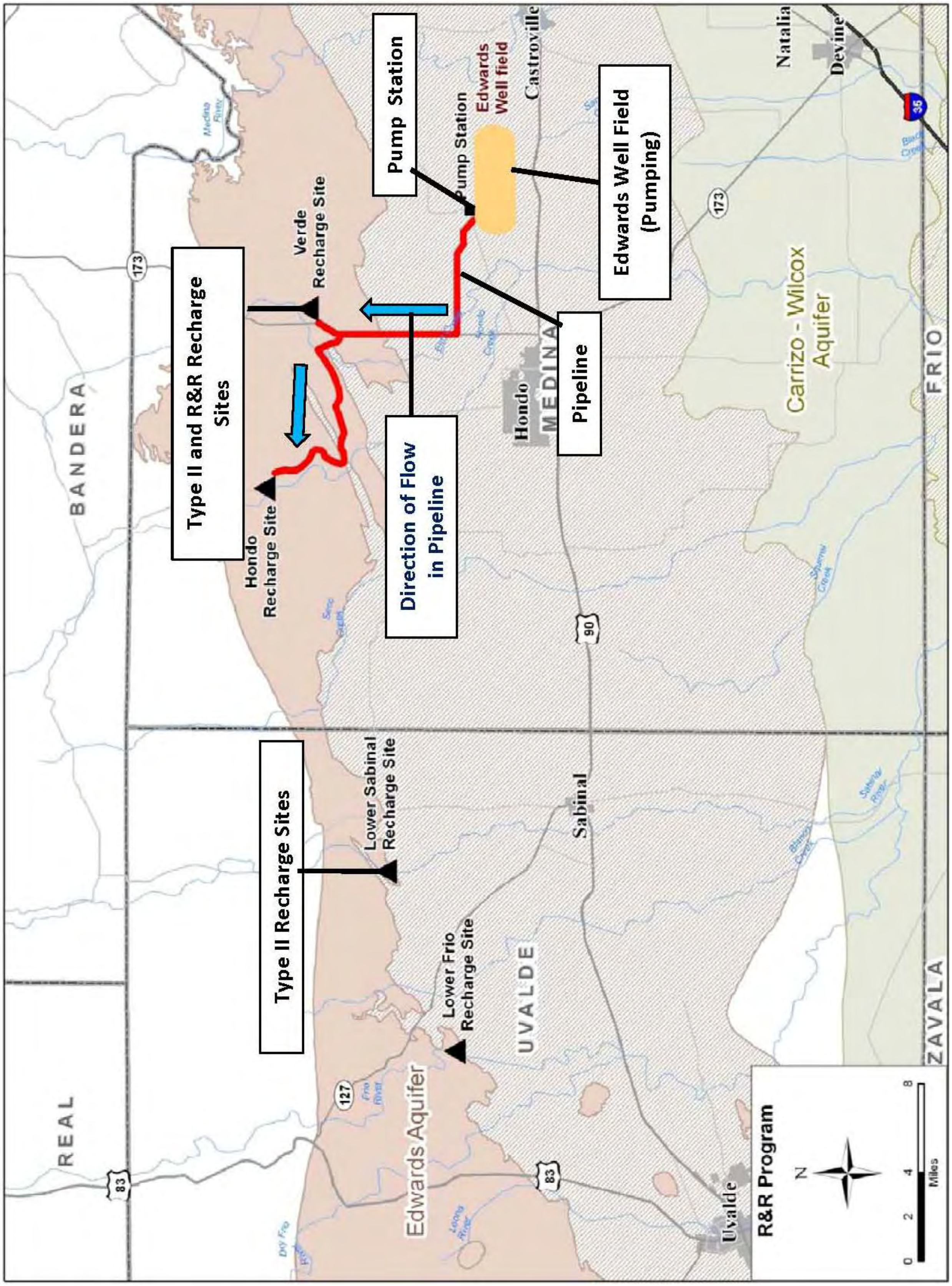


Figure 4-3. Schematic of R&R Program

Operational plan includes:

- Recirculation system will be operated during periods when the J-17 monitoring well level, Comal Springs discharge, and San Marcos Springs discharge are above CPM Stage III levels.
- Fundamental assumptions for R&R operations approximate those provided in Mr. Patterson's April 18, 2010 document. As directed, HDR and Todd Engineers exercised some measure of professional judgment in application of these fundamental assumptions subject to modeling and budgetary constraints.

Scale optimization runs include:

- Run #1: Simulation with a trigger of 150 cfs at Comal Springs and R&R recharge equally split between the Lower Hondo and Lower Verde recharge sites.
- Run #2: Same as Run #1, but with Comal Springs trigger set at 100 cfs.
- Run #3: Similar to Run #2, but with distribution of R&R adjusted to 75 percent going to Hondo and 25 percent going to Verde. The trigger remains at 100 cfs.
- Run #4: Same as Run #3, but with the Comal Springs trigger set at 30 cfs.

Results summarizing the number of months when springflow at Comal and San Marcos are below selected thresholds for the baseline and Runs #1-#4 are presented in Table 4-6. These results suggest the following:

- Comal Springs:
  - Run #4 is the most effective in reducing the number of zero springflow months. However, there are still nine months of zero flow.
  - All runs produced a similar improvement in the number of months for thresholds greater than 30 cfs.
  - None of the runs produced results significantly better for all categories than the others.
- San Marcos Springs:
  - With the exception of the 52 cfs threshold, results for all the runs and throughout the range of thresholds show little improvement in springflow conditions.

Selected statistical summaries for Comal and San Marcos Springs for the baseline and Runs #1-#4 are presented in Table 4-7. These results suggest the following:

- Comal Springs:
  - Flows under the baseline scenario and for the minimum and 6-month minimum moving average for all runs are zero, except the 6-month minimum moving average for Run #4, which is 2 cfs.
  - The long-term average springflow is improved up to 26 cfs.

- San Marcos Springs:
  - The results for the minimum and 6-month minimum moving average are substantially improved over baseline conditions.
  - The long-term average springflow is improved by up to 3 cfs.

Table 4-6.
Number of Months with Springflow below Selected Thresholds for R&R Program (1947-1973)

Springflow Duration below Given Thresholds (1947-1973)						
Spring	**Threshold (cfs)**	**Number of Months**				
		Baseline (348K)	**Run #1: 150 cfs trigger w/ 50-50 split**	**Run #2: 100 cfs trigger w/ 50-50 split**	**Run #3: 100 cfs trigger w/ 25-75 split**	**Run #4: 30 cfs trigger w/ 25-75 split**
Comal	0	38	16	12	13	9
	30	54	31	20	20	20
	60	73	43	38	39	43
	90	110	66	66	67	91
	120	145	101	122	122	134
San Marcos	0	0	0	0	0	0
	52	20	8	6	6	5
	80	52	51	51	51	50
	100	108	103	104	103	104
	120	147	146	146	146	146

Table 4-7.
Selected Springflow Statistics for R&R Program (1947-1973)

Springflow for Selected Statistics (1947-1973)						
Spring	**Threshold (cfs)**	**Springflow (cfs)**				
		Baseline (340K)	**Run #1: 150 cfs trigger w/ 50-50 split**	**Run #2: 100 cfs trigger w/ 50-50 split**	**Run #3: 100 cfs trigger w/ 25-75 split**	**Run #4: 30 cfs trigger w/ 25-75 split**
Comal	Minimum Month	0	0	0	0	0
	Minimum 6-Month Moving Average	0	0	0	0	2
	Long-Term Average	126	152	150	150	148
San Marcos	Minimum Month	2	25	28	27	36
	Minimum 6-Month Moving Average	12	34	37	37	45
	Long-Term Average	127	129	129	129	130

4.1.4 Trade-Off: Bexar County

The concept for the Bexar County trade-off alternative is to use SAWS ASR facilities in South Bexar County for storage and recovery of Edwards water and to use the recovered water for springflow protection. The concept is to: (1) pump water obtained from irrigation leases at the Artesia and Seale Stations, (2) transport the water through the east side pipeline to Twin Oaks, (3) store the water in the ASR well field via ASR wells, (4) recover the water with the ASR wells and deliver to Twin Oaks, (5) transport the water back to Artesia and Seale Stations during severe drought, and (6) make water available for springflow protection in one of three ways. These three ways include: (1) trade-off, (2) direct recharge, and (3) indirect recharge.

Major technical assumptions include:

- Lease 50,000 acft/yr of irrigation IRP for storage in SAWS ASR facilities for springflow protection. Any portion of the leased rights not being used for storage in SAWS ASR facilities will be unused (not pumped). The actual supply of water from the leases will be subject to CPM rules, left in the aquifer when SAWS ASR is full, and fully curtailed when ASR water is being recovered for springflow protection.
- ASR assumptions include: (a) initial storage of 80,000 acft; (b) full storage capacity of 200,000 acft; and (c) there is no water loss.

- The recovery rate for the stored water from SAWS ASR is limited to the current transmission capacity from SAWS ASR to Seale and Artesia Stations, which is 60 million gallons per day (MGD), or 5,600 acft/mo.
- The schedule and rate of water recovery for springflow protection is evaluated for two options. One is to trigger recovery to ON at full capacity when Comal Springs is flowing less than 50 cfs and to turn the recovery OFF when the flow is 50 cfs or more. The second is to develop an episodic schedule and rate of delivery for springflow protection while conserving water in storage. However, only limited effort was made to optimize the schedule and rate of water recovery from SAWS ASR. Additional effort could have improved the level of springflow protection. It's important to note that the ON-OFF option used up the full supply of stored water before the most intense part of the drought occurred. Thus, it did not provide any protection at this critical time. Also, the pipeline capacity was the most limiting constraint during the most intense part of the drought for the episodic option. Episodic recharge was applied with direct recharge facilities and with indirect recharge facilities.

The physical facilities for the trade-off, direct recharge, and indirect recharge (Figure 4-4a, 4-4b, and 4-4c, respectively) include:

- SAWS ASR existing water collection, transmission, and storage facilities.
  - Trade-Off: SAWS existing distribution system that allows recovered water from SAWS ASR that is initially delivered to Artesia and Seale stations to be delivered to customers normally served by SAWS well fields in northeast Bexar County with SAWS existing distribution system.
  - Direct Recharge: Water recovered from SAWS ASR at Artesia and Seale Stations is to be transported by a new pipeline and transmission facilities to a new Edwards injection well field between Cibolo Creek and Comal Springs.
  - Indirect Recharge: Water recovered from SAWS ASR at Artesia and Seale Stations is to be indirectly picked up (pumped) by the Naco and Stahl Stations, and delivered by a new pipeline and transmission facilities to an Edwards injection well field, which is located between Cibolo Creek and Comal Springs. Also, SAWS existing distribution system is assumed to have the capacity to deliver the recovered water from SAWS ASR that is initially delivered to Artesia and Seale stations to customers normally served by SAWS' Naco and Stahl Stations.

a. Trade-Off

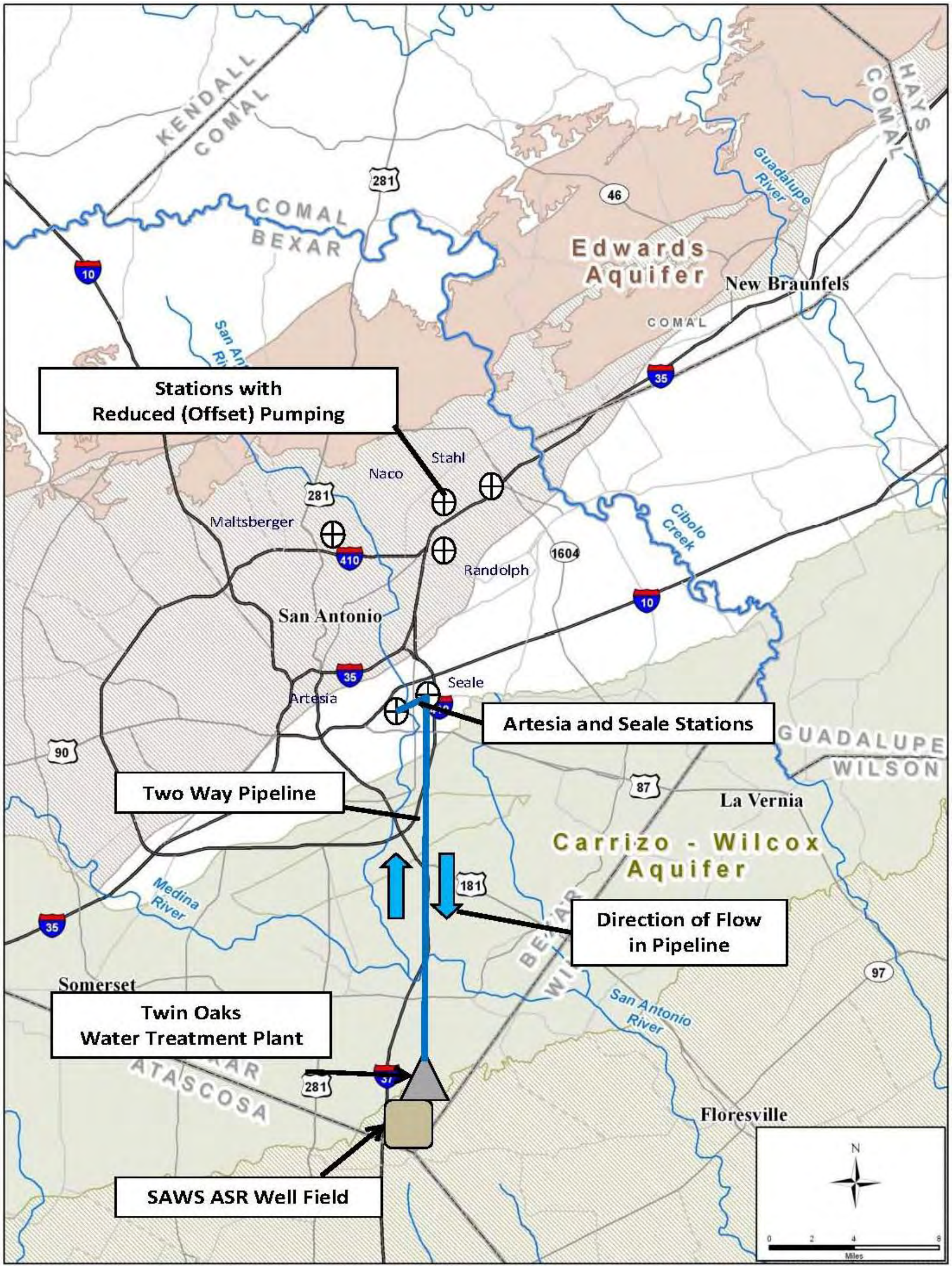


Figure 4-4. Schematic Trade-Off: Bexar County Program

b. Direct Recharge

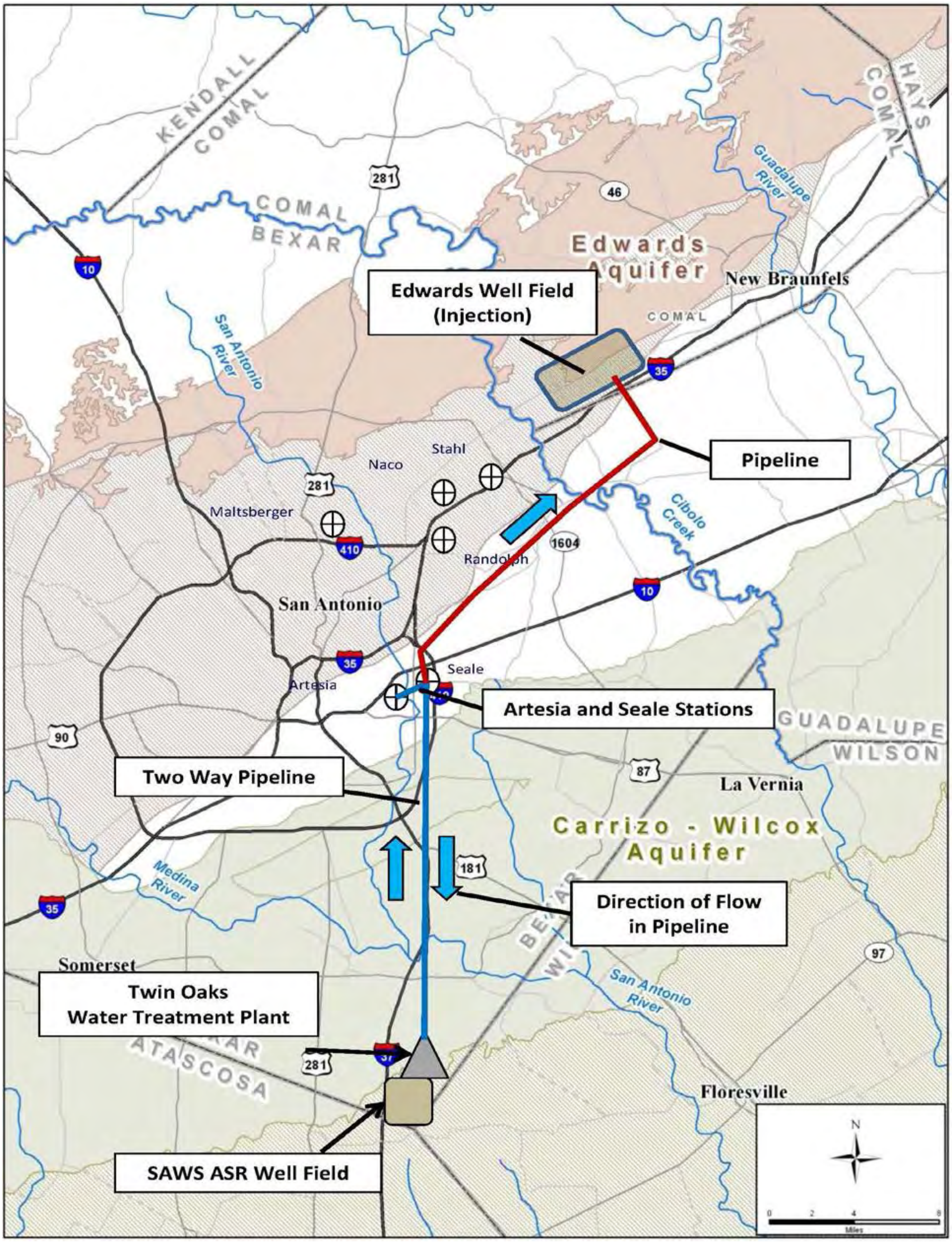


Figure 4-4. Schematic Trade-Off: Bexar County Program (Continued)

c. Indirect Recharge

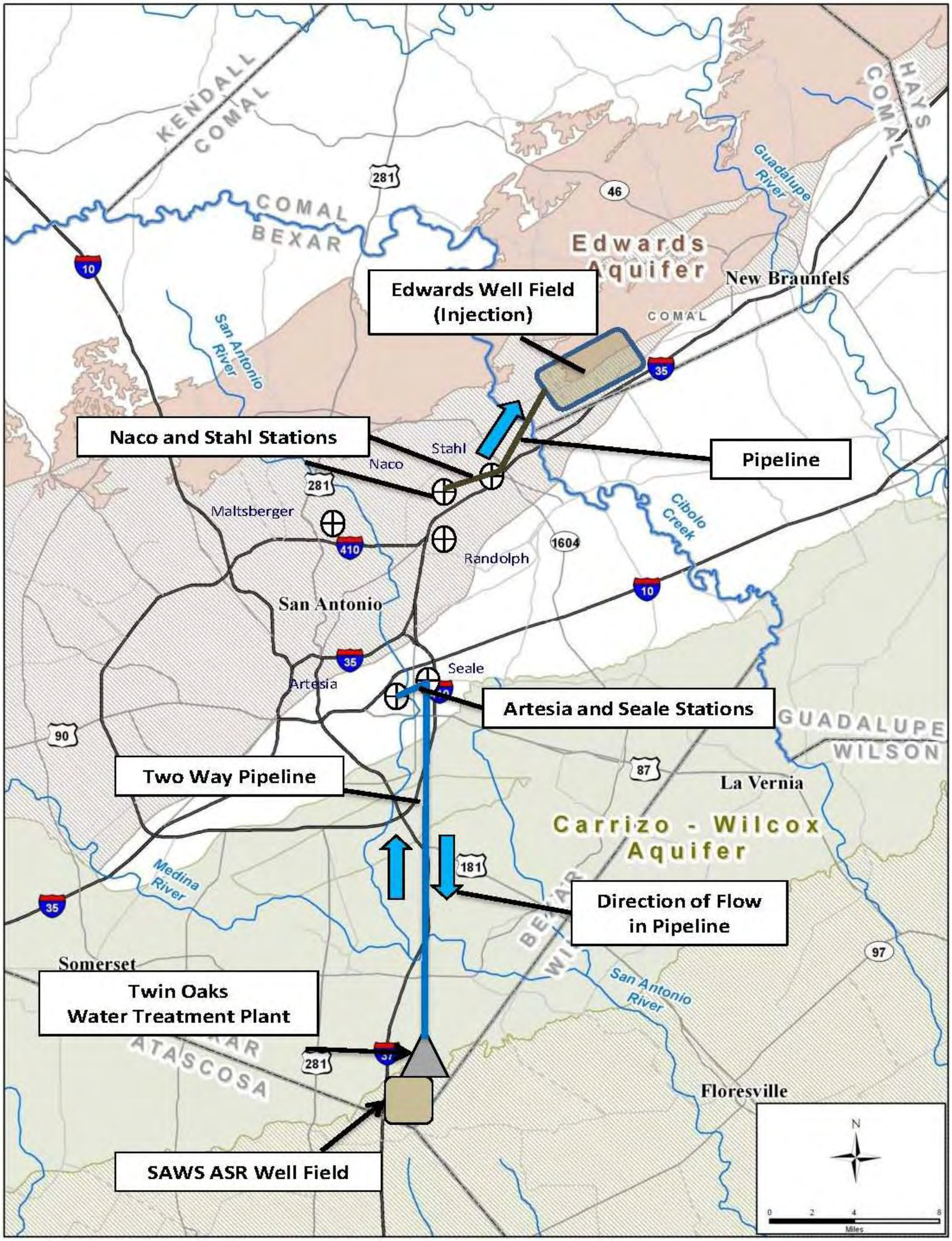


Figure 4-4. Schematic Trade-Off: Bexar County Program (Concluded)

Results summarizing the number of months when springflow at Comal and San Marcos Springs are below selected thresholds for the baseline and Runs #1-#6 are presented in Table 4-8. These results suggest the following:

- Comal Springs:
  - None of the runs and options fully eliminates the occurrence of zero flow months at Comal Springs.
  - Results for the ON-OFF option are very similar for all three runs, as they are for the episodic option for all three runs.
  - Overall, the episodic option provides considerably fewer no flow months than the ON-OFF option. This is caused by the ON-OFF option draining of the available ASR storage prior to the most intense part of the drought.
- San Marcos Springs:
  - The results show considerable reduction (relative to the baseline) in the number of months with springflows less than 52 cfs for all runs and options.
  - The program shows little change from baseline conditions for thresholds greater than 52 cfs.

