HISTORICAL WATER USE BACKCASTING STUDY

LUKE AIR FORCE BASE, ARIZONA

FINAL REPORT

February 1997

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LUKE AIR FORCE BASE, ARIZONA

by

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ABBREVIATIONS

ADJSF	Variable name representing adjusted square feet
ADWR	Arizona Department of Water Resources
AFB	Air Force Base
AFLSA	Air Force Legal Services Agency
AMA	Active Management Area
DRMO	Defense Reutilization and Marketing Office
F	Fahrenheit
FCC	Facility Category Code
GPD	Gallons per day
GPM	Gallons per minute
GPSFPD	Gallons per square foot per day
IWRAPS-AF	Installation Water Resources Analysis and Planning System - Air Force
LAFB	Luke Air Force Base
LAU	Lower Alluvial Unit
MAU	Middle Alluvial Unit
MGAL	Million Gallons
QDIFF	Difference between summer and winter daily water use (gpd)
UAU	Upper Alluvial Unit
USBR	United States Bureau of Reclamation
USGS	United Sates Geological Survey

EXECUTIVE SUMMARY

The goal of this report is to present historic (backcast) water use for Luke Air Force Base (LAFB), Arizona for 1941 through 1961. Historic water use (including system losses) from LAFB records can be used as groundwater pumping amounts because groundwater extracted from the underlying aquifer was the sole water source. Historical water use amounts were derived primarily using regression analysis and the Installation Water Resources Analysis and Planning System - Air Force (IWRAPS-AF). IWRAPS-AF is a computer software package designed to forecast or backcast water use and assess the effectiveness of conservation measures at Air Force Installations (Willett et. al. 1995a, and Strus et. al. 1995).

IWRAPS-AF assumes that all water delivered for installation use is utilized by either water use sectors or special purpose water use sectors. A water use sector (building sector) is a group of buildings having water use that can be explained by a similar actual-to-required square footage relationship. Actual square footage is what exists at a particular time. Required square footage is what was considered necessary. The relationship (equation) acts in the following way: Assume both facility A and B perform the same type of function and have the same square footage. The facility having the greater required area would be assumed as having the greater water usage. Water use sectors include gyms, schools, and hospitals, administrative offices and other activities.

Special purpose water use sectors are other facilities having known (metered) water use. Special purpose water use sectors include swimming pools, car washes, and golf courses.

The backcast for a particular year is the sum of sectorally disaggregated seasonal water uses plus unaccounted water use (a percentage of sector use). Winter (November through March) water use is a function of the square footage of buildings using water and the level of activity (intensity) within the buildings. The intensity of water use within a building is based on space shortage or surplus and is normally determined by comparing actual square footage with required square footage listed on the installation's real property file. Because records of required square footage were not available for this study, required square footage was assumed to equal actual square footage.

Summer (April through October) water use is derived from winter water use plus an amount that is a function of adjusted square footage, average maximum summer temperature, average summer precipitation, and installation mission (Strus et. al. 1995).

Planning and Management Consultants, Ltd. previously applied the IWRAPS-AF model to LAFB using detailed water use and sector information for 1992 (Derhgawen et. al. 1993). IWRAPS-AF was relatively accurate. It only underestimated actual winter water use by 2% and overestimated summer water use by 7.6% (Derhgawen, U. K. et. al., 1993). For the present backcasting effort, BEM SYSTEMS, INC. searched historical records. BEM provided to USU information concerning base building construction dates, square footage and classifications (FCC's). BEM provided the monthly sum of daily precipitation and monthly average of daily maximum and minimum temperatures for 1917-1995.

Results reported here built upon the efforts of PMCL and BEM SYSTEMS, INC. This involved: (1) analyzing historical data, and (2) applying regression analysis combined with the IWRAPS-AF model (the Regression Approach) to derive water use for 1941-1961. This involved first calibrating a regression equation for 1962-1973, a period for which actual pumping records exist and water use practices were similar to those of 1941-1961. Then USU used the regression equation, real property and weather data to derive 1941-1961 water use. Directly applying the IWRAPS-AF model alone was inappropriate because water use practices in 1992 differ from those of 1941-1961.

The Regression Approach accurately calculates groundwater pumping and use for the period of good records, 1962-1973. Because water management practices were consistent throughout 1941-1973, the regression approach accurately represents groundwater pumping for 1941-1961 also. Winter, Summer, and Annual Water Use ranges for 1941-1961 are 8.8 - 50.4, 169.6 - 724.6, and 178.5 - 775.1 respectively.

I. INTRODUCTION

PURPOSE

Currently, Luke Air Force Base (LAFB), Arizona, is adjudicating its claims to extract groundwater from the lower Gila River watershed (Figure 1). No groundwater extraction records were kept during 1941-1961. All water used on base was pumped from the underlying aquifer. Therefore, historic water use (including system losses) approximately equals historic groundwater extraction. In 1962 and 1992 LAFB wells produced 742.62 and 470.42 mgal respectively.

STUDY OBJECTIVES

The goal of this study is to derive (backcast) water use on Luke Air Force Base for 1941 through 1961. These backcasts are developed utilizing statistical analysis and the Installation Water Resources Analysis and Planning System for the Air Force (IWRAPS-AF). IWRAPS-AF calculates total water use by summing calculated seasonal use by many water use category sectors. Water use is calculated for both winter and summer seasons. Calculated amounts also change with time based upon annual weather, building square footage changes due to construction and/or demolition, and changes in special purpose water uses (not included among IWRAPS-AF building categories).

HISTORICAL BACKGROUND

Luke AFB is located about 15 miles west of the center of Phoenix, Arizona (Figure 2). The 5,000 acre base has an arid to semiarid climate with low rainfall and relative humidity, high temperature, and minimal cloud cover. The property on which Luke AFB was established in 1941 was leased from the City of Phoenix. More privately owned property was acquired later as the base expanded.

Luke AFB is named in honor of Lt. Frank Luke, Jr., a Phoenix native and the first American aviator to win the Medal of Honor. When construction began in March 1941, the base was named Litchfield Park Air Base. On 29 September 1941 the base was renamed Luke Field. When the base was reactivated on 1 Jan 1951 it was designated Luke Air Force Base.