Selected statistical summaries for Comal and San Marcos Springs for the baseline and Runs #1-#6 are presented in Table 4-9. These results suggest the following:

- Comal Springs:
  - No flow conditions exist for all runs and options.
  - The 6-month minimum flow is 8 cfs for the direct and indirect recharge options.
  - The ON-OFF option noticeably increases the long-term average, while the episodic option increases the long-term average by a very small amount.
- San Marcos Springs:
  - Results for the minimum month and minimum 6-month moving average are similar for all runs with the ON-OFF option and with the episodic option.
  - Overall, the episodic option provides considerably higher minimum springflows than the ON-OFF option.
  - None of the runs and options significantly increases the long-term average springflow.

Table 4-8.
Number of Months with Springflow below Selected Thresholds for Trade Off: Bexar County Program (1947-1973)

Springflow Duration below Given Thresholds (1947-1973)								
Spring	**Threshold (cfs)**	**Number of Months**						
		Baseline (348K)	**Run #1: Trade-off (On-Off)**	**Run #2: Trade-off (Episodic)**	**Run #3: Direct Recharge (On-Off)**	**Run #4: Direct Recharge (Episodic)**	**Run #5: Indirect Recharge (On-Off)**	**Run #6: Indirect Recharge (Episodic)**
Comal	0	38	8	11	10	2	10	2
	30	54	13	39	12	37	14	37
	60	73	37	65	30	67	32	67
	90	110	85	106	80	106	82	106
	120	145	145	148	136	148	141	148
San Marcos	0	0	0	0	0	0	0	0
	52	20	6	5	8	5	8	5
	80	52	51	50	50	50	51	50
	100	108	104	107	106	108	106	108
	120	147	146	146	146	146	146	146

Table 4-9.
Selected Springflow Statistics for Trade Off: Bexar Program (1947-1973)

Springflow for Selected Statistics (1947-1973)

Spring	Threshold (cfs)	Springflow (cfs)						
		Baseline (348K)	Run #1: Trade-off (On-Off)	Run #2: Trade-off (Episodic)	Run #3: Direct Recharge (On-Off)	Run #4: Direct Recharge (Episodic)	Run #5: Indirect Recharge (On-Off)	Run #6: Indirect Recharge (Episodic)
Comal	Minimum Month	0	0	0	0	0	0	0
	Minimum 6-Month Moving Average	0	0	0	0	8	0	8
	Long-Term Average	126	136	129	138	129	137	129
San Marcos	Minimum Month	2	31	37	23	46	23	46
	Minimum 6-Month Moving Average	12	40	45	34	50	34	50
	Long-Term Average	127	130	129	130	130	129	130

4.1.5 Trade-Off: Comal and Hays Counties

The concept for the Trade-off for Comal and Hays Counties is to: (1) operate selected Type II recharge structures, (2) capture the enhanced recharge, less losses, at an Edwards well field in northeast Bexar County, (3) transport the water to a new Carrizo ASR well field in Wilson County, (4) store the water in the new Carrizo ASR well field, (5) add Stage V pumping restrictions on municipal and industrial wells in Comal and Hayes Counties, (6) recover stored water during severe drought, and (7) use this water to replace the lost water attributed to the Stage V restrictions.

Major technical assumptions include:

- Source of water:
    - Type II Recharge Structures include: Frio, Sabinal, Hondo, Verde, San Geronimo and Salado-Flood Retarding Structures.

- Pumping Reductions:
  - When critical springflow conditions at Comal and San Marcos Springs are being approached during a drought, the Edwards water supply for major municipal and industrial permit holders in New Braunfels and San Marcos is to be replaced with water in ASR storage.
  - The ASR recovered water is to be delivered at rates that are equivalent to allowable Edwards pumping for these permit holders.
  - In other words, the utilities are to be provided an alternative water supply in exchange for curtailing their allowable pumping from the Edwards during critical springflow conditions.

- ASR Operation
  - At the beginning of the model simulation, the enhanced recharge from the Type II structures will be pumped until the estimated amount of storage needed for springflow protection is achieved. The water will be stored in the ASR facilities. After being filled, a small percentage will be pumped and injected into the ASR wells to overcome any losses and to maintain the Edwards water bubble around the ASR wells.
  - The overall permitted level of pumping in the Edwards will be at IRP rates, which produces a minimum (nominal) permitted pumping level of approximately 348,000 acft/yr (excluding domestic and livestock and Federal uses).
  - Set triggers for recovery and Stage V restrictions to maintain Comal springflows between 30 and 60 cfs.
  - When the flow from Comal and San Marcos Springs nears appropriate trigger levels, water is to be recovered from ASR storage and delivered to major distribution centers in New Braunfels and San Marcos.

The physical facilities (Figure 4-5) include:

- A well field and collection system is to be located in the general vicinity of Loop 1604 and I-35 in northeast Bexar County.
- An ASR well field is tentatively planned for northwestern Wilson County. The storage will be in the Carrizo Aquifer.
- Pipelines for transmission of the source Edwards water from the Edwards well field to the ASR well field in Wilson County and from the ASR well field to interconnects with major water utilities in New Braunfels and San Marcos. Part of the pipeline will be two-way with water flowing to the ASR well field in the fill cycle and returning to major distribution centers in the recovery cycle. Pump stations are required.

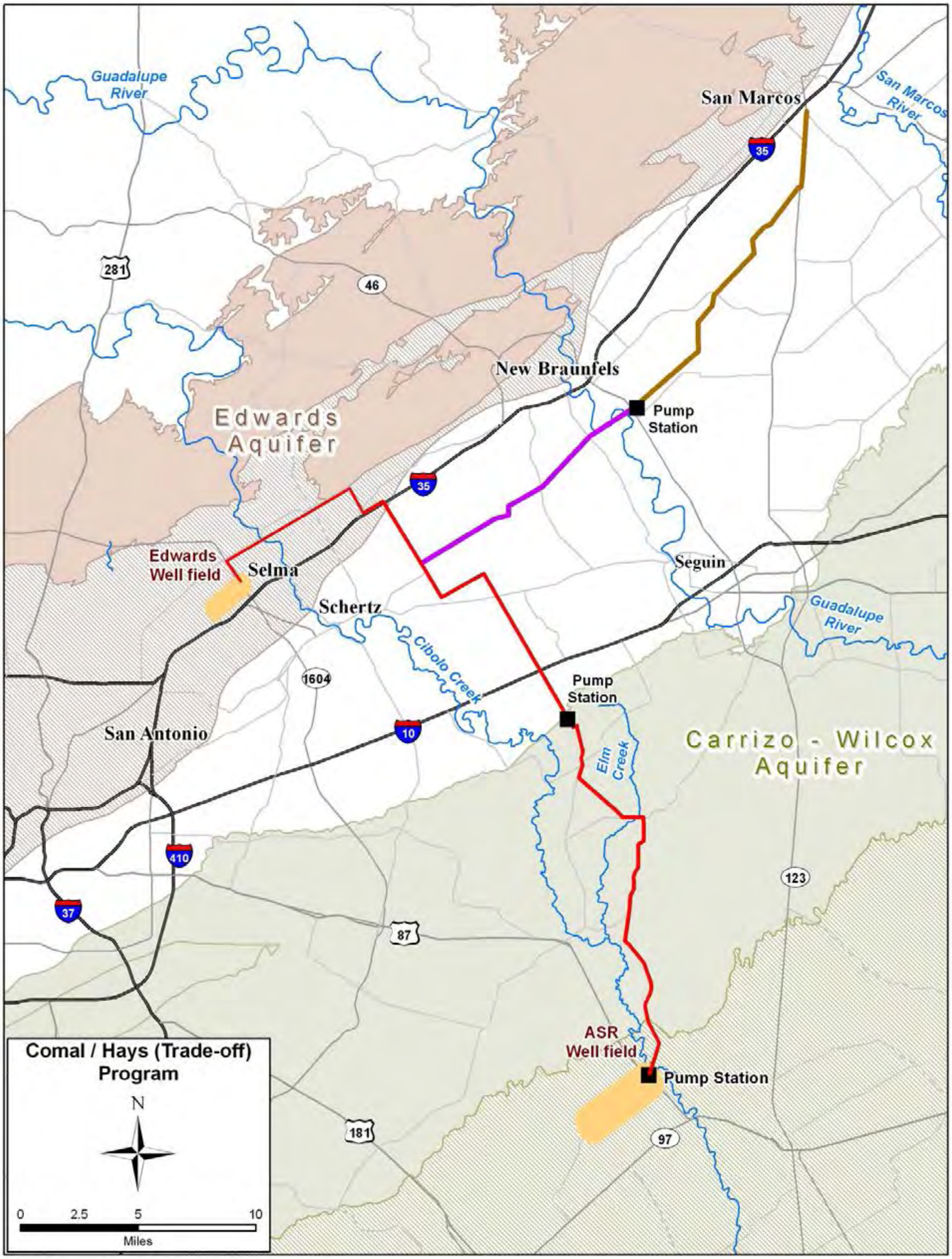


Figure 4-5. Schematic of Trade Off: Comal and Hays Counties Program

Results summarizing the number of months when springflows at Comal and San Marcos Springs are below given thresholds for the baseline and alternative run #1 are presented in Table 4-10. These results suggest the following:

- Comal Springs:
  - The program reduces the number of zero flow months by only 6.
  - The number of months with flows less than 60 cfs is improved slightly.
- San Marcos Springs:
  - The results for the range of thresholds less than 100 cfs show some improvement in springflow conditions.

Table 4-10.
Number of Months with Springflow below Selected Thresholds for Trade Off: Comal and Hays Program (1947-1973)

Spring	Threshold (cfs)	Number of Months	
		Baseline (348K)	Run #1
Comal	0	38	32
	30	54	47
	60	73	69
	90	110	109
	120	145	151
San Marcos	0	0	0
	52	20	7
	80	52	39
	100	108	96
	120	147	147

Selected statistical summaries for Comal and San Marcos Springs for the baseline and Run #1 are presented in Table 4-11. These results suggest the following:

- Comal Springs:
  - No flow still occurrs.
  - The minimum 6-month moving average increases from zero to 8 cfs.
- San Marcos Springs:
  - The minimum flow increases substantially for the minimum and minimum 6-month average.
  - There is little improvement in the long-term monthly average.

Table 4-11.
Selected Springflow Statistics for
Trade Off: Comal and Hays Counties Program
(1947-1973)

Spring	Threshold (cfs)	Springflow (cfs)	
		Baseline	Run #1:
Comal	Minimum Month	0	0
	Minimum 6-Month Moving Average	0	8
	Long-term Average	126	132
San Marcos	Minimum Month	2	44
	Minimum 6-Month Moving Average	12	50
	Long-term Average	127	130

4.2 Cost Estimates

Cost estimates for each of the alternatives are based on the following methods and assumptions:

- **Annual cost:** Operating costs are generally averaged over the MODFLOW simulation period (1947-1973).
- **Project Cost:** Includes capital and upfront costs such as facilities, equipment, engineering, environmental studies, land acquisition, permitting, etc. Cost estimating procedures are from those used in the 2011 South Central Texas Regional Water Plan. The costs are in September 2008 dollars.
- **Edwards Water Permit Purchase:** The cost for permanent acquisition is assumed to be $5,500/acft.
- **Edwards Water Permit Lease:** The cost for short-term lease is assumed to be $125/acft/yr.
- **Water Replacement Cost:** Referenced to the 2011 South Central Texas Regional Water Plan.
- **Debt Service:** Interest rate is 6 percent per year. Bond period is 20-years for non-reservoir facilities and 40-years for reservoirs.

- **Operation and Maintenance:** Estimated using procedures from the 2011 South Central Texas Regional Water Plan.
- **Energy:** $0.09/KwHr.

Unlike the Bottom-Up Program, most of these alternatives had extensive facilities such as well fields, pipelines, and pump stations and, as a result, are expected to be considerably more expensive. Also, the long-term cost for these alternatives is based on a 27-year period (1947-1973) instead of the 54-year period (1947-2000) for the Bottom-Up Program.

Cost estimates for each of the runs and options of the alternatives are tabulated in Table 4-12. It's important to note that one cannot readily compare the costs among the many alternatives and options because their effectiveness in terms of springflow protection is not equal. Some of the alternatives are generally effective in springflow protection while others offer marginal improvement over baseline conditions. Without consideration of effectiveness, annual costs of the Recharge & Recirculation Program(s) are the most expensive while the Bexar County Trade-Off with the Trade-Off option is the least expensive. Costs for ASR Program Runs #2 and #3 should not be compared to Run #1 because there is no cost accounting for economic losses that could be attributed to greater withdrawal reductions in CPM Stage IV. Finally, it is noted that the annual cost of purchasing Edwards permits is much more expensive than that for leasing the same amount of water.

Table 4-12.
Estimated Costs for Alternative Programs

Program	Run	Investment		Annual				
		Project, includes Water Purchase	Edward Water Purchase	Edwards Water Lease (27-Year Average) or Replacement	Debt Service or Depreciation	O&M	Energy (27-Yr Average)	Total
ASR: Program #1 with Purchase of 66,700 acft of Irrigation Permits								
1	1-P	$789,262,000	$366,850,000	$0	$68,811,000	$3,094,000	$974,000	$72,879,000
1	2-P	$668,781,000	$366,850,000	$0	$58,307,000	$2,193,000	$547,000	$61,047,000
1	3-P	$620,510,000	$366,850,000	$0	$54,099,000	$1,816,000	$240,000	$56,155,000
ASR: Program #1 with Intermittent Lease of up to 66,700 acft of Irrigation Permits								
1	1-L	$405,880,000	$0	$1,911,000	$35,386,000	$3,224,000	$1,163,000	$41,684,000
1	2-L	$314,639,000	$0	$1,206,000	$27,432,000	$2,545,000	$707,000	$31,890,000
1	3-L	$246,446,000	$0	$734,000	$21,486,000	$2,016,000	$278,000	$24,514,000
Combination: Type II, Dry-Year Option, Land Stewardship and SAWS ASR								
2	1	$162,213,000	$0	$697,000	$10,984,000	$1,166,000	$0	$12,847,000
2	2		$0	$4,341,800	$0	$0	$0	$4,341,800
2	3	$87,372,000	$0	$0	$7,217,000	$1,393,000	$210,000	$8,820,000
2	4		$0	$0	$7,265,000	$529,000	$0	$7,794,000
2	Total	$249,585,000	$0	$5,038,800	$25,466,000	$3,088,000	$210,000	$33,802,800
R&R: Program #3 with Purchase of 66,700 acft of Irrigation Permits								
3	1-P	$790,078,000	$366,850,000	$0	$68,244,000	$3,072,000	$9,160,000	$80,476,000
3	2-P	$790,078,000	$366,850,000	$0	$68,244,000	$3,072,000	$11,938,000	$83,254,000
3	3-P	$811,794,000	$366,850,000	$0	$70,137,000	$3,238,000	$12,221,000	$85,596,000
3	4-P	$811,794,000	$366,850,000	$0	$70,137,000	$3,238,000	$14,920,000	$88,295,000
R&R: Program #3 with Lease of 66,700 acft of Irrigation Permits								
3	1-L	$393,880,000	$0	$8,338,000	$33,701,000	$3,072,000	$9,160,000	$54,271,000
3	2-L	$393,880,000	$0	$8,338,000	$33,701,000	$3,072,000	$11,938,000	$57,049,000
3	3-L	$415,596,000	$0	$8,338,000	$35,595,000	$3,238,000	$12,221,000	$59,392,000
3	4-L	$415,596,000	$0	$8,338,000	$35,595,000	$3,238,000	$14,920,000	$62,091,000
Bexar County Trade-Off with Trade-Off Option								
4	1a	$0	$0	$6,250,000	$7,265,000	$529,000	$1,392,000	$15,436,000
4	1b	$0	$0	$6,250,000	$7,265,000	$529,000	$862,000	$14,906,000
Bexar County Trade-Off with Direct Recharge Option								
4	2a	$132,845,000	$0	$6,250,000	$18,847,000	$1,546,000	$3,021,000	$29,664,000
4	2b	$132,845,000	$0	$6,250,000	$18,847,000	$1,546,000	$1,889,000	$28,532,000
Bexar County Trade-Off with Indirect Recharge Option								
4	3a	$81,331,000	$0	$6,250,000	$14,356,000	$1,186,000	$1,884,000	$23,676,000
4	3b	$81,331,000	$0	$6,250,000	$14,356,000	$1,186,000	$1,172,000	$22,964,000
Comal/Hays M&I Trade-Off								
5	1	$227,636,000	$0	$696,000	$36,358,000	$2,811,000	$950,000	$40,815,000

Appendix A
Application of USGS MODFLOW Model for Evaluation of EARIP Programs

1.0 Introduction

This report evaluates various management programs using the Edwards Aquifer MODFLOW numerical model (EAA model) developed by USGS and others[9]. The EAA model, also called MODFLOW in this report, is a calibrated transient model for the simulation period 1947-2000 with monthly stress periods. The simulation period begins with initial head conditions generated from a steady state simulation of historical conditions, which is assumed to be the average for the 1939–1946 period. The original model estimated hydrologic conditions and pumping on a monthly basis throughout the transient period. For this study, the original model hydrologic conditions were used, but pumping was adjusted to represent the current authorized pumping in the aquifer as discussed in the Section 2: Baseline Conditions.

The model extent, shown in Figure A-1, includes both the San Antonio and Barton Springs segments of the Edwards aquifer in the San Antonio region of Texas. The San Antonio segment of the aquifer primarily includes all or parts of Kinney, Uvalde, Medina, Bexar, Comal, and Hays Counties. This segment is bounded on the west and east by groundwater divides near Brackettville and Kyle, respectively, and contains the most productive and transmissive parts of the aquifer. The Barton Springs segment of the aquifer includes parts of Hays and Travis Counties and is bounded on the southwest by the groundwater divide near Kyle and on the northeast by the Colorado River. No pumping in Travis County is included in the model simulations. The San Antonio segment of the aquifer discharges primarily to Comal and San Marcos Springs, whereas the Barton Springs segment discharges primarily to Barton Springs.

2.0 Model Application

Due to large file sizes, the USGS originally divided the transient EAA model into two halves to allow it to work with pre- and post- processors. The first half of the model (1947-1973) covers much drier hydrologic conditions than the second half (1974-2000), with approximately 30 percent less natural recharge. During the first half of the simulation period, the aquifer is subject to CPM withdrawal reductions for 95 percent of the time (310 months) compared to only 64 percent of the time in the second half of the model (208 months). These differences in recharge and length of time in critical period affect the benefits associated with the management

[9] Lindgren, R.J., Dutton, A.R, Hovorka, S.D., Worthington, S.R.H. and Painter, S., 2004, Conceptualization and simulation of the Edwards Aquifer, San Antonio Region, Texas: U.S. Geological Survey Scientific Investigations Report 2004-5277, 143p.

programs. Since performance of the programs is judged primarily on the benefits during the drought of record (1947-1957), several EARIP Alternatives and Programs were only simulated using the first half of the model (1947-1973).

Due to the large model size, a specific solver, the mathematical process used to solve the numerical questions for each cell at each stress period, was applied in the model to decrease run time. The original USGS model used the algebraic multi-grid solver (LMG). For this study, a more recent and publicly available solver was used, referred to as the geometric multi-grid solver (GMG). Testing conducted for a previous EAA study by Todd Engineers validated the application of GMG for this model. Using GMG, run times for the first half of the model were reduced to around 30 minutes.

In order to simulate EAA CPM rules, EAA retained HydroGeoLogic, Inc. (HydroGeoLogic) to develop computerized management modules to work in concert with the USGS MODFLOW model. These modules read in model output such as head and springflow for assigned triggers as the model is running. Based on the values of these triggers, the management modules can adjust pumping by use or by county, thereby simulating withdrawal reductions associated with CPM. Current CPM triggers and rules are set up in the modules and applied to MODFLOW for each simulation in this study.

To assist with development of the baseline scenario and the analysis of modeling results, several software programs (tools) were created by Todd Engineers that edit MODFLOW recharge and well files as well as the files associated the Management Modules. These tools were mostly developed in the programming language PERL to manipulate the MODFLOW text files directly. They included a program to read the volumetric budget from the "*.lst*" file (a model output) and a program to read the CPM stage from the "*.log*" file (a management module output). Tools that assisted in the creation of scenario specific files included subroutines to adjust pumping based on certain conditions (hydrologic conditions, ASR status, etc,) and to prepare recharge regimes. The MODFLOW software known as Groundwater Vistas was used to create the recharge packages for each scenario and obtain the water level and spring flow data for each stress period.

For more information about the original model, the reader is referred to the USGS model documentation (Lindgren, et al., 2004). For more information about the management modules, the reader is referred to the documentation prepared by HydroGeoLogic[10]..

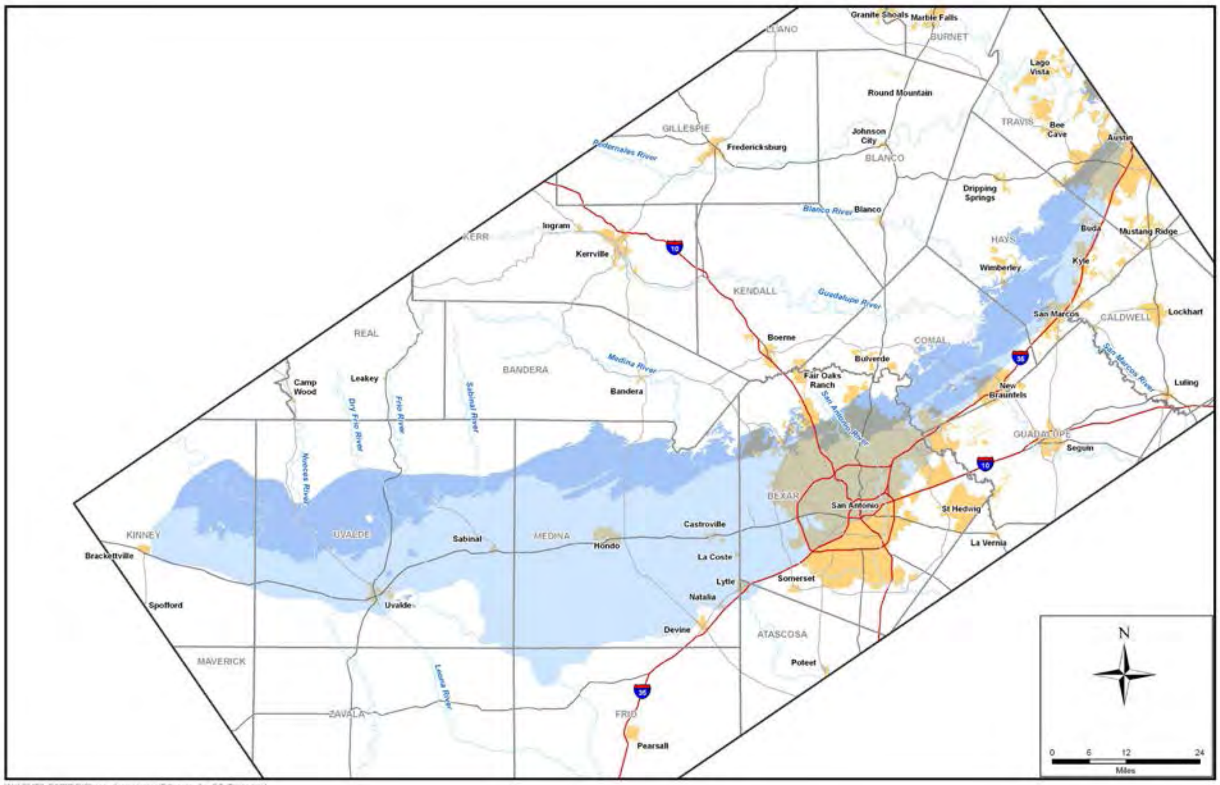


Figure A-1. Extent of the EAA MODFLOW Model

3.0 Limitations

The EAA model, like any numerical model, is a simplified representation of a complex, natural system and has limitations. Although the model represents the best available predictive tool with which to analyze management programs, numerous uncertainties are associated with both the model and the applications for this study. The model uncertainties and limitations are briefly stated here to highlight model application issues.

To simulate current and future pumping, pumping totals were increased above the original EAA model pumping amounts. This increase in pumping may stress the boundary conditions outside the range for which the model was calibrated. The result is that a larger portion of the model may now be subject to cells going dry due to numerical problems than

[10] HydroGeoLogic, Inc., November 2004, Reference Manual for the Groundwater Management Package for MODFLOW-2000: Prepared for Edwards Aquifer Authority.

occurred in the original model. For all simulations in this study, the USGS re-wetting tool was used to prevent this numerical instability. The problem and solution are discussed further in the section describing Section 2: Baseline Conditions.

In addition to the dry cell problem, changes in the distribution of pumping and pumping totals may have unintended consequences. When updating the EAA model, recharge and pumping rates were selected independently to reflect what may happen in the future rather than what has occurred in the past. Although recharge and pumping are decoupled in the model, in reality, the amount of recharge (and precipitation) would have a direct influence on the amount of pumping. For example, wet conditions would likely result in less pumping as precipitation satisfies more of the irrigation water demand; similarly, in dry conditions, more water would likely be pumped for irrigation. By assuming pumping is always at the permitted limit, the total demand is very likely to be an over-estimate, which usually would cause results to be considered "conservative."

The EAA model has other limitations that should be considered when evaluating management programs and analyzing model results. Two fundamental limitations include:

- The model provides a better calibration of the confined zone than the recharge zone, and predictions of head in the recharge area may be less reliable.
- MODLFOW is based on porous media equations. However, the Edwards is a dual-porosity karst system. The model cannot simulate turbulent flow occurring in the conduits. In addition, locations of the simulated conduits have a strong impact on the areas surrounding the conduits. While the model can predict regional variations in water levels and springflow, it probably should not be used to predict the fate and transport of particles of water or contaminants.

Notwithstanding these limitations, the model is considered to be a valuable tool to examine volumetric flow responses in the confined zone, particularly at the major springs. Although enhanced recharge in the unconfined zone is simulated in several programs, the effects are measured in the confined zone through spring discharge and water levels at selected index wells (J-17 and J-27). The observed spring discharge for Comal Springs was well matched by the simulated discharge in the original model. Because simulations are consistent with the regional design of the model, program results are expected to fall within the range of model capabilities.

Appendix B
Comparison of Two Methods of Applying Enhanced Recharge for Springflow Protection at Comal and San Marcos Springs

1.0 Introduction

Some of the engineering solutions considered by the EARIP for springflow protection include recharging the Edwards Aquifer in the vicinity of Comal Springs. The target area considers the potential efficiency and travel time to Comal Springs and San Marcos Springs. In general, one could expect the efficiency to be highest when the recharge site is nearest the target spring. Likewise, one could expect that the recharge water would be better acclimated to native aquifer conditions the farther the site is away from the springs. With these two major considerations, the target recharge sites for Comal and San Marcos Springs are about midway between Cibolo Creek and Comal Springs and to the west of I-35 (Figure B-1). As documented by Maclay, R.W. (1995)[11], Collins, E.W. and Hovorka, S.D. (1997)[12], Small, T.A., and Hanson, J.A. (1994)[13], Small, T.A., and Hanson, J.A. (1995)[14], and others, this target area is geologically very complex because of the numerous faults and zones of very high permeability. The Comal Springs Fault runs southwest-northeast in the area and nearly or completely separates the continuity of the aquifer in the downdip direction and often separates the confined and unconfined zones of the Edwards in this vicinity.

There are two methods of enhancing recharge to the Edwards in the target area. One is to surface recharge in the outcrop (updip zone), either along Dry Comal Creek or its tributaries or in surface reservoirs. The other is to use injection wells in the confined zone. The Comal Springs Fault separates the two potential recharge sites. At this location, the direct injection of recharge would be into a groundwater flowpath from the main body of the Edwards to Comal Springs. From Comal Springs toward San Marcos Springs, this flowpath veers in the downdip direction and terminates in the saline zone of the Edwards. The zone immediately updip of the Comal Springs Fault is sandwiched between this fault and the San Marcos Springs Fault and is the major flowpath to San Marcos Springs. Within this hydrogeologic setting, one would expect that recharge with injection wells would benefit Comal Springs more than San Marcos Springs, and the surface recharge sites would benefit San Marcos Springs more than Comal Springs.

[11] Maclay, R.W., 1995, Geology and hydrology of the Edwards Aquifer in the San Antonio area, Texas: U.S. Geological Survey Water Resources Investigations Report 95-4186.

[12] Collins, E.W. and Hovorka, S.D., 1997, Structure map of the San Antonio Segment of the Edwards Aquifer and Balcones Fault Zone, South-Central Texas: Structural Framework of a Major Limestone Aquifer: Kinney, Uvalde, Medina, Bexar, Comal,and Hays Counties: Bureau of Economic Geology, The University of Texas at Austin Miscellaneous Map No. 38.

[13] Small, T.A., and Hanson, J.A., 1994, Geologic framework and hydrogeologic characteristics of the Edwards Aquifer outcrop, Comal County, Texas: U.S. Geological Survey Water Resources Investigations Report 94-4117.

[14] Small, T.A., and Hanson, J.A., 1995, Geologic framework and hydrogeologic characteristics of the Edwards Aquifer outcrop, Hays County, Texas: U.S. Geological Survey Water Resources Investigations Report 95-4265.

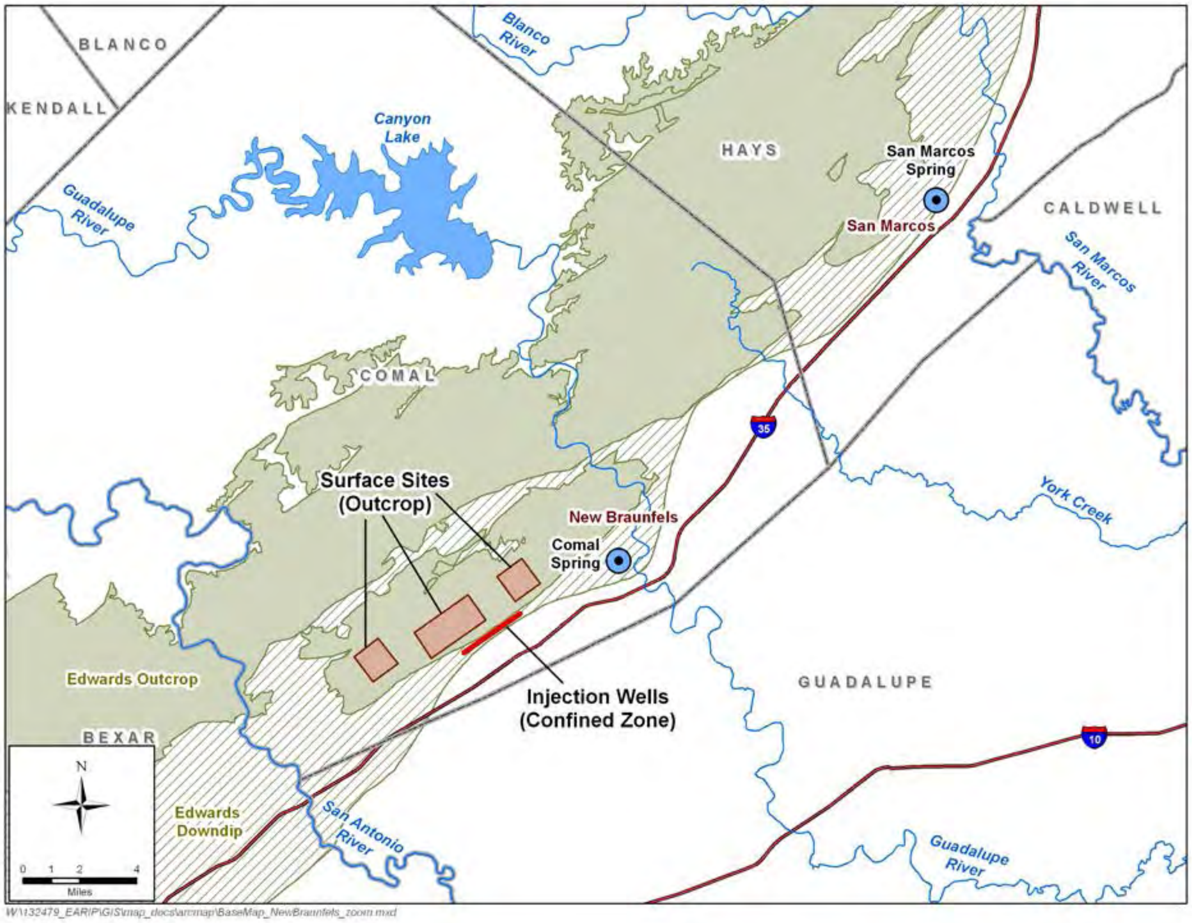


Figure B-1. Location of Test Enhanced Recharge Sites

With this uncertainty as to which method to enhance recharge provides the best springflow protection for both springs, a series of test simulations with MODFLOW were conducted to evaluate the efficiency of the two methods in providing desired springflow protection.

2.0 Model Test Procedures

The preliminary phase of the testing was to conduct a series of experimental model runs that used injection wells into a conduit (major flowpath) in MODFLOW that leads to Comal Springs and to develop an episodic enhanced recharge schedule and rates that would maintain approximately 30 cfs of flow from Comal Springs. The approximate episodic enhanced recharge tested uses about 205,700 acft of water. Figure B-2 shows the selected episodic recharge along with the baseline flow from Comal Springs. The next step was to apply the same episodic recharge to surface water features in the outcrop area (updip of Comal Springs Fault).

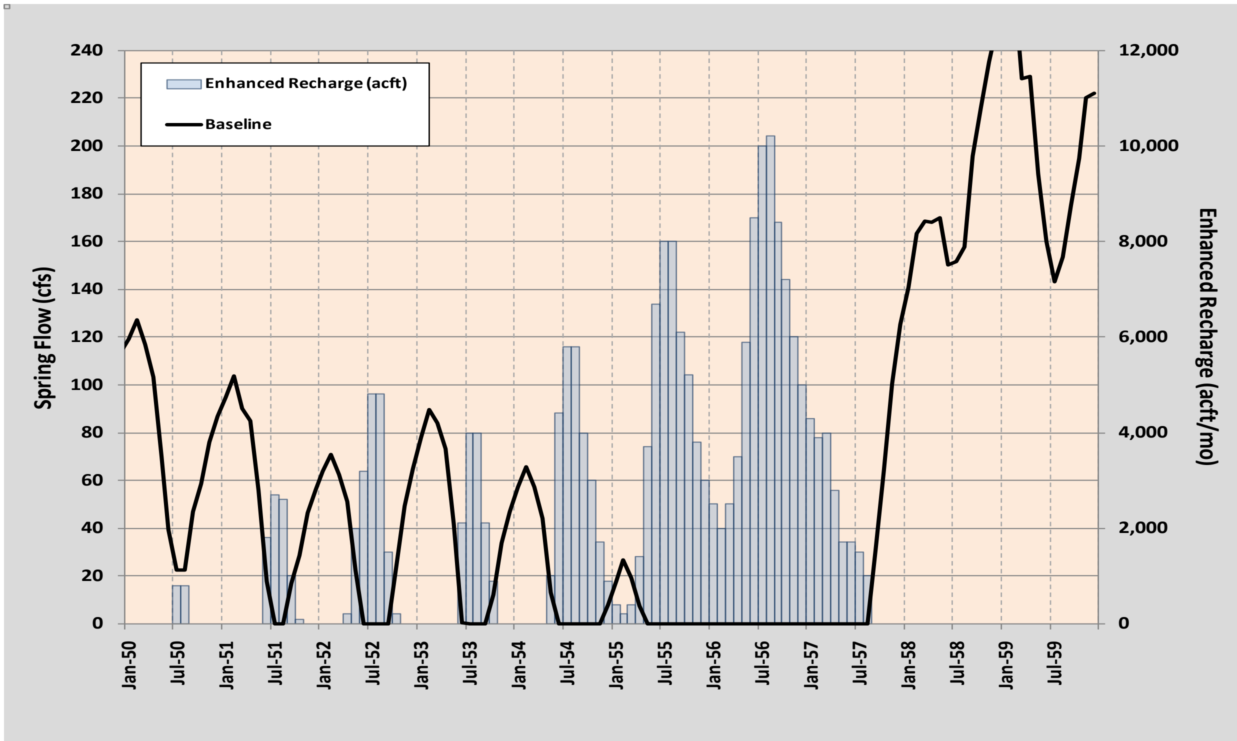


Figure B-2. Episodic Enhanced Recharge and Baseline Flow from Comal Springs

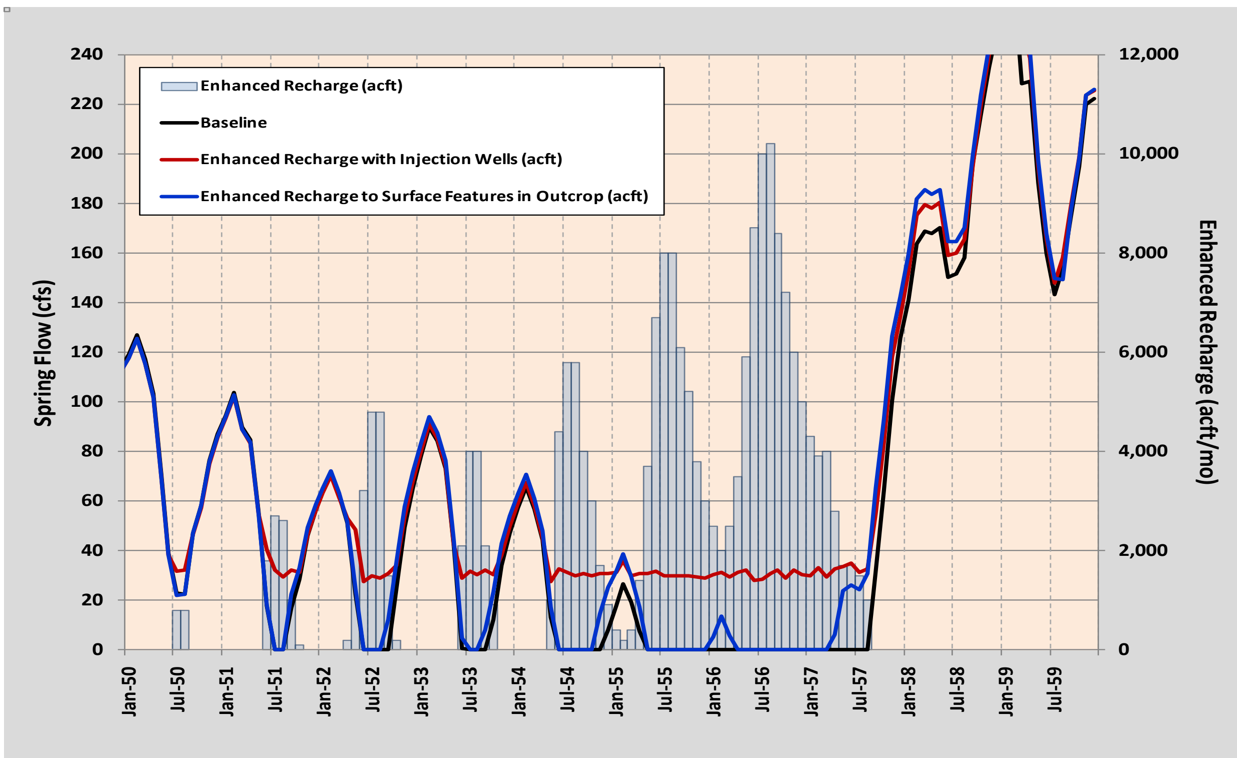


Figure B-3. Episodic Enhanced Recharge and Simulated Flow from Comal Springs

Figures B-3 and B-4 illustrate the episodic recharge sequence and resulting flows from Comal Springs and San Marcos Springs, respectively. Inspection of these charts indicates that the injection wells are much more effective in providing springflow protection for Comal Springs and that the surface recharge is much more effective for San Marcos Springs.