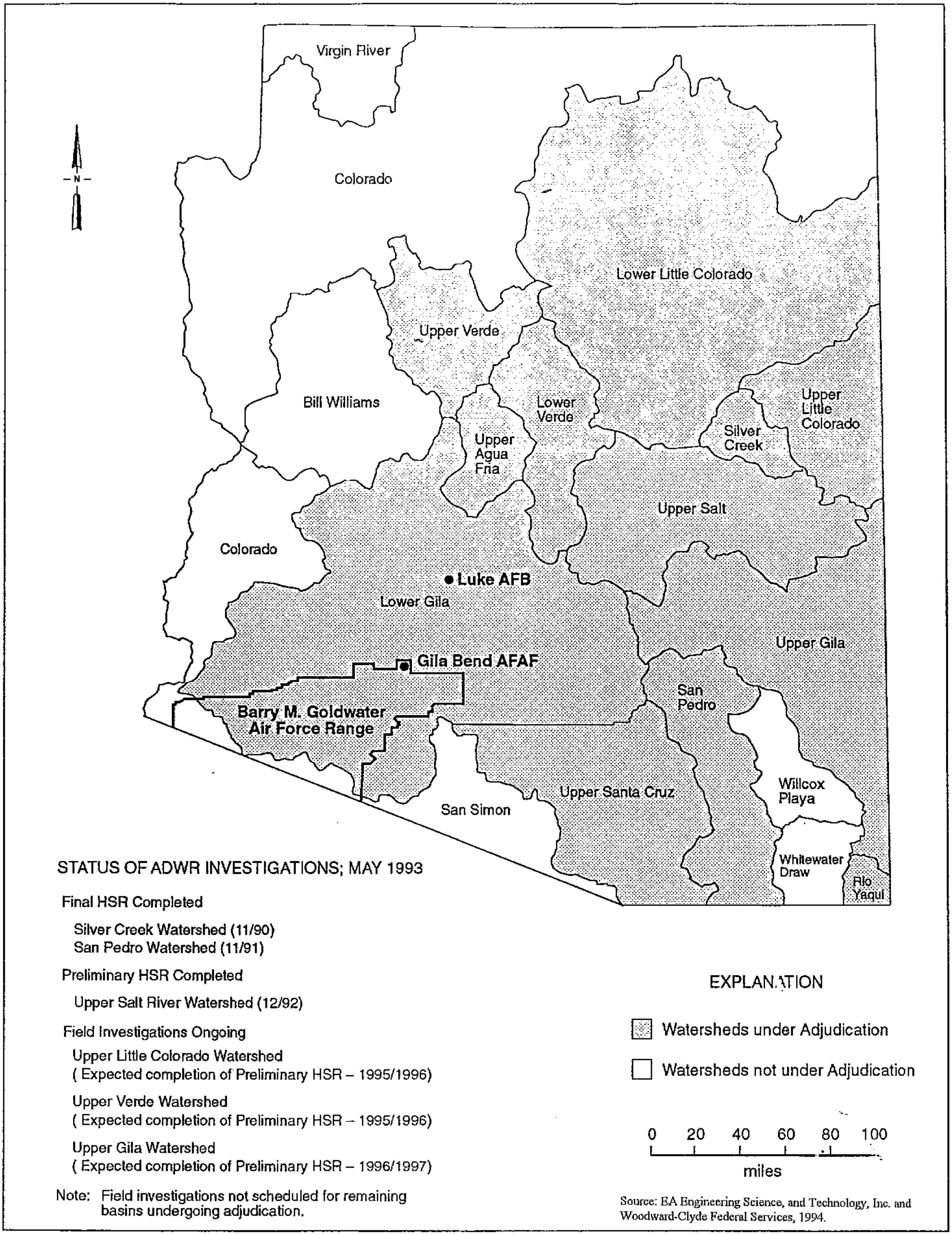


Figure 1. Watersheds Undergoing Adjudication

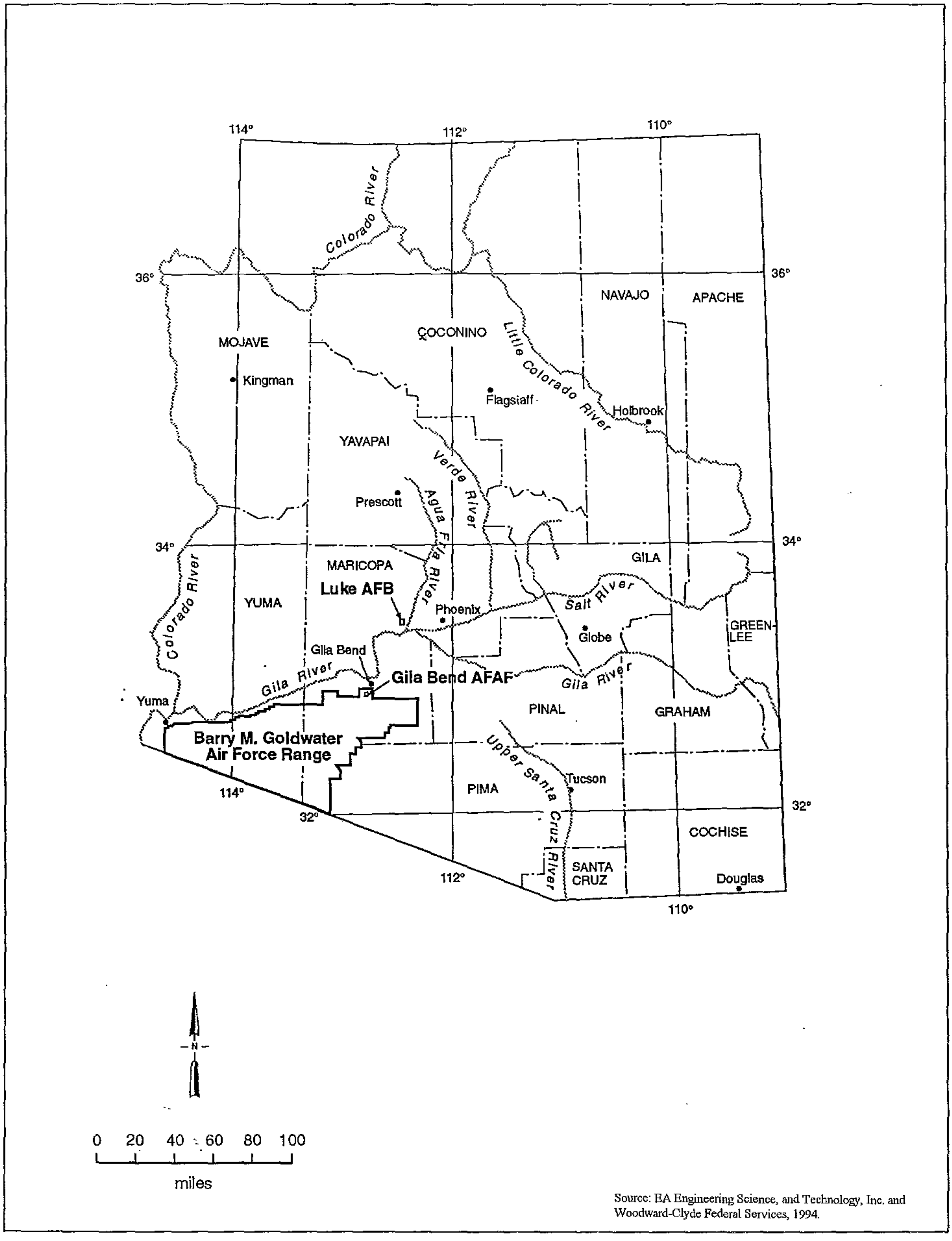


Figure 2. Luke Air Force Base Location Map

The initial emergency construction efforts were completed on 19 July 1941. By 7 December 1941 accommodations existed for 3,700 military personnel. In April 1942 a new building phase intended to double the base capacity was begun. In April 1945 orders were issued to stop construction at Luke Field.

Advanced flying training was conducted from Sky Harbor Airport until 15 July 1941 when the base runway was completed. By October 1941 the flying program was in full swing. The base mission was training fighter pilots in gunnery and fighter tactics. Training utilized AT-6 trainers and P-40, P-38, and P-51 aircraft, on up to six runways simultaneously. Luke aviators flew one million hours by February 7, 1944. By the end of World War II Luke Field was the world's largest single-engine and advanced flying training base. It had graduated 17,000 flyers.

Luke Field was deactivated on 30 November 1946. Subsequently, the base was utilized by the 197th Fighter Squadron of the Arizona Air National Guard for P-51 fighter proficiency training. Luke Field was also utilized for short periods for fighter gunnery training by southwestern guard and Air Force organizations.

The 127th Fighter Group joined the 197th at LAFB on 1 February 1951. The two organizations fused as the 127th Flying Training Wing. The 127th remained on active duty until 1 November 1952 when it was replaced with the 3600th Flying Training Wing. On 1 July 1958, the 4510th Combat Crew Training Wing (CCTW) was activated as the host unit and was reassigned from Air Training Command (ATC) to Tactical Air Command (TAC).

The LAFB population varied with time, from 3434 in December 1941 to very few in 1947-1950 to 6906 in December 1994. The base population during the study period listed in Table 1 includes assigned military and civilian personnel (Tobin, T. A., 1996).

Table 1. (Tobin, T. A., 1996)