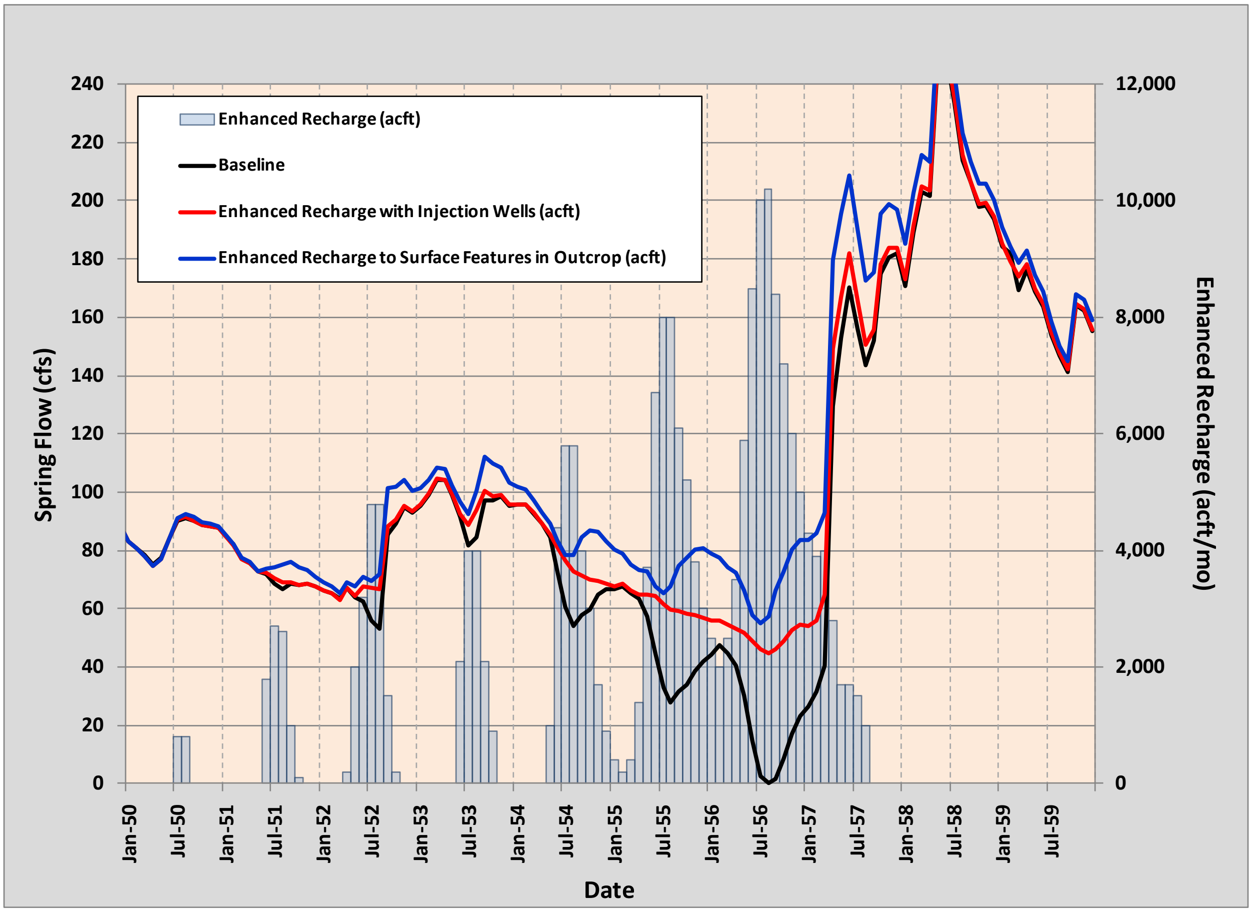


Figure B-4. Episodic Enhanced Recharge and Simulated Flow from San Marcos Springs

3.0 Efficiency of Two Recharge Methods for Springflow Protection

The efficiency of the two enhanced recharge methods is indicated by the percentage of enhanced recharge flowing from the springs. This percentage is calculated by dividing the cumulative enhanced springflow by the cumulative enhanced recharge. Figures B-5 and B-6 show these percentages for enhanced recharge along with the baseline springflow.

The results at Comal Springs (Figure B-5) indicate:

- Comal Springs is much more responsive to recharge with injection wells than through surface features in the outcrop. About 71 percent of the initial slug of recharge in the conduit during 1950, when the baseline springflow was about 25 cfs, promptly discharged from Comal Springs. In contrast, no recharge in the outcrop area discharged during the first year.

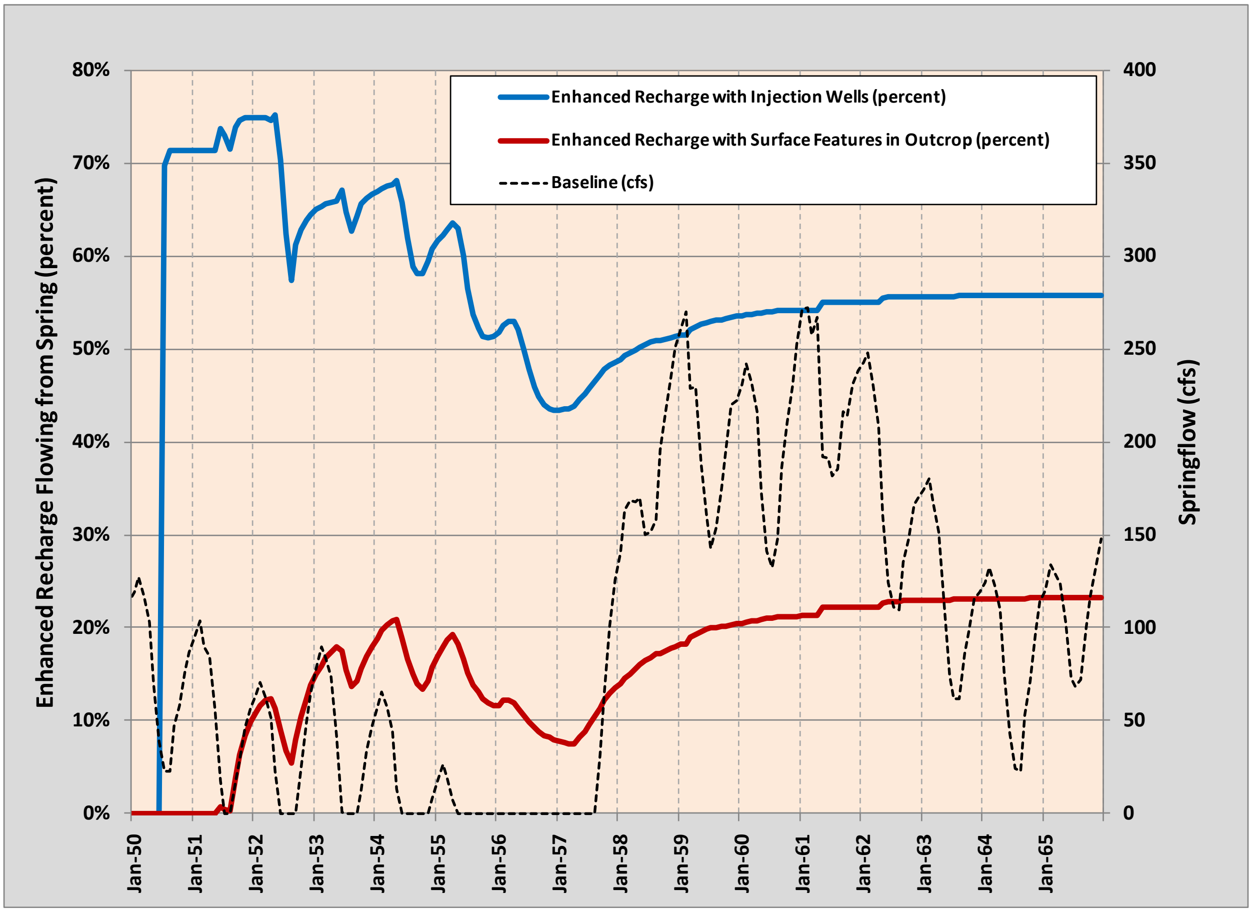


Figure B-5. Comparison of Effectiveness of two Enhanced Recharge Methods at Comal Springs.

- As the drought became more intense from the summer of 1952 to the summer of 1957, the percentage of enhanced recharge that was injected into the conduit and exited the Edwards via Comal Springs generally declined to a low of about 44 percent. This is attributed to some of the water being lost to production wells or remaining in aquifer storage. During this same period, the percentage of enhanced recharge on the outcrop substantially lagged the recharge in the conduit. By the middle of the drought of record, about 20 percent of the enhanced recharge on the outcrop was discharging from Comal Springs. By the summer of 1957, the efficiency was about 8 percent.
- After the drought, the enhanced recharge continued to discharge from the springs for about five years.
- Eventually, about 56 and 23 percent of the enhanced recharge in the aquifer conduit and outcrop, respectively, discharged from the springs. The balance (44 percent or 77

percent) discharged from San Marcos or Barton Springs, was lost to wells, or remained in aquifer storage.

The results at San Marcos Springs (Figure B-6) indicate:

- Both enhanced recharge methods show a much more subdued response than at Comal Springs. This is expected because of the contrast in distances from the recharge sites.
- San Marcos Springs is much more responsive to recharge in the outcrop than recharge in the conduit.
- By the end of the 1956 summer, about 40 and 20 percent of the enhanced recharge in the outcrop and conduit, respectively, flowed from this spring.

By the end of 1965, about 59 percent of the enhanced recharge in the outcrop discharged from San Marcos Springs. For enhanced recharge in the conduit, maximum cumulative discharge was about 25 percent. The balance (41 percent or 75 percent) discharged from Comal or Barton Springs, was lost to wells, or remained in aquifer storage.

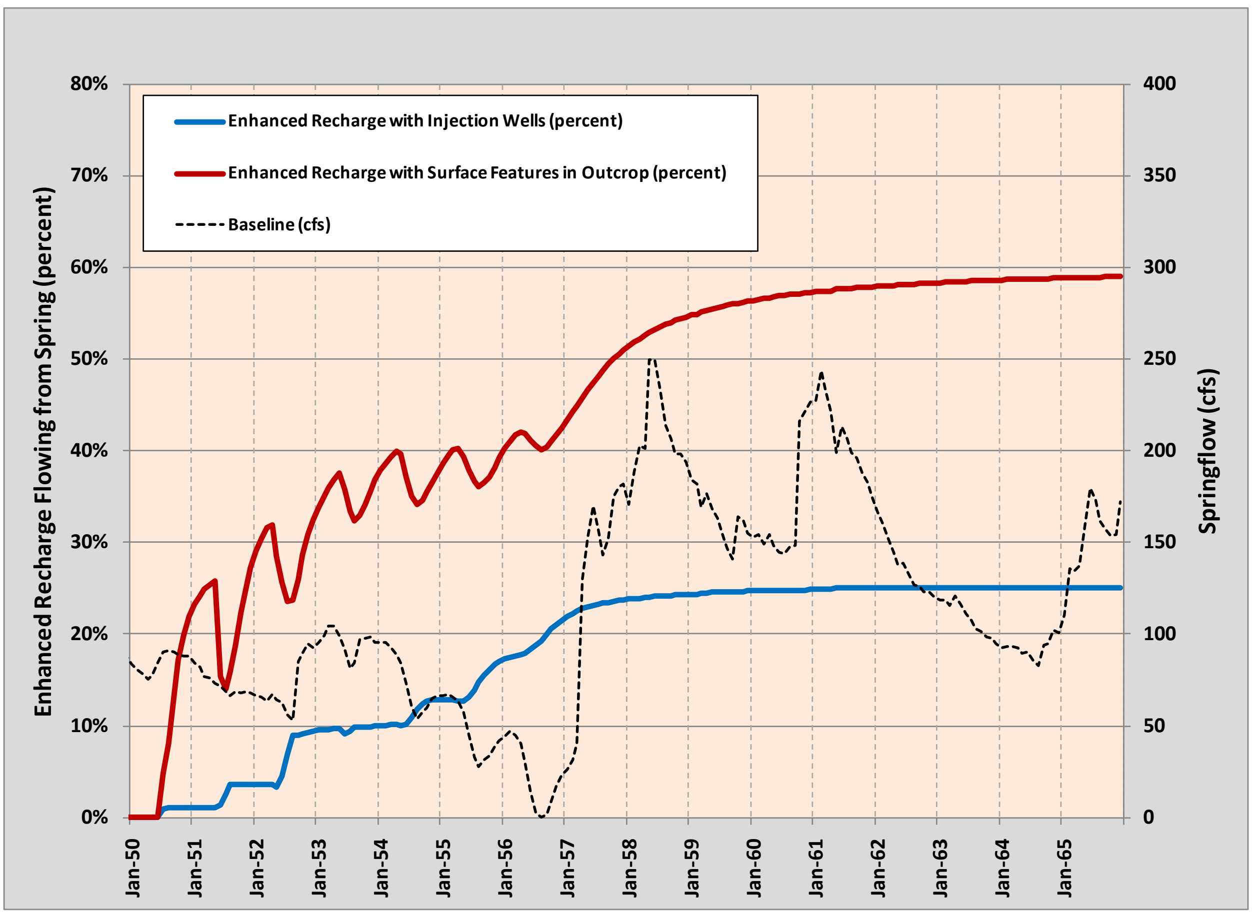


Figure B-6. Comparison of Effectiveness of two Enhanced Recharge Methods at San Marcos Springs.

For either method of episodic recharge enhancement, this analysis suggests that about 80 percent of the enhanced recharge discharges from Comal and San Marcos Springs and about 20 percent is lost to wells or remains in aquifer storage.

In conclusion, the MODFLOW model suggests that recharge in a conduit leading to Comal Springs is relatively effective in providing springflow protection for Comal Springs, but not San Marcos Springs. In contrast, recharge on the outcrop is much more effective for San Marcos Springs than for Comal Springs.

Appendix C
Recovery Factors for Enhanced Recharge at Type II Structures

1.0 Introduction

One management program evaluated in this project involves the concept of recharge and recirculation (R&R). This program examines how enhanced recharge might be extracted downgradient in the aquifer and recirculated back to the recharge zone as a means of dynamically storing the water until needed to augment springflow. However, not all of the water applied to the recharge zone can be captured for recirculation because of almost immediate losses from aquifer storage to springflow and/or to pumping, which may increase locally as recharge results in relief from CPM reductions (i.e., increased withdrawals). Recovery factors were developed to estimate the portion of enhanced recharge that could be recovered by wells prior to such losses. Recovery factors are based on the percentages of enhanced recharge that can be recovered based on recharge and recovery locations and timing.

2.0 Recovery Factors

The factors were developed using the results of preliminary model runs in which slugs of enhanced recharge were introduced separately at selected Type II Recharge Sites during dry (1947) and average hydrologic conditions (1974). In these runs, the percentages of recharge remaining in aquifer storage over time were evaluated. Enhanced recharge initially contributes to groundwater storage, but with time, storage decreases as spring discharge increases or as pumping increases due to relaxed CPM stages. Therefore, the net storage available for recovery and recirculation decreases over time. Using these data, recovery factors were developed for selected recharge sites (Figure C-1) that have been previously identified and used in numerous recharge enhancement studies. These sites were grouped by similar aquifer response. Recovery factors are tabulated in Table C-1.

In developing the factors, the percentages of enhanced recharge remaining in the aquifer were recorded for each elapsed six month period; percentages were developed for each half of the model and averaged. Recharge remaining in the aquifer over two years is assumed to be unrecoverable. Because the retention time and fate of enhanced recharge are similar at the previously-identified western recharge sites (Indian Creek, Lower Frio, and Dry Frio), the factors derived for Lower Frio were applied to all three sites. The central sites (Lower Hondo and Lower Verde) also exhibit similar retention times and aquifer response and, as such, the factors for these two sites were averaged. Factors for Lower Sabinal, San Geronimo, and Cibolo were treated separately to reflect the different retention times and aquifer responses associated with recharge at each site. No factors were estimated for Lower Blanco since water recharged at Lower Blanco was assumed to be unrecoverable due to its down-gradient location and proximity to San Marcos Springs.

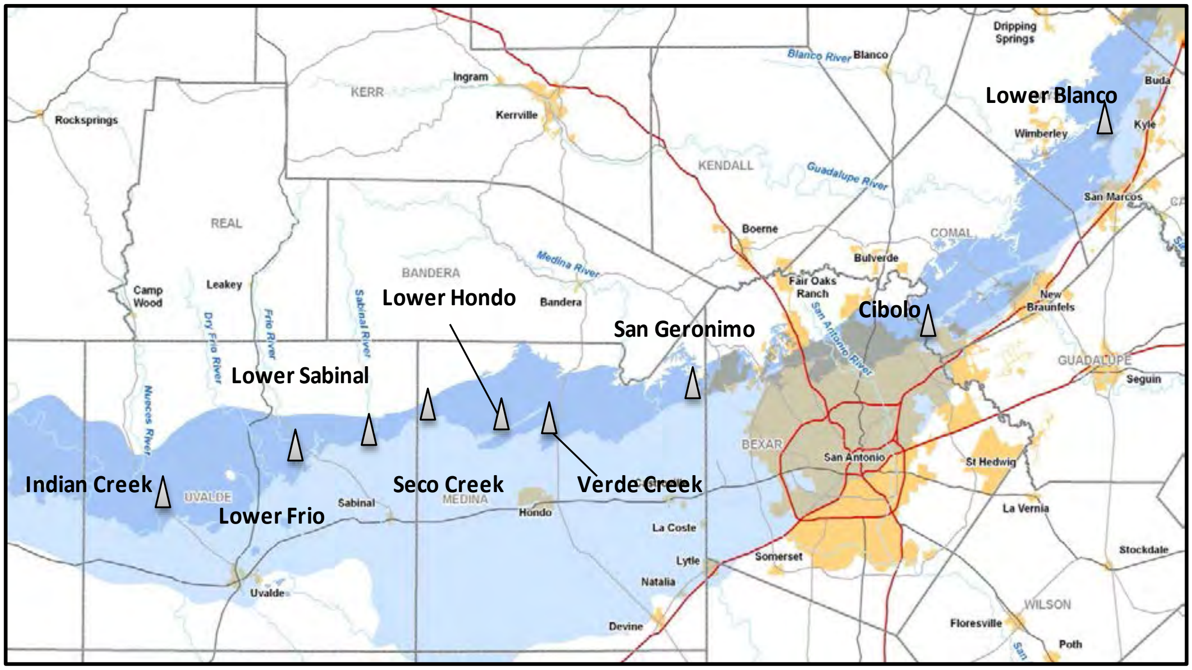


Figure C-1. Location of Selected Type II Recharge Sites

Table C-1.
Recovery Factors for Selected Type II Recharge Structures

Time Delay Between Recharge and Pumping (Months)	Selected Type II Recharge Sites			
	Indian Creek, Dry Frio and Lower Frio (%)	Lower Sabinal (%)	Lower Hondo and Lower Verde (%)	Cibolo and San Geronimo (%)
0	100	98	99	93
6	97	76	87	58
12	90	53	73	40
18	83	45	62	33
24	79	41	53	27

Appendix D
Comparison of Two Levels of Baseline Pumping

1.0 Introduction

As stated in Section 2, the benefits of potential management programs need to be measured against a standard in order to quantify the relative benefits of each program. This standard, or baseline, is represented by groundwater and springflow conditions (i.e., levels and discharges, respectively) that would occur absent implementation of the EARIP management programs being evaluated. The establishment of baseline conditions for evaluation of the water management alternatives and programs by the EARIP participants is consistent with those used in TCEQ WAM (water availability model) and TWDB MAG (managed available groundwater) analyses. In these two cases, model simulations are based on full permitted amounts of water being diverted or pumped each and every year to the extent physically and legally available. Conceptually, this assumption appears to be a worst case scenario. Under drought circumstances, however, assessments of projected water demands and existing supplies for municipalities dependent on the Edwards Aquifer clearly indicate that such existing supplies would be fully used to the extent legally available subject to current Critical Period Management (CPM) reductions.

The purpose of this appendix is to provide results of a study to illustrate differences between baseline pumpage of EAA Initial Regular Permit (IRP) amounts (Table 2-1) and a dataset based on recent annual pumpage.

2.0 Selection of a Representative Baseline for Recent Conditions

The selection of a recent representative pumpage is based on review of EAA reported estimates of Edwards withdrawals from 1980 to 2009. These data are presented in Figure D-1. As shown, pumpage tended to be greater in the 1980s (prior to creation of the EAA and enforcement of critical period management rules) and somewhat lower in the 1990s and 2000s, with the maximum pumpage of 542,400 acft/yr in 1989 and the lowest pumpage of 317,400 acft/yr in 2004. For purposes of comparison to baseline, the selected representative pumpage for recent conditions is the maximum rate in the last decade, which was about 454,500 acft/yr (454K) and occurred in 2006.

Baseline pumpage is subject to CPM, which is applied against the full IRP value. After applying CPM reductions, annual pumping in the model for the 1947-1973 period for the two tests is shown in Figure D-2. As shown, the pumping in the model is essentially the same for many of the years even though the unrestricted IRP baseline is about 139,000 acft/yr greater than the unrestricted 454K baseline. This is about 24 percent of the IRP and suggests that, when the CPM is in Stages III and IV, the pumpage for the two baselines will be the same.

3.0 Comparison of IRP and 454K Baseline Results

Comparisons of the 454K baseline with the IRP baseline are made for Comal Springs and San Marcos Springs in Figures D-3 and D-4 which show the springflow hydrographs for Comal Springs and San Marcos Springs, respectively. As shown, the springflows are essentially the same, except for transient, unusually high flows. Table D-1 shows the number of months when springflow is below selected thresholds for the 1947-2000 simulation period. For the range of flow, the greatest difference is 3 fewer months for the 454K baseline for Comal Springs when the flow is below thresholds of 60 cfs and below 120 cfs.

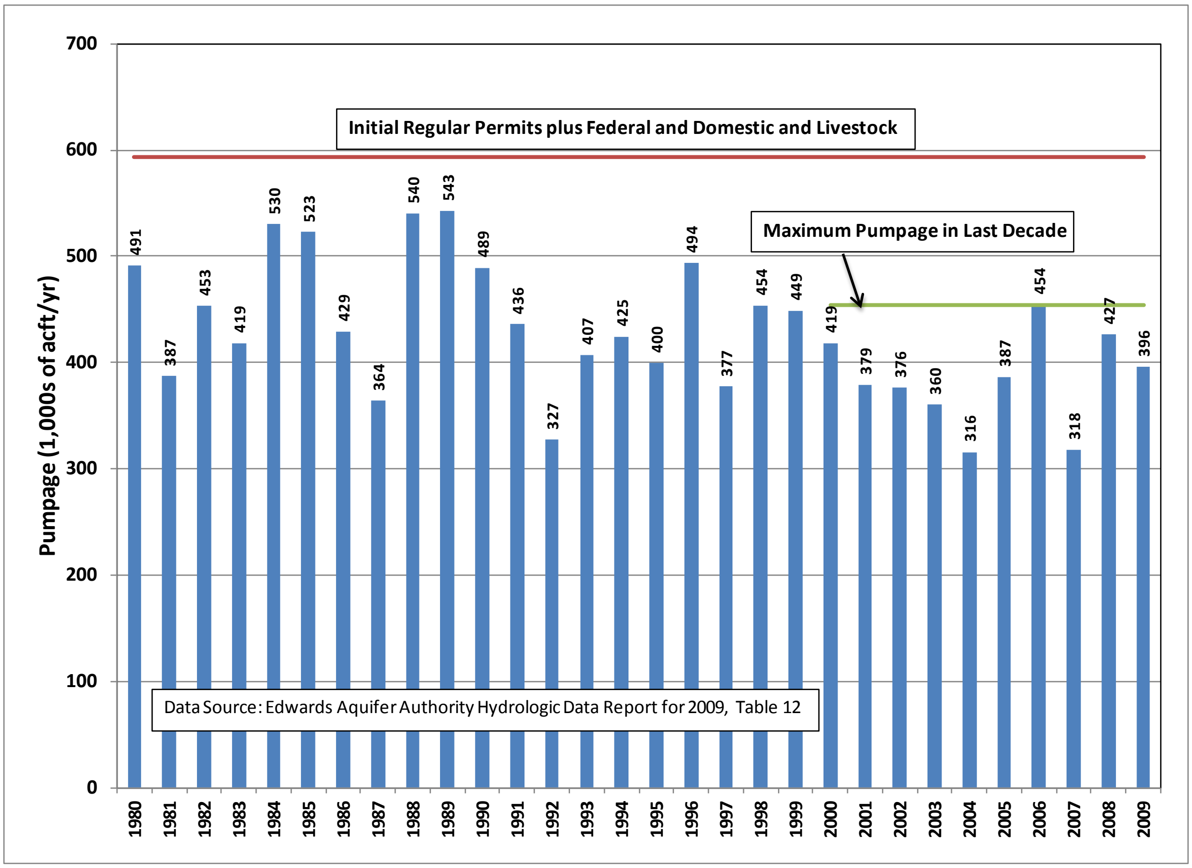


Figure D-1. Annual Edwards Pumping for 1980-2009.

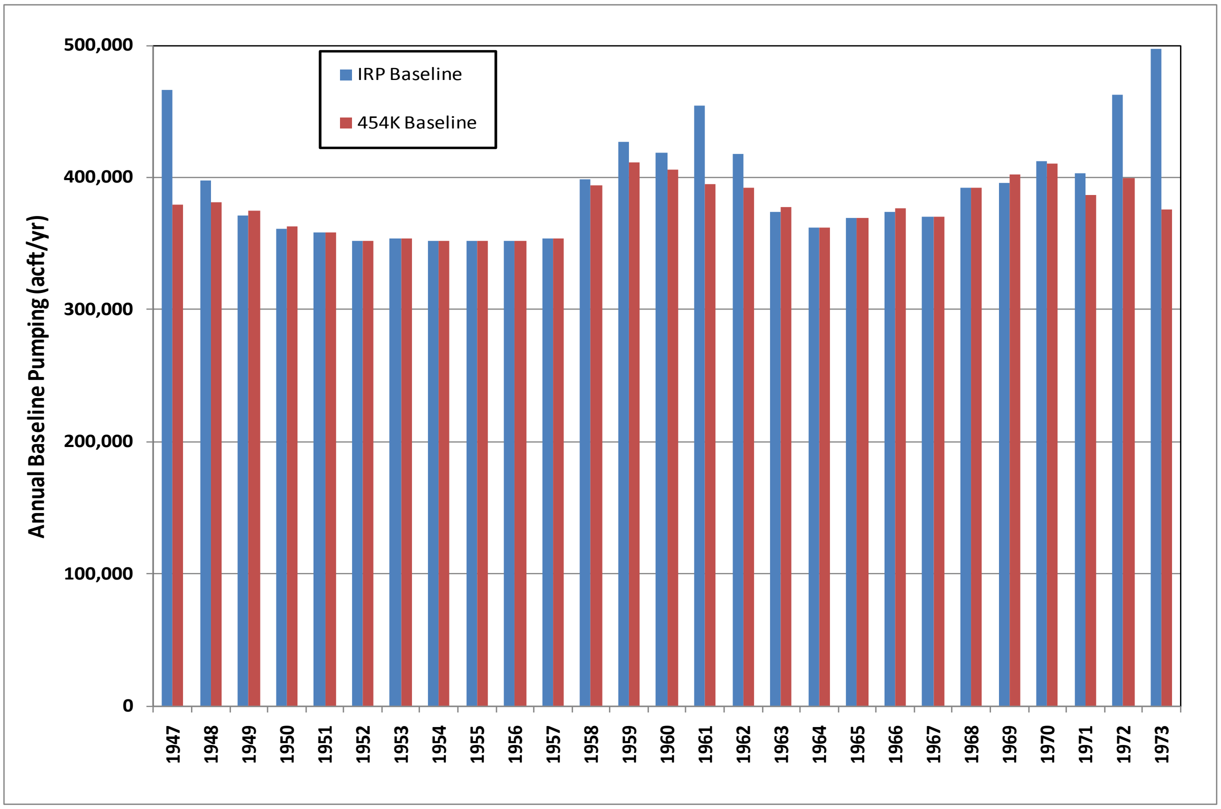


Figure D-2. Annual Pumping in the Two Baselines after CPM is Applied.

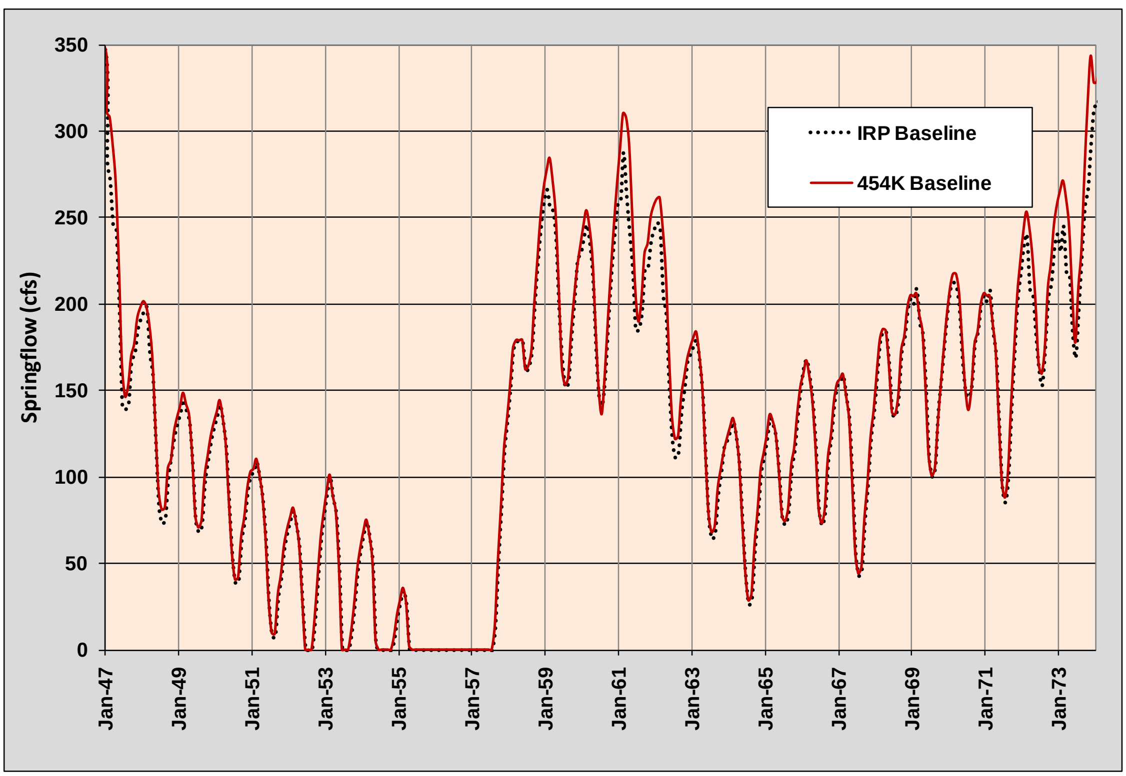


Figure D-3. Comparison Modeled Discharge from Comal Springs for the Two Baselines.

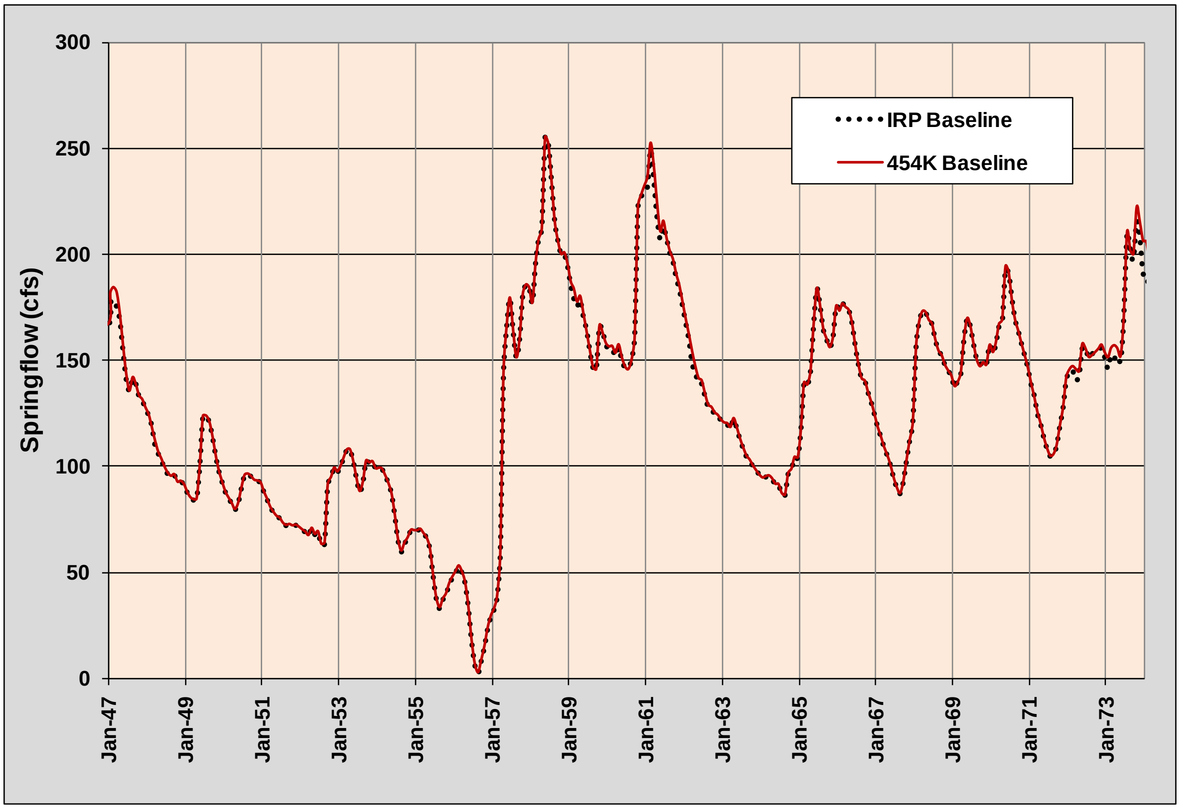


Figure D-4. Comparison Modeled Discharge from San Marcos Springs for the Two Baselines.

Table D-1.
Number of Occurrences of Springflow Below Selected Thresholds (1947-2000)

		Months Below Threshold	Months Below Threshold
Springs	**Threshold (cfs)**	**IRP Baseline**	**454K Baseline**
Comal	**0**	38	37
	30	54	53
	60	73	70
	90	110	108
	120	145	142
SanMarcos	**0**	0	0
	40	14	13
	80	52	52
	120	147	146
	160	242	240

Appendix E
Technical Evaluation of Preliminary Bottom-Up Program Presented to EARIP Participants on January 13, 2011

1.0 Introduction

The design of the preliminary Bottom-Up Program presented to EARIP participants on January 13, 2011 is generally consistent with the description provided in Section 3.

2.0 Water Management Alternatives

The Bottom-Up Program consists of four components, including: (1) Voluntary Irrigation Suspension Program Option; (2) Municipal Conservation; (3) SAWS ASR with Trade-Off Option; and (4) Stage V CPM Emergency Reductions.

2.1 Voluntary Irrigation Suspension Program Option (VISPO)

The operational concept of VISPO is to establish an agreement between irrigators and the EARIP so that irrigation farmers are willing to curtail or eliminate authorized pumping when drought conditions threaten springflow protection. The agreement would pay the farmers a "standby fee" each year for participating in VISPO plus an "implementation fee" for actual curtailment when a drought condition is triggered. In early 2011, five and ten year agreements were under consideration.

Testing of the VISPO component for springflow protection involved the following technical assumptions:

- VISPO applies to about 40,000 acft/yr (IRP value) of Edwards pumping rights with 20,000 acft/yr in Medina County, 15,000 acft/yr in Uvalde County, and 5,000 acft/yr in Bexar County.
- Suspensions are triggered on January 1 if the water level in J-17 is below 650 ft-msl level on September 1 of the previous year.
- Suspensions are assumed to be equally distributed across all irrigation wells in the respective counties.
- Simulated pumping reductions associated with VISPO are consistent with applicable CPM stage.
- Most, if not all, of the Edwards water committed to VISPO is from the base (or restricted) portions of irrigation IRPs.
- The cost estimate is based on information from the VISPO Work Group.

2.2 Municipal Conservation

Municipal water conservation (Conservation) is based on a draft Voluntary Dedicated Water Supply Program developed by a Conservation Work Group of the EARIP, which explored water conservation potential for small communities and water systems and the agricultural sector. Most opportunities for conservation are assumed to include: residential uses of "exempt" wells, "lost water" through municipal infrastructure deficiencies, industrial and commercial processes, rural and small community residential plumbing technologies, excessive landscape watering, use of gray water, and use of condensate and rainwater harvesting for landscape irrigation.

Testing of the Conservation alternative for springflow protection consisted of the following technical assumptions:

- Total pumping reductions are 10,067 acft/yr when the Edwards Aquifer is not in CPM. These reductions are to be accomplished through: toilet retrofit (1,531 acft/yr); replacement of inefficient fixtures (1,286 acft/yr); leak detection and repair (3,750 acft/yr); large-scale retrofit (2,500 acft/yr); and landscape watering savings (1,000 acft/yr).
- Pumping reductions are geographically distributed in proportion to municipal IRPs. This is considered a reasonable approximation because EARIP modeling assumptions and the MODFLOW management modules do not readily accommodate shifts from initial urban savings to rural communities over time.
- Pumping is reduced according to CPM rules.
- Cost estimates for the conservation layer are calculated using unit rates provided by the Work Group and updated though discussions.

2.3 SAWS ASR with Trade-Off Option

The San Antonio Water System (SAWS) Aquifer Storage & Recovery (ASR) facilities are used for storage and transport of Edwards water. Such water will be obtained by leasing irrigation and other Edwards permits and storing withdrawals under these permits using the SAWS ASR facilities in south Bexar County. When needed for springflow protection, stored water is to be recovered and delivered into SAWS water distribution system to reduce or off-set (trade-off) SAWS pumping of the Edwards Aquifer by equal amounts.

The following technical assumptions are used in evaluation of the SAWS ASR with Pumping Off-Set Option:

- Lease of 50,000 acft/yr of unrestriced irrigation IRP for storage in SAWS ASR facilities for springflow protection. Any portion of the leased rights not being used for storage in SAWS ASR facilities is unused (not pumped). The actual supply of water from the leases is subject to CPM rules and pumped as needed to fill ASR storage, left in the aquifer when SAWS ASR is full and fully curtailed when water is being recovered for springflow protection.

- Preliminary operational and modeling procedures are for “dynamic sharing” of injection, recovery, and transmission capacities between SAWS and EARIP. In this context, “dynamic sharing” means that the maximum commitment of SAWS ASR recovery and transmission capacity for direct springflow protection to EARIP could be 100% during severe drought.
- The total conveyance capacity of existing SAWS ASR facilities would be made available for springflow protection when the monthly average groundwater levels at J-17 are below 630 ft-msl (the corresponding Comal Springs discharge is approximately 70 cfs). The selected wells with reduced pumping (to be off-set) are on the northeast side of SAWS water distribution system.
- SAWS ASR use is based on these assumptions: (a) an initial storage of 40,000 acft; (b) storage capacity available to the EARIP of 150,000 acft; and (c) annual water loss of 10 percent of the volume of water available for recovery.
- The recovery rate for stored water from SAWS ASR is limited to the current transmission capacity from SAWS ASR to the Seale and Artesia Stations, which is 60 million gallons per day (MGD), or 5,600 acft/mo.
- Project and operational cost estimates for this alternative are as provided by SAWS. Annual power costs reflect long-term average storage and recovery operations based on the 1947-2000 simulation period.

2.4 Stage V CPM Reductions

In the event that implementation of the first three components (layers) of the Bottom-Up Program is not sufficient for springflow protection, an additional CPM stage (Stage V) is added as an “emergency” measure.

The following technical assumptions are used in evaluation of Stage V CPM Reductions:

- Permitted pumping during Stage V is reduced by 44 percent from the IRP values in both the San Antonio and Uvalde Pools. Domestic and livestock pumping are not restricted. Federal pumping, which is unpermitted, is assumed to be reduced in critical period by the same percentages as permitted pumping.
- Stage V is in effect in both the San Antonio and Uvalde Pools when the water level at J-17 is lower than 625 ft-msl (the corresponding Comal Springs discharge is approximately 40 cfs). However, Stage V is not triggered in the Uvalde Pool until the Uvalde Pool has been in Stage IV on the basis of J-27 water levels.
- Percentage reductions are equal for the San Antonio and Uvalde pools. Stage V CPM is considered to be an “emergency” situation and all permit holders are required to make an equal sacrifice. The reduction factor for the two pools is 44 percent based on the percentage reduction to move from an IRP total of approximately 572,000 acft/yr to a critical period floor of 320,000 acft/yr. The associated reductions in permitted pumping during Stage V (relative to Stage IV) in the San Antonio and Uvalde Pools are 19,200 acft/yr and 8,200 acft/yr, respectively.

- A range of potential costs attributable to Stage V CPM are estimated using available information from the 2011 South Central Texas Regional Water Plan. Approximate costs for demand reduction include: conservation, drought management, and replacement water supplies delivered to Bexar County as necessary to produce about 27,400 acft/yr.

3.0 Layers

Springflow protection at Comal and San Marcos Springs from the Bottom-Up Program is assessed on the basis a of series MODFLOW simulations. These simulations include baseline conditions and the successive stacking of four layers. As implied, the baseline represents conditions with full IRP pumping constrained only by EAA CPM rules. Successive layers are added one at a time in the Bottom-Up Program. Incrementally, one may determine the degree of improvement in springflow protection for a layer by comparison with the results for a previous layer. It's important to note that performance of Bottom-Up Program components in the stacked layer approach may be different if examined individually or in a different sequence.

The selected measures or indicators of springflow protection for Comal and San Marcos Springs are simulated hydrographs from MODFLOW, numbers of months below preselected springflow thresholds, minimum monthly springflow, minimum 6-month moving average springflow, and long-term average springflow. The periods of particular interest are considered to be from 1947-1957 (drought of record) and from 1947-2000 (MODFLOW simulation period).

3.1 Voluntary Irrigation Suspension Program Option (Layer #1)

Pumping reductions attributable to VISPO are triggered for years when drought conditions are anticipated. Figure E-1 illustrates years in the MODFLOW simulation period during which this option is on standby and implemented. As illustrated, the option was implemented and irrigation suspended in each year from 1947 through 1972 and in 17 of the next 28 years.

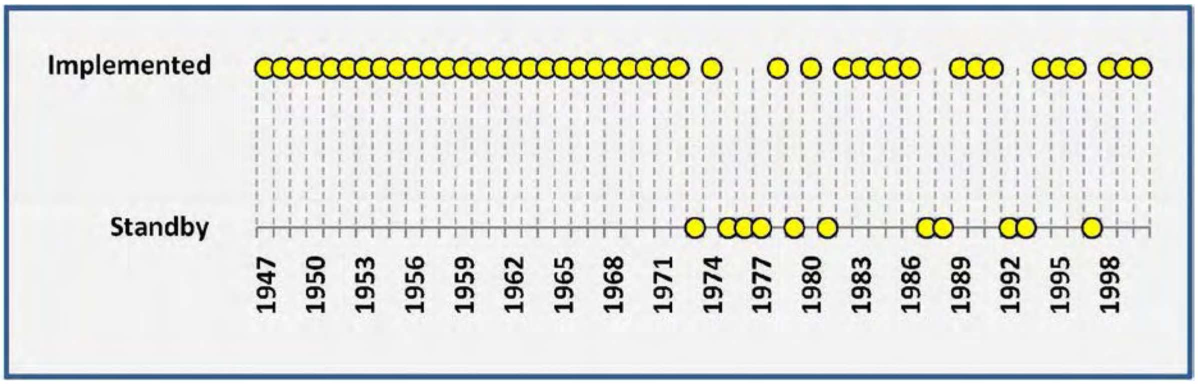


Figure E-1. Annual Status of VISPO Operations (1947-2000)

The permitted pumping for participants in VISPO is subject to suspension and any CPM reductions that may be in effect. For example, if suspension is triggered and there are no CPM restrictions for entire year (highly unlikely), the full IRP pumping reductions would be 40,000 acft. On the other hand, if CPM Stage IV is in effect for the entire year that suspension is triggered, the actual reductions in Edwards withdrawals would be only 25,000 acft. It's important to note that pumping reductions due to VISPO may allow increases in other permitted pumping, which can change CPM duration and magnitude. For example, if baseline pumping (without VISPO) causes the San Antonio Pool to be in Stage IV for eight months in a given year, and reductions in VISPO pumping are sufficient to reduce the duration in Stage IV to 4 months, the Stage V restrictions would be relaxed by 4 months for all permits in the San Antonio pool. For the periods 1947-1957 and 1947-2000, VISPO pumping reductions and increases in allowable pumping due to less time in given CPM stages are presented in Table E-1. This table shows that, for the 1947-1957 period, the average VISPO net pumping reductions are 26,535 acft/yr. For the 1947-2000 period, VISPO net pumping reductions average 23,158 acft/yr. The average VISPO net pumping reductions are less for the 1947-2000 period than the 1947-1957 period because it is activated less frequently due to wetter hydrologic conditions.