Population of Luke Air Force Base (Military and Civilian)

Date	Population
Dec 1941	3434
Dec 1942	6526
Dec 1943	5187
Dec 1944	5398
Dec 1945	3572
Sep 1946	375
1947-1950	(unknown)
Dec 1951	3842
Dec 1952	4877
Dec 1953	4782
Dec 1954	5422
Dec 1955	4677
Dec 1956	4820
Dec 1957	4284
Dec 1958	4251
Dec 1959	4274
Dec 1960	4398
Dec 1961	4595

PHYSICAL SETTINGS OVERVIEW

Physiography

Luke Air Force Base is located in the western portion of the Salt River Valley (SRV). The SRV is an alluvium-filled valley that extends approximately 35 miles in an east-west direction and approximately 25 miles north to south. The Hieroglyphic Mountains are approximately 15 miles to the north. The White Tank Mountains are approximately 5 miles to the west, and the Sierra Estrella are approximately 11 miles to the south. Squaw Peak lies approximately 17 miles to the east. The confluence of the Salt and Gila rivers is approximately 11 miles southeast of the base. The channel of the Agua Fria River is approximately 2.5 miles east of the eastern boundary of the base housing area.

Climate

Luke Air Force Base has a desert climate characterized by mild winters, hot, dry summers, and a high percentage of sunshine. Temperature extremes range from highs well above 100 degrees Fahrenheit (°F) during most of the summer to winter lows that occasionally drop below freezing. LAFB has an average annual temperature of 71 degrees F, ranging from a mean monthly high of 92 degrees F in July to a mean monthly low of 52 degrees F in January. Mean annual precipitation is about 7 inches per year. August has the highest monthly mean precipitation of 1.2 inches. Mean precipitation in the other months ranges from 0.9 inches in December to 0.1 inches during May and June. Average summer high temperature and average monthly summer rainfall are shown on Figure 3. Free water surface evaporation is approximately 70 inches per year and nearly equals the average annual evapotranspiration rate in the area. Both exceed annual precipitation by over 50 inches per year (Geraghty & Miller, Inc., 1992).