Table E-1.
Average Annual Pumping Reductions for Layer #1

Units: acft/year

Condition	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	25,000	15,000	40,000
1947-1957	15,684	10,851	26,535
1947-2000	13,655	9,503	23,158

3.2 VISPO + Municipal Conservation (Layer #2)

In the tentatively adopted Bottom-Up concept, the Municipal Conservation component is added to the VISPO component. The Municipal Conservation component is active each year and the net reductions in pumping are affected by CPM. The full potential pumping reductions for Layer #2 total 50,067 acft/yr.

For the periods 1947-1957 and 1947-2000, cumulative net pumping reductions for VISPO and Municipal Conservation (Layer #2) are presented in Table E-2. This table shows that the average pumping reductions through Layer #2 for the 1947-1957 period were 33,042 acft/yr. For the 1947-2000 period, net pumping reductions through Layer #2 averaged 31,030 acft/yr. During the drought of record period, the net effect of the Municipal Conservation alternative was a pumping reduction of 6,507 acft/yr.

Table E-2.
Average Annual Pumping Adjustments through Layer #2*

Units: acft/year

	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	34,803	15,264	50,067
1947-1957	22,060	10,983	33,042
1947-2000	21,355	9,676	31,030

* Note: Cumulative Adjustments for VISPO and Municipal Conservation

3.3 VISPO + Municipal Conservation + SAWS ASR with Trade-Off Option (Layer #3)

In Layer #3 of Bottom-Up Program, the SAWS ASR with Trade-Off component is added to the VISPO and Municipal Conservation components. Key elements of the SAWS ASR with Trade-Off Option alternative are: (1) leasing of IRPs to either fill SAWS ASR or to suspend the permitted pumping, (2) filling SAWS ASR, and (3) recovering stored water for trade-off (off-set) of SAWS permitted pumping at selected pump stations. An illustration of the SAWS ASR facilities is presented in Figure E-2.

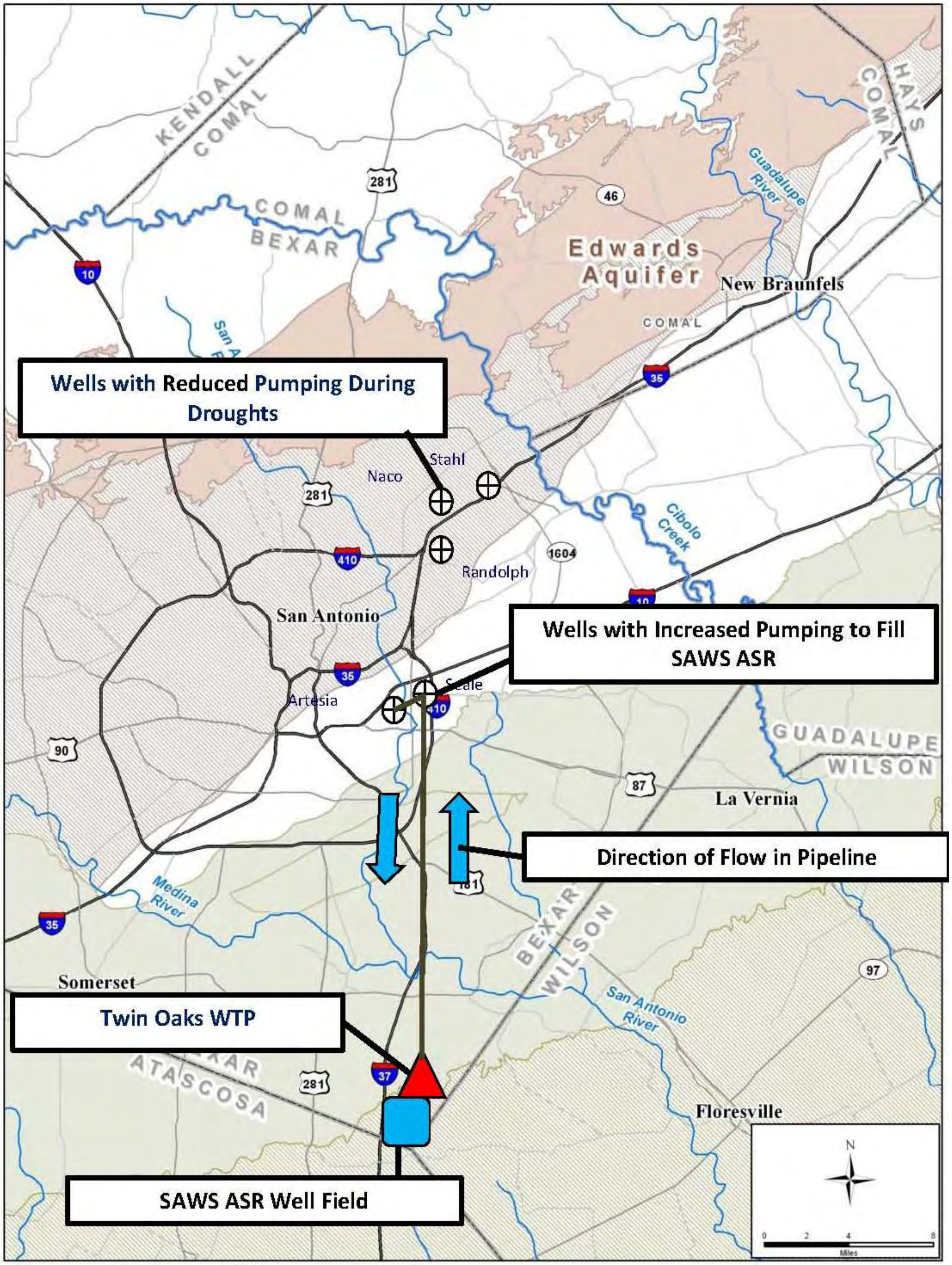


Figure E-2. SAWS ASR Operational Concept

Figure E-3 illustrates the monthly pumping of Edwards lease water to SAWS ASR and the recovery of water for springflow protection. For the 1947-1957 period, about 201,000 acft of Edwards leases were pumped to SAWS ASR during 72 months and about 125,000 acft were recovered for pumping off-set during 60 months. Due to limitations of the transmission facilities, the monthly flow rates are capped at 5,600 acft/mo. Figure E-4 illustrates the storage balance in SAWS ASR for the 1947-2000 period. This chart illustrates that the initial storage started at 40,000 acft, nearly reached the ASR allocated capacity to EARIP of 150,000 acft in 1952 and was nearly emptied in the summer of 1957. The recovery shown in Figure E-4 reflects near optimization of maximizing springflow protection and utilizing the capacity of SAWS ASR that is available to EARIP.

For the periods 1947-1957 and 1947-2000, cumulative net pumping reductions for VISPO, Municipal Conservation, and SAWS ASR (Layer #3) are presented in Table E-3. This table shows that, for the 1947-1957 period, the average cumulative pumping reduction through Layer #3 was 68,664 acft/yr. For the 1947-2000 period, cumulative pumping reductions through Layer #3 averaged 74,733 acft/yr. During the drought of record period, the net effect of the SAWS ASR alternative was a pumping reduction of 35,622 acft/yr. CPM is a strong controlling factor in the pumping reductions.

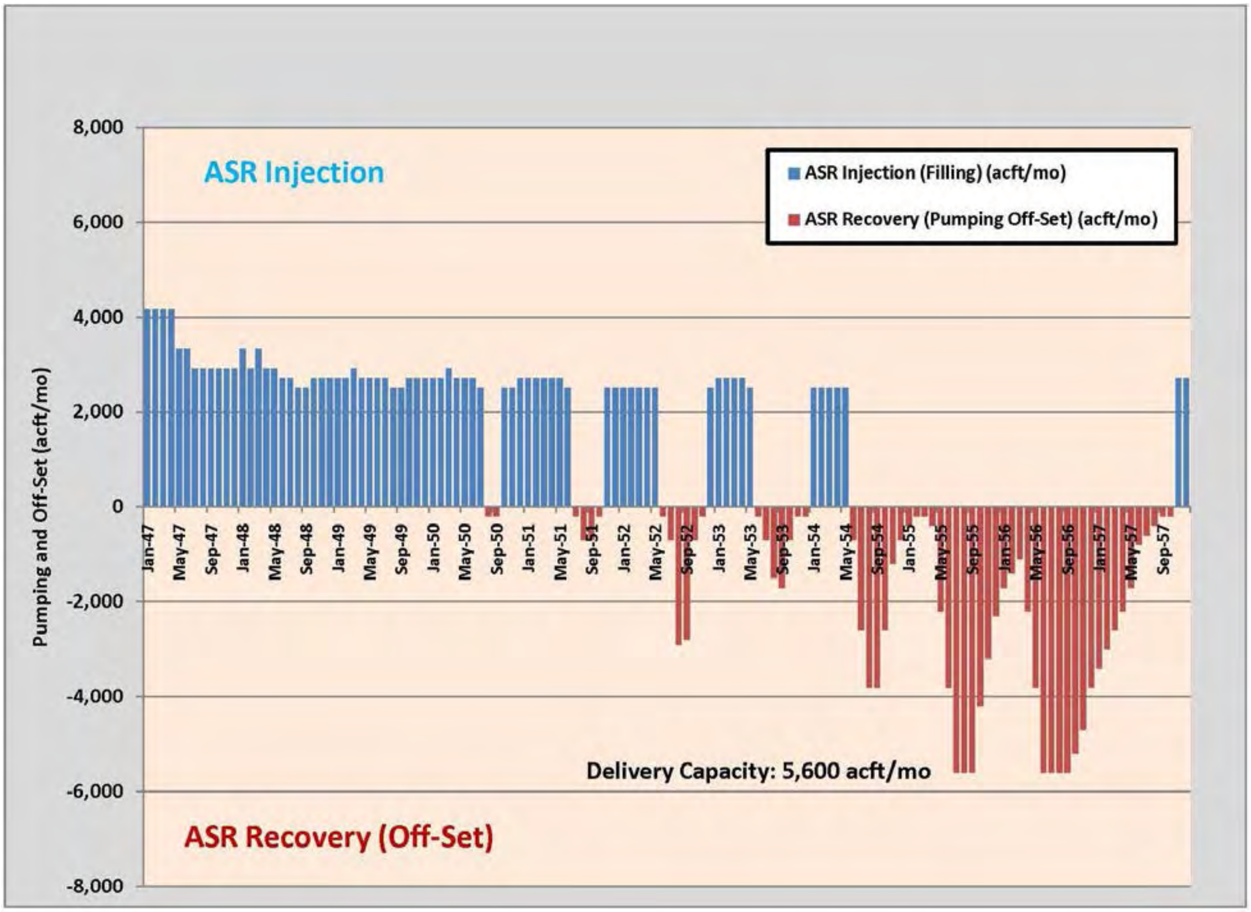


Figure E-3. Rate and Schedule of SAWS ASR Injection and Recovery (1947-1957)

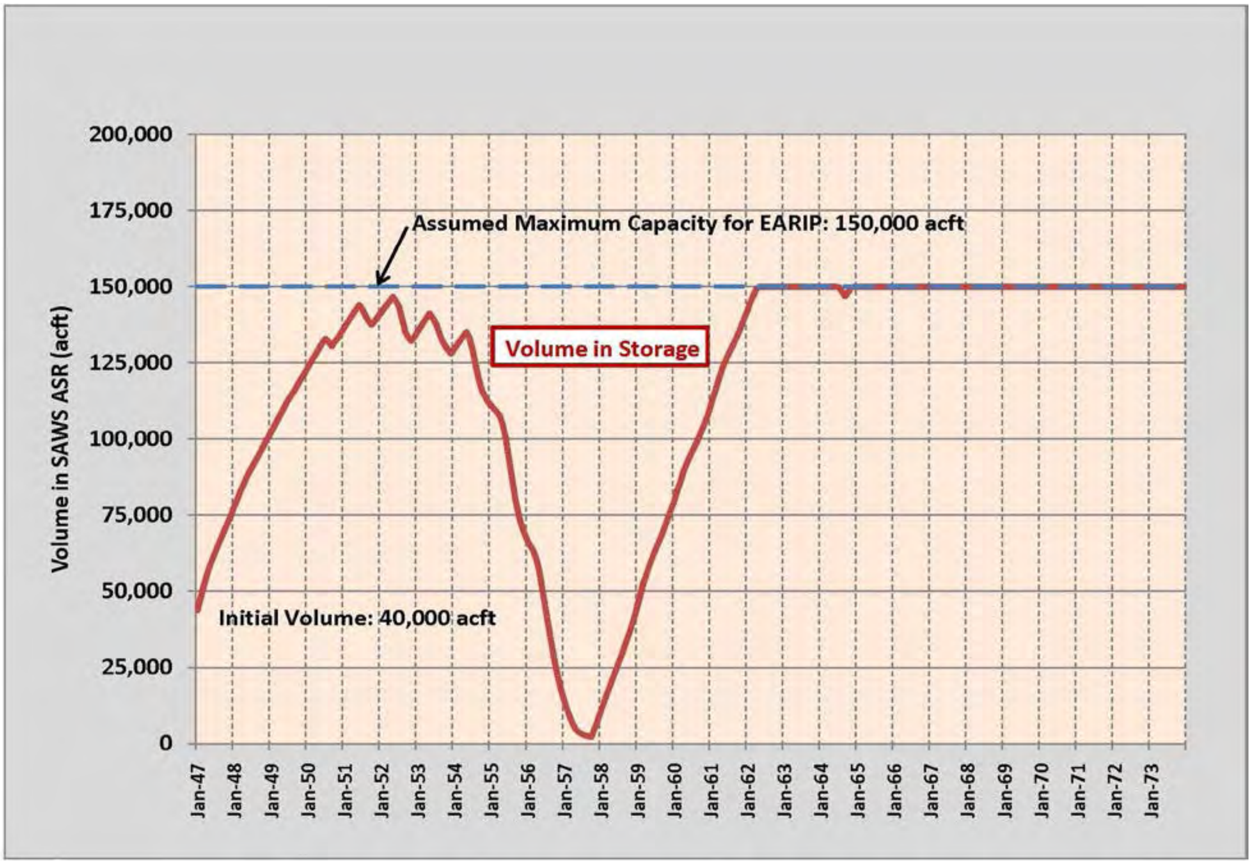


Figure E-4. Storage of EARIP water in SAWS ASR

Table E-3.
Average Annual Pumping Adjustments for Layer #3*

Units: acft/year

	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	59,659	40,408	100,067
1947-1957	35,680	32,984	68,664
1947-2000	38,835	35,898	74,733

* Note: Cumulative Adjustments for VISPO, Conservation and SAWS ASR

3.4 VISPO + Municipal Conservation + SAWS ASR with Trade-Off Option + Stage V (Layer #4)

In Layer #4 of Bottom-Up Program, CPM Stage V is added to the VISPO, Municipal Conservation, and SAWS ASR with Trade-Off components. Key elements of Stage V are triggering this emergency action off of J-17 water levels and applying an equal 44 percent reduction to permitted wells in both the San Antonio and Uvalde pools. Based on the Bottom-Up Program and the J-17 results of Layer #3, Stage V was activated for seven months, of which, four months were in 1956, as illustrated in Figure E-5.

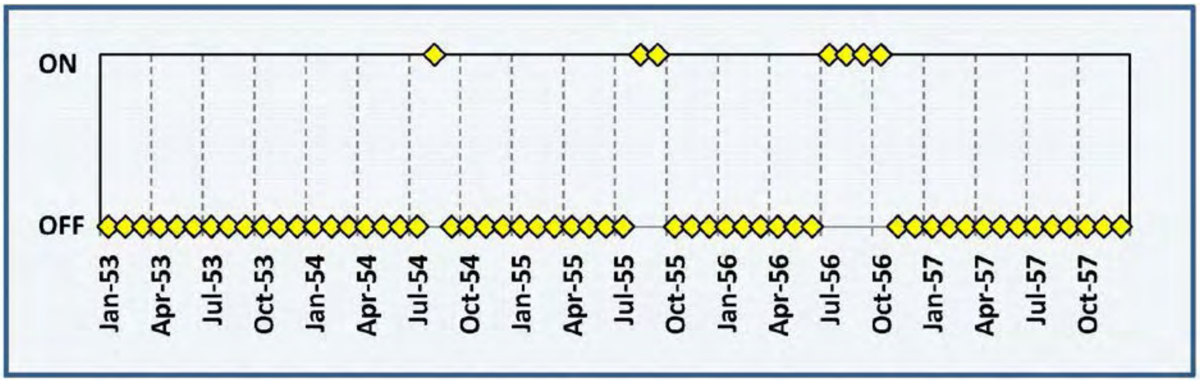


Figure E-5. Occurrences of Stage V

For the periods 1947-1957 and 1947-2000, cumulative net pumping reductions for VISPO, Municipal Conservation, SAWS ASR, and Stage V (Layer #4) are presented in Table E-4. This table shows that for the 1947-1957 period the average Layer #4 net pumping reductions were 70,140 acft/yr. For the 1947-2000 period, Layer #4 net pumping reductions averaged 75,033 acft/yr. As stated earlier, CPM is a strong controlling factor in the pumping reductions.

Table E-4.
Average Annual Pumping Adjustments for Layer #4*

Units: acft/year

	San Antonio Pool	Uvalde Pool	Total
Potential Reductions (IRP Face Value)	78,859	48,608	127,467
1947-1957	36,714	33,426	70,140
1947-2000	39,046	35,988	75,033

* Note: Cumulative Adjustments for VISPO, Conservation, SAWS ASR, and Stage V

4.0 Results

4.1 Springflow Hydrographs

Hydrographs from the MODFLOW model simulations are used to temporal display of the variations in magnitude of springflow over time. For comparison purposes, hydrographs are presented for the five scenarios (baseline and each of the four Bottom-Up Program layers). Study of the hydrographs provides qualitative information on the changes in springflow over time for each additional layer of the Bottom-Up Program.

The MODFLOW calculated springflows for the 1947-1960 period for Comal and San Marcos Springs are presented in Figure E-6 and E-7, respectively. Observations upon review of Figures E-6 and E-7 focusing on the drought of record include the following: (1) the modest improvement in springflow when the Municipal Conservation and Stage V layers are added; (2) very substantial improvement from the VISPO and SAWS ASR components for 1951-1957 at

Comal Springs and for 1955-1957 at San Marcos Springs and (3) substantial improvement in Comal Springs flow due to implementation of Stage V during the summer of 1956.. These hydrographs indicate that the Bottom-Up Program limited the minimum springflow at Comal and San Marcos Springs to about 25 and 50 cfs, respectively. A study of the recovery schedule from SAWS ASR (Figure E-3) shows that the capacity of the SAWS ASR water transmission facilities (pipelines and pumps) is the limiting factor in the level of springflow protection at Comal Springs. If the capacity of the water transmission system had been greater, water could have been recovered at a greater rate for SAWS ASR Trade-Off pumping, which would have provided more springflow at Comal Springs.

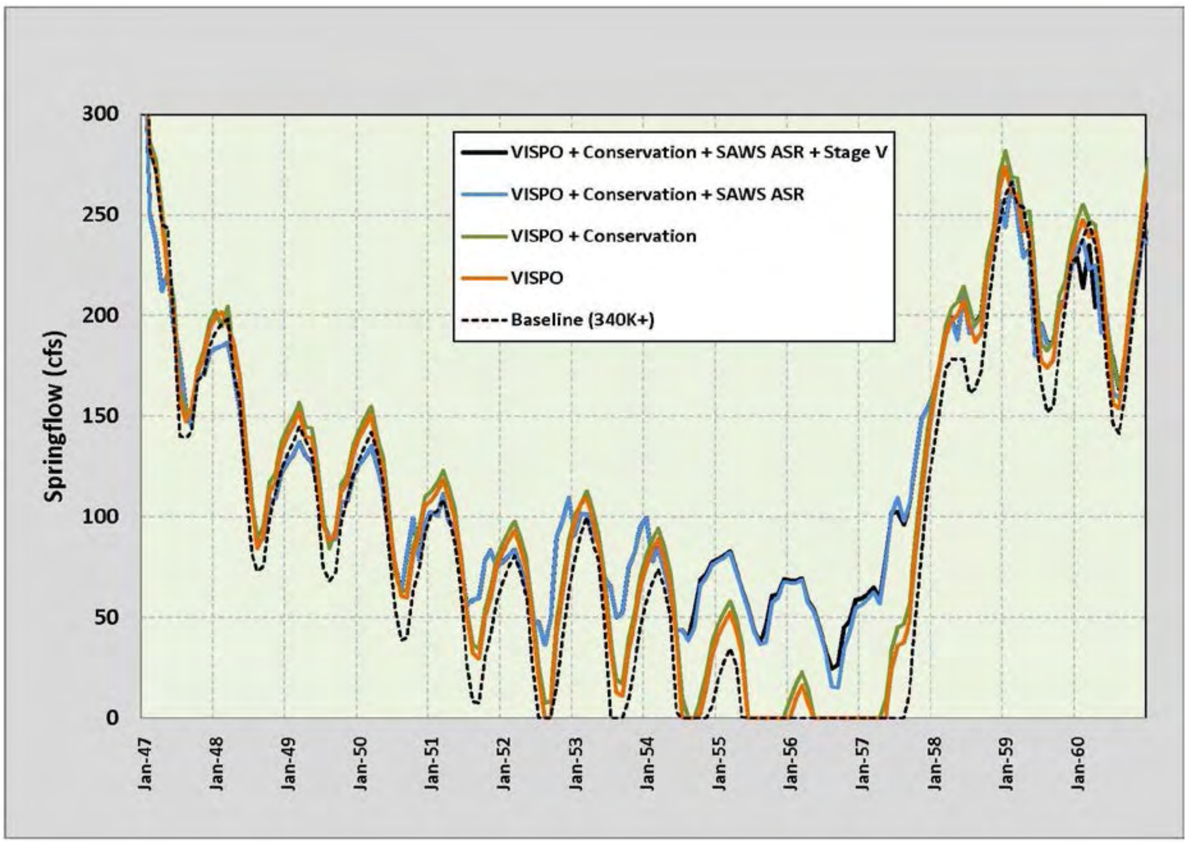


Figure E-6. Simulated Springflow at Comal Springs (1947-1960)

The MODFLOW calculated springflows for the entire 1947-2000 simulation for Comal and San Marcos Springs are presented in Figure E-8 and E-9, respectively. These hydrographs show that the Bottom-Up Program usually increases springflow by small amount in periods other than the drought of record. Most of the increases are attributeable to adding VISPO and SAWS ASR alternatives, which lead to significantly less Edwards pumping.

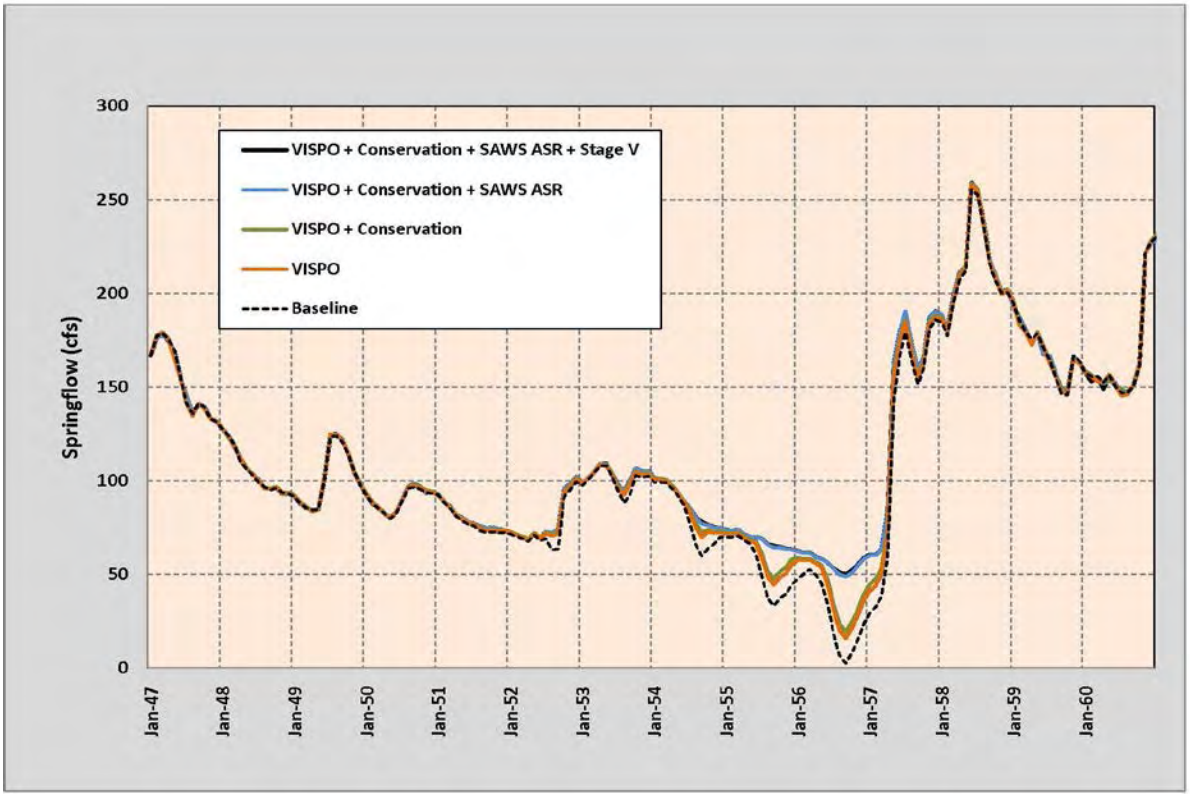


Figure E-7. Simulated Springflow at San Marcos Springs (1947-1960)

Further study of Figures E-8 and E-9 suggests that Comal Springs has a much more direct response to water management alternatives than San Marcos Springs. This is mostly attributable to: (1) a strong hydrogeologic connection between Comal Springs and the main body of the Edwards; and (2) discharge from San Marcos Springs being subject to discharge from Comal Springs and geologic faults located between Comal and San Marcos Springs that function as partial barriers to groundwater flow.

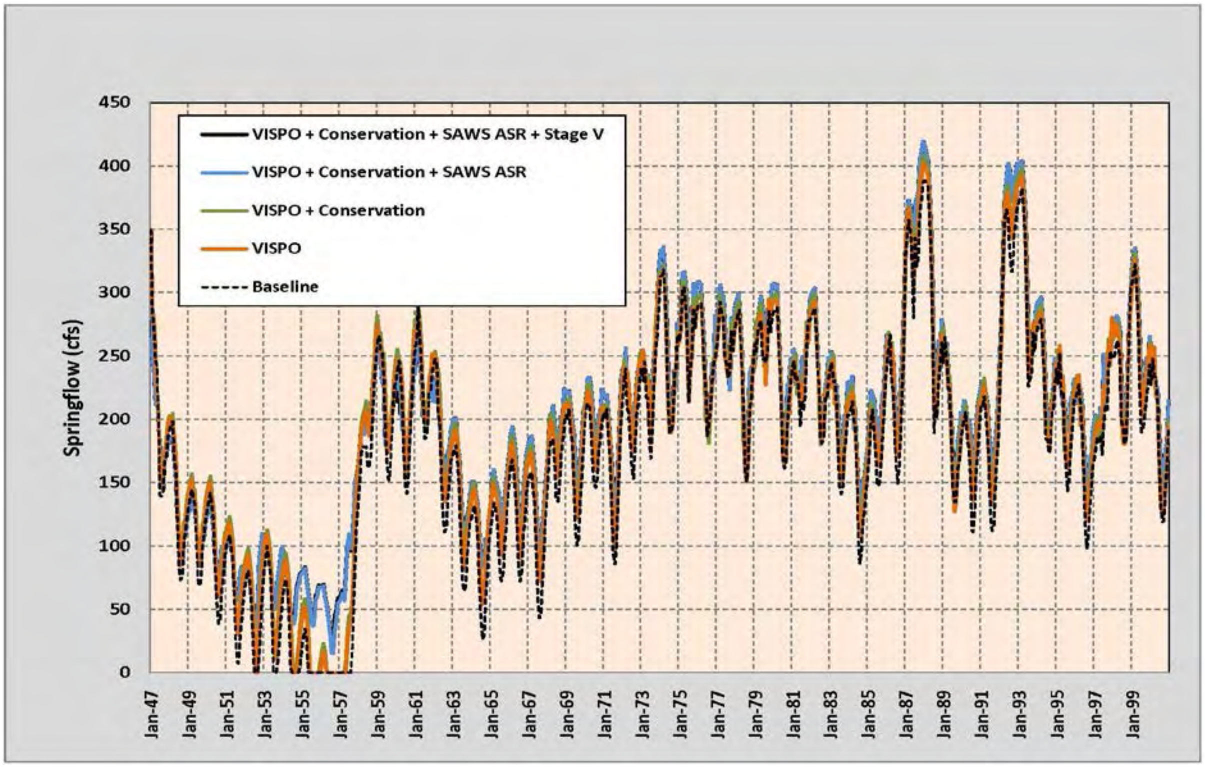


Figure E-8. Simulated Springflow at Comal Springs (1947-2000)

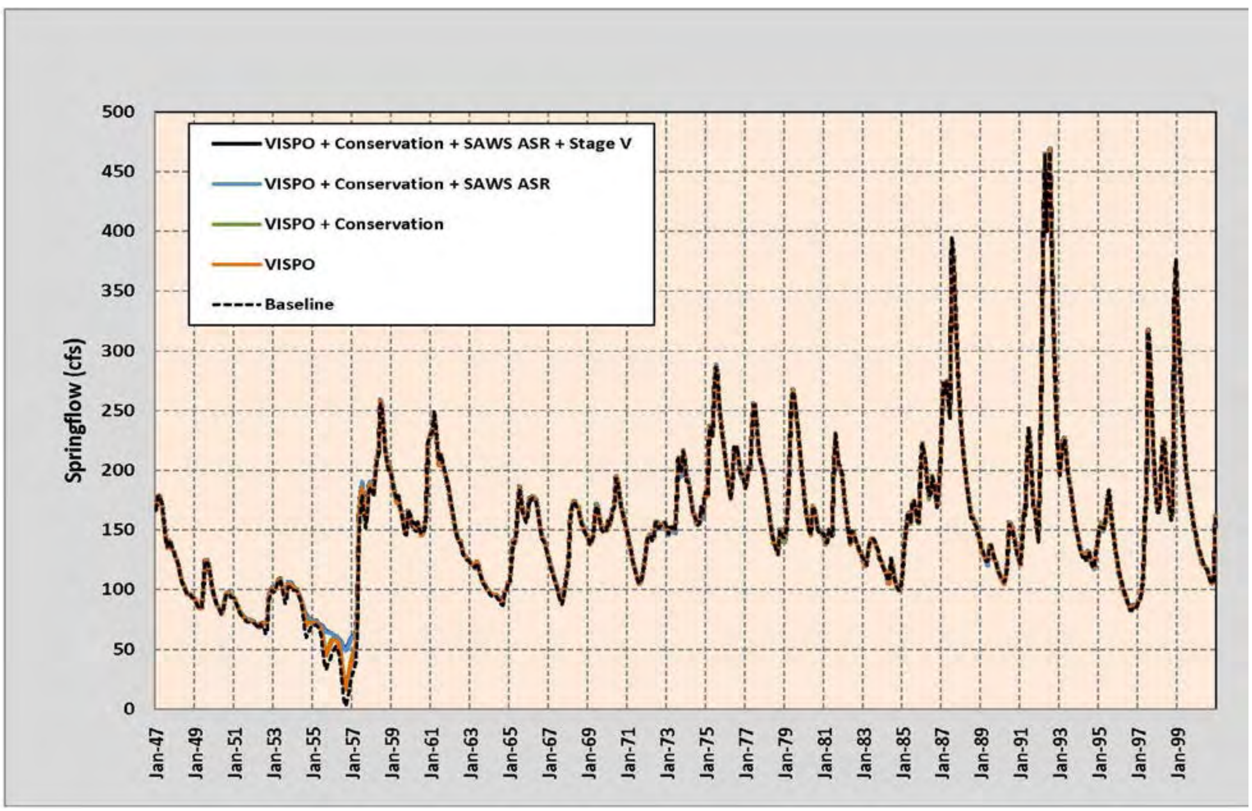


Figure E-9. Simulated Springflow at San Marcos Springs (1947-2000)

4.2 Frequency of Springflow below Thresholds

A measure of considerable importance in the protection of endangered species is the number of months that springflow at Comal and San Marcos Springs is below selected thresholds. Counts of the monthly occurrences for the selected thresholds of springflow are presented for Comal and San Marcos Springs in Table E-5 for the period 1947-2000. Review of these results shows very substantial improvement in springflow protection with VISPO and SAWS ASR. Critical thresholds are 30 cfs at Comal Springs and 52 cfs at San Marcos Springs. This table shows that there were no months of zero springflow and two months below the thresholds at Comal and San Marcos for these critical conditions. Finally, this analysis indicates that the extents of the periods of time below all the thresholds were reduced or stayed the same with the Bottom-Up Program.

Table E-5.
Number of Occurrences of Springflow Below Selected Thresholds (1947-2000)

Spring	Threshold (cfs)	Number of Months				
		Baseline	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
Comal	**0**	38	26	21	0	0
	30	54	36	34	2	2
	60	73	58	55	31	28
	90	111	87	83	76	76
	120	157	129	124	118	117
San Marcos	**0**	0	0	0	0	0
	52	20	14	12	3	2
	80	52	50	50	48	48
	100	121	118	115	115	115
	120	189	189	188	187	187

4.3 Frequency of CPM

Water users in the Edwards are interested in the amount of time that their permits will have CPM restrictions. These results for the period 1947-2000 are summarized for the San Antonio Pool on the basis of J-17 water levels for all EAA CPM stages for the Bottom-Up Program in Table E-6. These results show that the number of months with no CPM constraints generally increased for each Bottom-Up layer, which, obviously is an improvement over the baseline conditions. However, the amount of time in Stage I increased in an amount that generally offset the improvement for no CPM conditions. In the more severe Stage II to IV CPM restrictions, the number of months generally became less or stayed the same with each successive Bottom-Up layer. Stage V only applied to the last layer of the Bottom-Up Program.

Table E-6.
Number of Occurrences of CPM in San Antonio Pool (1947-2000)

Stage, as indicated by Comal Springs, except for Stage V	Number of Months				
	Baseline	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
None	205	223	228	237	237
I	71	82	91	107	109
II	151	153	149	142	140
III	99	88	86	72	72
IV	122	102	94	90	83
V	0	0	0	0	7

4.4 Springflow Statistics

A few key statistics of importance to biologists in evaluating the performance of springflow protection from the Bottom-Up Program are minimum springflow, minimum 6-month moving average springflow, and long-term average springflow. These statistics are presented for the period 1947-2000 in Table E-7 for Comal and San Marcos Springs. As shown in this summary, the minimum monthly average springflows for Comal and San Marcos Springs are 25 and 50 cfs, respectively, for the full Bottom-Up Program. For the minimum 6-month moving average, the minimum monthly average springflows for Comal and San Marcos Springs are 37 and 53 cfs, respectively. The long-term average springflows were 200 cfs at Comal and 154 cfs for San Marcos.

Table E-7.
Springflow for Selected Statistics (1947-2000)

Spring	Statistic	Baseline (340K+)	VISPO	VISPO + Conservation	VISPO + Conservation + SAWS ASR	VISPO + Conservation + SAWS ASR + Stage V
Comal	Minimum Month	0	0	0	15	25
	Minimum 6-Month Moving Average	0	0	0	30	37
	Long-Term Average	178	188	192	200	200
San Marcos	Minimum Month	2	16	19	49	50
	Minimum 6-Month Moving Average	12	25	29	52	53
	Long-Term Average	153	153	154	154	154

5.0 Cost Estimates

As discussed earlier, the Bottom-Up Program is a key component of the Initial Adaptive Management Phase. Accordingly, the concept is to postpone engineering solutions to later phases and adopt management alternatives to the extent possible. With this concept, none of the selected alternatives in the Bottom-Up Program requires new facilities. Instead, the water management alternatives can be developed under existing EAA rules and with SAWS existing facilities. As a result, the cost basis for the water management alternatives were largely prepared by EARIP work groups. The presented cost estimates for the Bottom-Up Program do not include administrative or management cost, which is assumed to be provided by the sponsoring stakeholders and without cost to the EARIP.

5.1 Assumptions and Definitions

The costs bases for the VISPO, Municipal Conservation, and SAWS ASR components of the Bottom-Up Program were provided by EARIP Work Groups and processed by HDR. Where Edwards irrigation IRPs are to be procured, the contractual arrangements are assumed to be leases or temporary contracts instead of purchases. A background summary for the cost of each program component follows:

- **VISPO:** The tentative working proposal for the VISPO Work Group is to offer holders of irrigation permits either a 5-year or 10-year option under which EARIP would pay a standby fee and an implementation fee. For a 5-year commitment, the standby fee ($50.00/ acft/yr) would escalate at a rate of 1.5 percent per year for 10 years in the program, and the implementation fee ($150.00/ acft/yr) would escalate at the rate of 3 percent per year. For the 10-year commitment, the standby fee would be $57.50/ acft/yr for the first five years and $70.20/acft/yr for the second five years; and, the implementation fee would be $172.50/ acft/yr for the first five years and $210.60/ acft/yr for the second five years. For purposes of this EARIP report, it is assumed that: (1) 70 percent of the leases are in the 5-year option and 30 percent are in the 10-year option, and (2) the annual fee per acft of water for the 1947-2000 period is the composite average fee for the first ten years for leases under 5-year option and the first 10 years for leases under the 10-year option. The long-term average annual cost is based on an annual calculation that considers the standby each year and the and whether or not the implementation fee as needed.
- **Municipal Conservation:** The Conservation Work Group provided the following guidelines:

  List of elements and their initial cost and annual pumping reductions:

  - High Efficiency Toilets: $12,000,000 (1,531 acft/yr)
  - High Efficiency Water Fixtures: $480,000 (1,286 acft/yr)
  - Lost Water (Reducing leaks or lost water in small municipal water systems): $3,750,000 (3,750 acft/yr)
  - Large Scale Retrofit (Supporting industries): $2,500,000 (2,500 acft/yr)
  - Landscape: $1,000,000. (1,000 acft/yr)

  Implementation of the 10-year option is assumed to occur evenly over 10 years.

  As envisioned by the Conservation Work Group, these are incentive programs so the costs shown are those potentially borne by the EARIP. Total costs to obtain water savings and pumping reductions may be substantially greater.
- **SAWS ASR with Trade-Off Option:** The concept is to obtain leases and options on 50,000 acft/yr of Initial Regular Permits (IRPs) on Edwards Aquifer irrigation and other

permits. The leases and options will be divided into thirds (tiers). The first third, approximating 16,667 acre-feet of permits, will be leased at all times. The middle third and final third of the leases would be implemented during moderate and severe drought conditions, respectively. The first third of the leases (continual) are assumed to cost $125/ acft/yr. For the second and third tiers, lease costs have two elements. One is a standby cost, which is assumed to be $40/ acft/yr, and would occur each year; and the other is an implementation cost of $150/ acft/yr, which would be paid only when the second and third tiers are implemented. The tentative working EARIP-SAWS agreement is that SAWS would: (1) waive costs equivalent to depreciation of a third of the $250,000,000 asset over 30 years on a straight line basis, and (2) be reimbursed $3,080,000 per year for water treatment, power, and other operations and maintenance expenses.

- **Stage V:** The EARIP did not develop guidelines on an appropriate method of estimating these costs. As general information, HDR has presented a range of water supply alternatives that may be considered to replace an equivalent of 27,400 acft/yr on an intermittent basis. The unit costs for these alternatives are from the 2011 South-Central Texas Regional Water Plan. These alternatives and the assumed unit cost include:
  - Irrigation water conservation ($160/acft/yr),
  - Municipal water conservation ($600/acft/yr),
  - Near-term water management strategies for SAWS ($1,300/acft/yr),
  - Long-term water management strategies for SAWS ($2,300/acft/yr), and
  - Drought management ($150/acft/yr to $15,000+/acft/yr).

One concept for implementing the SAWS water management strategies is for the EARIP or others to sponsor a new water supply for SAWS. In exchange, SAWS would temporarily transfer a prorated amount of their Edwards permits or leases to these sponsors (e.g., outlying municipalities).

5.2 Summary

A summary of the estimated cost, not including administrative and management costs, is provided in Table E-8 for layers 1-3 and Table E-9 for layer 4. For the first three layers, the total investment cost over 10 years is estimated to be $19,730,000. The greatest annual cost is for Edwards irrigation water leases, which totals $16,466,000 per year. The total annual cost is estimated to be $22,259,000. The most costly layers are the VISPO and SAWS ASR alternatives which cost about $10,000,000 each. It’s important to note that these two programs also have the greatest impact on springflow protection.

Table E-8. Estimated Cost for Layers 1-3 of Bottom-Up Program

Program Component	Investment	Annual				
		Edwards Water Leases	Depreciation over 30-years	O&M	Energy	Total
				(54-Yr Average)		
Layer 1: VISPO (10-Year Option)	N/A	$10,216,000	N/A	N/A	N/A	$10,216,000
Layer 2: Municipal Conservation (10-Year Program)	$19,730,000	N/A	N/A	N/A	N/A	$1,973,000
Layer 3: SAWS ASR	N/A	$6,250,000	$2,778,000	$833,000	$209,000	$10,070,000

Table E-9. Range of Estimated Cost for Layer 4 of Bottom-Up Program

Alternative (from 2011 Region L Water Plan)	Unit Cost (acft/yr)	Annual Cost
Irrigation Water Conservation	$140	$3,836,000
Municipal Water Conservation	$600	$16,440,000
Near-Term Water Management Strategies for SAWS	$1,300	$35,620,000
Long-Term Water Management Strategies for SAWS	$2,300	$63,020,000
Drought Management	$150 to $15,000+	$4,110,000 to $411,000,000+
Note: Annual cost is based on acquiring 27,400 acft/yr		

Appendix F
List of MODFLOW Runs in Development of Selected Springflow Protection Program

1.0 Introduction

During the course of development of the Bottom-Up Program, HDR and Todd Engineers formulated, prepared input files, conducted model simulations, and summarized results for numerous model runs. This process was directed by the Steering Committee and the Program Manager and continued until the Stakeholders informally agreed on a phased approach in implementing a Habitat Conservation Plan (HCP) and informally adopted the Bottom-Up Program for springflow protection.

Technical assumptions for the simulations were prepared by HDR. Almost all of the simulations in the evaluation of water management alternatives and programs were performed by Todd Engineers. They also conducted sensitivity tests to evaluate the performance of various levels of baseline pumping and pumping reductions. To efficiently do this work, Todd Engineers wrote and utilized several computer programs to prepare data sets for a MODFLOW simulation and to process the model results. HDR's simulations were limited to an evaluation of determining the performance of providing enhanced recharge for springflow protection by use of injection wells discharging directly into a conduit leading to Comal Springs or by use of surface recharge structures and features. This evaluation included the development of an episodic recharge schedule and rate to optimize springflow protection for a given amount of water available for recharge.

A listing of the significant simulations preformed by Todd Engineers is provided in Table F-1, and the ones performed by HDR are listed in Table F-2. As shown, Todd Engineers performed nearly 80 significant simulations, and HDR nearly 10 sensitivity tests.

Table F-1.
List of MODFLOW Simulations Performed by Todd Engineers

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
Program 1							
1	ASR_Wells	Pumped unused rights from new managed well field	Base	Unused_ne_ Bexar	Base	Program1	Prelim
2	ASR_Recharge	Recharge regime A in conduit location to maintain > 30cfs springflow at Comal , no pumping of unused rights	Conduit	Base	Base	Program1	Prelim
3	ASR_RechargeB	Recharge regime B in conduit location to maintain > 30cfs springflow at Comal , no pumping of unused rights	Conduit	Base	Base	Program1	Prelim
4	ASR_B	Pumping unused rights and recharge regime B in conduit location with managed pumping	Conduit	ASR_wells	Base	Program1	Iteration
5	ASR_C	Pumping unused rights and recharge regime C in conduit location (pumping occurs when recharge does not)	Conduit	ASR_wells_c	Base	Program1	Final
6	ASR_320K	Revise CPM pumping reductions so the minimum is 320K AFY. Same as ASR_all with new rules file	Conduit	ASR_wells	320K	Program1	Iteration

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
7	ASR_286K	Revise CPM pumping reductions so the minimum is 286K AFY. Same as ASR_all with new rules file	Conduit	ASR_wells	286K	Program1	Iteration
8	ASR_320K_D	Revise CPM pumping reductions so the minimum is 320K AFY. ASR recharge regime D	Conduit	ASR_wells_D	320K	Program1	Final
9	ASR_286K_E	Revise CPM pumping reductions so the minimum is 286K AFY. ASR recharge regime E	Conduit	ASR_wells_e	286K	Program1	Final
10	ASR_C_lease	Pumping unused rights and recharge regime C2 in conduit location (pumping occurs when recharge does not). Rights are leased	Conduit	ASR_wells_c_lease	Base	Program1	Final
11	ASR_320K_D2	Pumping unused rights and recharge regime D2 in conduit location (pumping occurs when recharge does not). Rights are leased	Conduit	ASR_wells_D_lease	320K	Program1	Final

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
12	ASR_286K_e 2	Pumping unused rights and recharge regime e2 in conduit location (pumping occurs when recharge does not). Rights are leased	Conduit	ASR_wells_e_ lease	286K	Program1	Iteration
13	ASR_286K_e 3	Pumping unused rights and recharge regime e3 in conduit location (pumping occurs when recharge does not). Rights are leased	Conduit	ASR_wells_e2 _lease	286K	Program1	Final
Program 2							
14	Type2	Recharging at Type 2 locations	Type 2s (LF,LS,LH,LV,S G,C,FRS)	Base	Base	Program2	Final
15	DYO	Implement DYO triggers on Type2	same Type2	DYO_well	Base	Program2	Final
16	Land	Add Land Stewardship	Type 2s + Dry Comal	DYO_well	Base	Program2	Final

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
17	SAWS_ASR	Simulated pumping reductions at the end of the drought.	Type 2s + Dry Comal + Offset pumping	DYO_well	Base	Program2	Final
Program 3							
18	Unused	Pumped unused rights from managed well field and recharge to LH and LV	zone 51,52	unused	Base	Output_credits_710	Prelim
19	Unused_Type2	Pumped unused rights from managed well field and recharge to LH and LV, Type 2 recharge from LF, LS, LH, LV	zones 49,50,51,52	unused	Base	Output_credits_710	Prelim
20	recovery150	Examining recharge recovery with a trigger of Comal springflow at 150cfs.	Type 2s (LF,LS,LH,LV), Recovery to LH, LV	Recovery_150.wel	Base	Program3	Final
21	recovery100	Examining recharge recovery with a trigger of Comal springflow at 100cfs.	Type 2s (LF,LS,LH,LV), Recovery to LH, LV	Recovery_100.wel	Base	Program3	Final

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
22	RR3	R&R trigger 100 cfs, Hondo/ Verde split adjusted to .75/.25	Type 2s (LF,LS,LH,LV), Recovery to LH, LV	Recovery_2_ 100.wel	Base	Program3	Final
23	RR4	R&R trigger 30 cfs, Hondo/ Verde split adjusted to .75/.25	Type 2s (LF,LS,LH,LV), Recovery to LH, LV	Recovery_2_ 30.wel	Base	Program3	Final
Trade Off Bexar							
24	TradeOff_B_ Base	Run creating new stages and pools without changing reductions to test implementation	Base	Base	TO_Base	Trade_Offs	Prelim
25	TradeOff_B1	More severe rules for Bexar County	Base	TO_Bexar	TO_Bexar	Trade_Offs	Iteration
26	TradeOff_B1 b	More severe rules for Bexar County. Iteration to ensure total water in storage is equviliant to the replacement water needed.	Base	TO_Bexar	TO_Bexar	Trade_Offs	Final

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
27	TradeOff_B2	More severe rules for Bexar County, improve on previous attempt	Base	TO_Bexar2	TO_Bexar 2	Trade_Offs	Iteration
28	TradeOff_B3	More severe rules for Bexar County, improve on previous attempt	Base	TO_Bexar3	TO_Bexar 3	Trade_Offs	Final
Trade Off Comal Hays							
29	TradeOff_C_B ase	Run creating new stages and pools without changing reductions to test implementation	Base	Base	TO_Coma l_Base	Trade_Offs	Prelim
30	TradeOff_C_T ype2	Run applying type 2 recharge and rules changes to ensure correct implementation	Type 2s (LF,LS,LH,LV,S G,FRS)	Base	TO_Coma l	Trade_Offs	Prelim
31	TradeOff_C_r ecovery	Final run including recharge, rules changes, and pumping recovery	Type 2s (LF,LS,LH,LV,S G,FRS)	TO_Comal	TO_Coma l	Trade_Offs	Final
Bottom Up Oct 2010 - 1947-2000							
32	DYO	A reduction of pumping of 40,000 AFY in dry years. The dry year option is triggered in every year of the simulation.	Base	DYO	base	Final 1010	Final

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
33	Conservation	This builds on the DYO run. A reduction of pumping of 10,067 AFY distributed based on municipal pumping by county.	Base	DYO_Con	base	Final 1010	Final
34	SAWS_ASR	Builds on DYO and Conservation. Unused rights are used to fill the ASR and when “recharge” is not needed for the aquifer based on by the regime developed by HDR (BU2).	Recovery	ASR	base	Final 1010	Final
35	Stage V	Builds on all previous runs. Creates a new stage V triggered by J-17 for SA and U as discussed in the assumptions technical memorandum.	Recovery	ASR	StageV	Final 1010	Final
36	Stage Vb	Builds on Layer 3. Creates a new stage V triggered by J-17 for SA and U.					
Bottom Up Dec 2010 - 1947-2000							

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
37	DYO	A reduction of pumping of 40,000 AFY in dry years. The dry year option is triggered in every year of the simulation.	Base	DYO	base	Final 1210	Final
38	Conservation	This builds on the DYO run. A reduction of pumping of 10,067 AFY distributed based on municipal pumping by county.	Base	DYO_Con	base	Final 1210	Final
39	SAWS_ASR	Builds on DYO and Conservation. Unused rights are used to fill the ASR and when “recharge” is not needed for the aquifer based on by the regime developed by HDR (BU2).	Recovery	ASR	base	Final 1210	Final
40	Stage V	Builds on all previous runs. Creates a new stage V triggered by J-17 for SA and U as discussed in the assumptions technical memorandum.	Recovery	ASR	StageV	Final 1210	Final

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
41	DYO	Simulates the VISPO program with new totals and triggers	base	DYO	base	Final_811	Final
42	Water_Con	This builds on the DYO run. A reduction of pumping of 10,067 AFY distributed based on municipal pumping by county.	base	DYO_Con	base	Final_811	Final
43	ASR	Builds on DYO and Conservation. Includes new totals for IRPs in all counties and operates pumping reductions based on the tier system.	Recovery	ASR	base	Final_811	Prelim
44	Stage V J-17, J-27	Stage V with trigger at J-17 and J-27	Recovery	ASR	Stage_Va	Final_811	Prelim
45	Stage V J-17	Stage V with trigger at only J-17	Recovery	ASR	Stage_Vb	Final_811	Prelim
Bottom Up Phase II - 1947-2000							
46	Version 1	Recovery at only Naco	Version 1 recovery	ASR_811b	base	Final_811	Prelim
47	Version 1_stage V	Recovery at only Naco	Version 1 recovery	ASR_811b	StageV_comal	Final_811	Prelim
48	Version 2	Recovery at Naco and Maltsberger	Version 2 recovery	ASR_811c	base	Final_811	Prelim

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
49	Version 2_stage V	Recovery at Naco and Maltsberger	Version 2 recovery	ASR_811c	StageV_comal	Final_811	Prelim
50	Version 2a	Recovery at all four eastside locations	Version 2a recovery	ASR_811c	base	Final_811	Prelim
51	Version 2a_stage V	Recovery at all four eastside locations	Version 2a recovery	ASR_811c	StageV_comal	Final_811	Prelim
52	Version 3	New Recovery regime (east and west)	Version 3 recovery	ASR_911	base	Final_911	Prelim
53	Version 3_stage V	New recovery regime with stage V, Comal trigger	Version 3 recovery	ASR_911	StageV_comal	Final_911	Prelim
54	Version 4	New Recovery regime	Version 4 recovery	ASR_911	base	Final_911	Prelim
55	Version 4_stage V	New recovery regime with stage V, Comal trigger	Version 4 recovery	ASR_911	StageV_comal	Final_911	Prelim
54	Version 5	New Recovery regime	Version 5 recovery	ASR_911	base	Final_911	Final
55	Version 5_stage V	New recovery regime with stage V, Comal trigger	Version 5 recovery	ASR_911	StageV_comal	Final_911	Final
56	Version 6	New Recovery regime	Version 6 recovery	ASR_911	base	Final_911	Final
57	Version 6_stage V	New recovery regime with stage V, Comal trigger	Version 6 recovery	ASR_911	StageV_comal	Final_911	Final

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
Additional Runs							
58	HDR_LB	Enhanced Recharge from Lower blanco and San Macros pump over added per HDR's calculations	Zone 55,58	Base	Base	Output_04 0310	Other
59	GWSIM1	Enhanced Recharge Based on GWSIM simulations, Recharge from HDR Scenario1 40 cfs	Zone 59	Base	Base	Output_04 0310	Other
60	GWSIM2	Enhanced Recharge Based on GWSIM simulations, Recharge from HDR Scenario2 60 cfs	Zone 59	Base	Base	Output_04 0310	Other
61	GWSIM3	Enhanced Recharge Based on GWSIM simulations, Recharge from HDR Scenario3 100 cfs	Zone 59	Base	Base	Output_04 0310	Other
62	Recover - LF	Hypothetical pulse at each type 2	Zone 49	Base	Base	Output_rec overy	Recovery
63	Recover - LS	Hypothetical pulse at each type 2	Zone 50	Base	Base	Output_rec overy	Recovery
64	Recover - LH	Hypothetical pulse at each type 2	Zone 51	Base	Base	Output_rec overy	Recovery
65	Recover - LV	Hypothetical pulse at each type 2	Zone 52	Base	Base	Output_rec overy	Recovery

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
66	Recover - C	Hypothetical pulse at each type 2	Zone 54	Base	Base	Output_rec overy	Recovery
67	454	Examines baseline if total pumping is reducted to 454K	base	Wel_454	base	454	Other
68	Stage V	Triggers CPM stage V for Uvalde from J-27 and San Antonio off J-17.	Base	Base	Stage V	Stage V	Other
69	Stage Vb	Triggers CPM Stage V for both Uvalde and San Antonio pools off J-17.	Base	Base	Stage Vb	Stage V	Other
70	ASR_Task 2a	Uses a comal springflow trigger of 5o cfs. If flow is above the trigger irrigation permits are pumped to ASR until max capacity of 200K is reached. When flow is under trigger, water is retrieved (at a rate of 5,600 AFM when available) from ASR for direct use at 4 SAWS pumping centers in lieu of pumping.	Framework 2a	ASR_2a	base	base	Other

Table F-1 (Continued)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
71	ASR_Task 2b	Uses an episodic recharge regime developed by Larry. Irrigation rights are pumped as needed from **Artesia and Seale pump centers**, the pumping states are shown in the framework file also attached. Recharge is applied to the conduit upgradient from Comal.	Framework 2b	ASR_2b	base	base	Other
72	ASR_Task 2c	Uses a comal springflow trigger of 50 cfs. If flow is above the trigger irrigation permits are pumped to ASR until max capacity of 200K is reached. When flow is under trigger, water is retrieved (at a rate of 5,600 AFM when available) from ASR. Water is "recharged" to the Artesia/Seale pump centers, recovered at Naco pump center and injected in the conduit.	Framework 2c	ASR_2c	base	base	Other

Table F-1 (Concluded)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
73	Baseline	Baseline run to use as comparison for program runs	Base	Base	Base	Base	Baseline
74	Unused	Baseline run to use as comparison for program runs. Unused rights are retired.	Base	Unused_zero	Base	Base	Baseline
75	320K	Baseline run to use as comparison for program runs. The CPM floor in stage 4 is 320K.	Base	Base	320K	Base	Baseline
76	286K	Baseline run to use as comparison for program runs. The CPM floor in stage 4 is 286K.	Base	Base	286K	Base	Baseline
77	Unused_320K	Baseline run to use as comparison for program runs. Unused rights are retired and the CPM floor in stage 4 is 320K.	Base	Unused_zero	320K	Base	Baseline
78	Unused_287K	Baseline run to use as comparison for program runs. Unused rights are retired and the CPM floor in stage 4 is 286K.	Base	Unused_zero	286K	Base	Baseline

Table F-2.
List of MODFLOW Simulations Performed by HDR

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
Program: Sensitivity Test to Evaluate Performance of Enhanced Recharge Locations and Rates near Comal Springs							
1	Direct (Injection_Wells)_1	Test Springflow Benefit with Injection Wells in Edwards Conduit	Base with Recharge Schedule_1	Base	Base	Program1	Sensitivity Test
2	Direct (Injection_Wells)_2	Test Springflow Benefit with Injection Wells in Edwards Conduit	Base with Recharge Schedule_2	Base	Base	Program1	Sensitivity Test
3	Direct (Injection_Wells)_3	Test Springflow Benefit with Injection Wells in Edwards Conduit	Base with Recharge Schedule_3	Base	Base	Program1	Sensitivity Test
4	Direct (Injection_Wells)_4	Test Springflow Benefit with Injection Wells in Edwards Conduit	Base with Recharge Schedule_4	Base	Base	Program1	Sensitivity Test
5	Indirect (Recharge_Structure)_1	Test Springflow Benefit with Natural Recharge on Outcrop	Base with Recharge Schedule_1	Base	Base	Program1	Sensitivity Test
6	Indirect (Recharge_Structure)_2	Test Springflow Benefit with Surface Recharge on Outcrop	Base with Recharge Schedule_2	Base	Base	Program1	Sensitivity Test

Table F-2 (Concluded)

Run Number	Identifier	Description	Recharge	Wel File	Rules File	DataBase	Type of Run
Program: Sensitivity Test to Evaluate Performance of Enhanced Recharge Locations and Rates near Comal Springs							
7	Indirect (Recharge_Structure)_3	Test Springflow Benefit with Surface Recharge on Outcrop	Base with Recharge Schedule_3	Base	Base	Program1	Sensitivity Test
8	Indirect (Recharge_Structure)_4	Test Springflow Benefit with Surface Recharge on Outcrop	Base with Recharge Schedule_4	Base	Base	Program1	Sensitivity Test
9	Indirect (Recharge_Structure)_5	Test Springflow Benefit with Surface Recharge on Outcrop	Base with Recharge Schedule_5	Base	Base	Program1	Sensitivity Test

Appendix G
Evaluation of Quarries for Surface Storage Reservoirs

1.0 Introduction

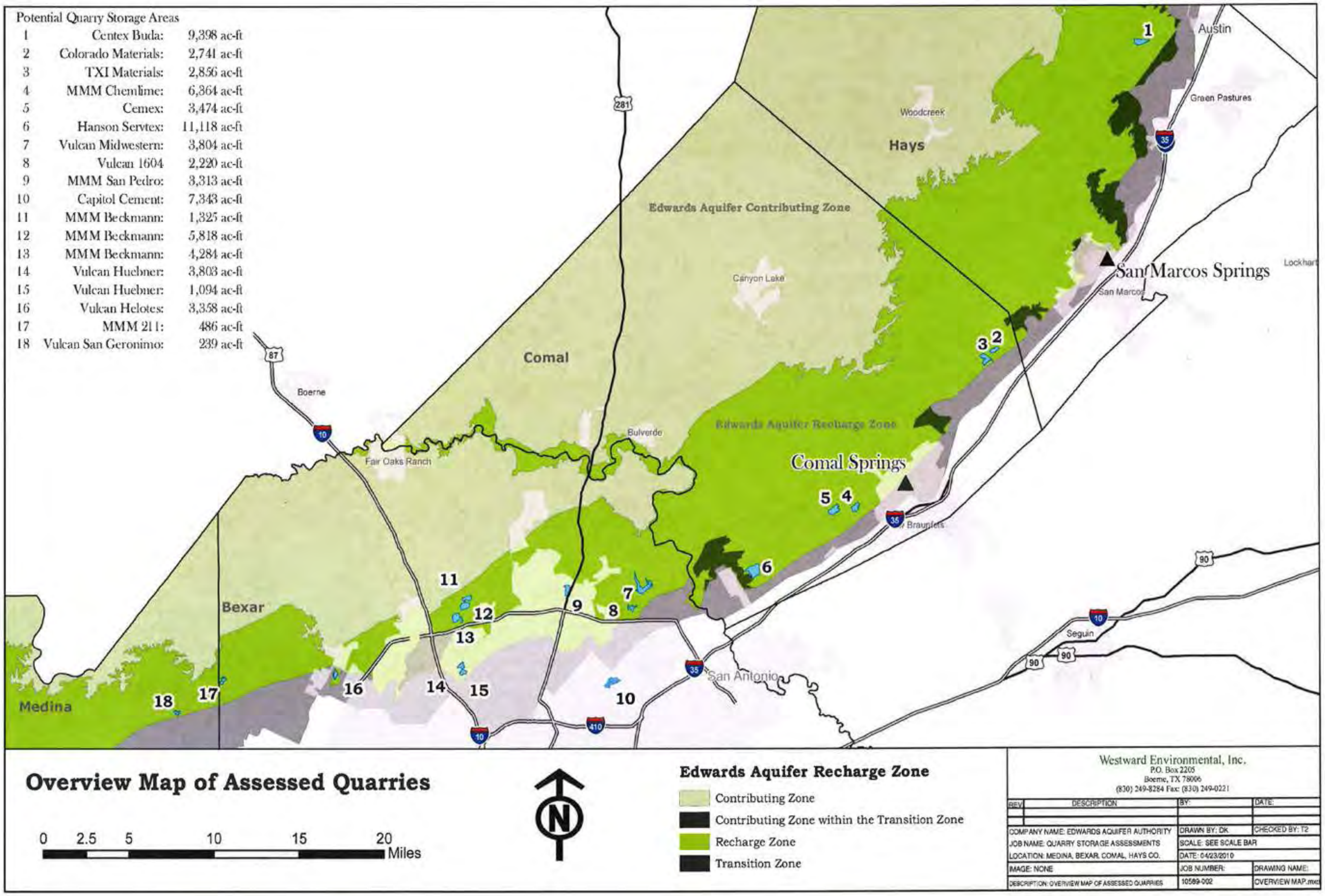
The following is a brief summary of a draft report by Westward Environmental, Inc. (WEI) titled ***Draft Quarry Evaluation Report*** and dated May 3, 2010. The full report is posted on the web at: http://earip.org/Reports/Draft%20Quarry%20Report.pdf

WEI was engaged by HDR and the Texas Agrilife Extension Service of the Texas A&M University System at the request of the EARIP Program Manager to develop technical information relating to quarries in Hays, Comal, Bexar, and eastern Medina Counties. This information is to assist in the engineering analysis and the decision making process regarding the potential use of quarries to store water, in the area of the Comal and San Marcos Springs for springflow protection.

Numerous quarries are located along the Balcones Escarpment between central Medina County and Travis County. In the draft report, these quarries are divided into three groups: those within ten miles of Comal or San Marcos Springs, those beyond ten miles, but within Bexar County, and all others. Key areas of mining activity (mined/excavated areas) were identified using publicity available aerial photography and topographic data. The excavated volumes of these areas were analyzed and calculated.

Analyses show approximately 35,952 acft of excavated quarry volume within ten stream miles, 36,083 acft of additional excavated quarry volume beyond ten miles within Bexar County, and 750 acft in eastern Medina/western Bexar Counties. It is noted that embankment construction and measures to control leakage would be necessary to effectively use these excavated volumes for water storage. The locations of and potential storage capacities associated with these quarries are shown in Figure F-1. WEI's review of the mining status of these quarries revealed that they are still in some stage of active mining activity and that none of the quarries reviewed within our target area are abandoned/exhausted.

Materials such as limestone fines and clay are present at several of the quarry sites or on adjacent properties. These materials present a possible source for liner, structural fill, or embankment construction. The six sites within ten miles of Comal or San Marcos Springs are also adjacent to Union Pacific rail lines, several gas pipelines, electrical transmission lines, and surface road right of ways which could serve as a potential corridors for water transmission lines in the direction of the springs or to recharge sites near the springs. Maps and exhibits identifying these areas are presented in the draft report.



F-1. Location of Large Quarries near Comal and San Marcos Springs