Land Use

Current land use within LAFB includes aircraft maintenance, munitions and fuel storage, runways, taxiways and aircraft parking aprons, roads and sidewalks, vehicle parking areas, family

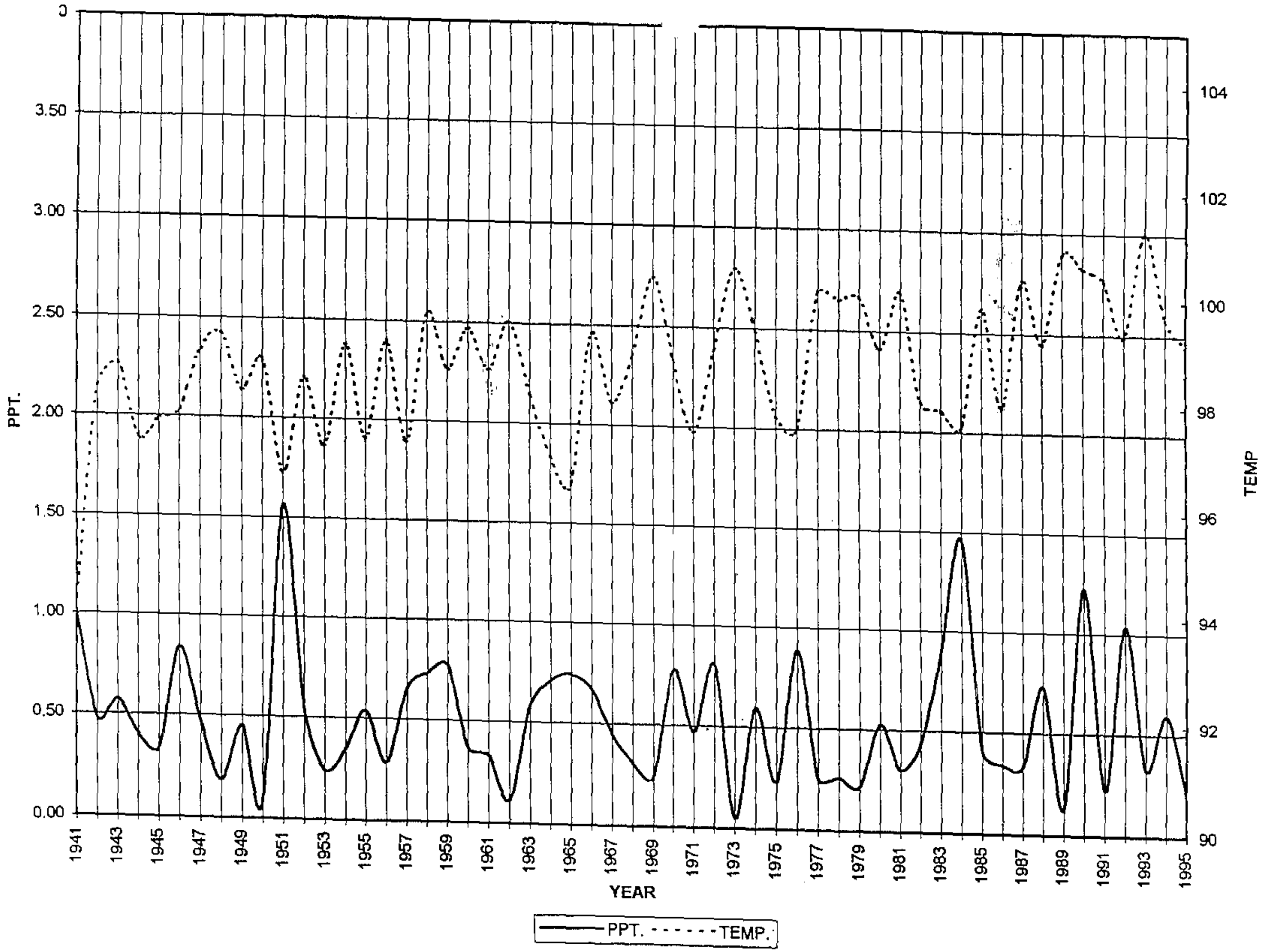


Figure 3. Average Summer Monthly Precipitation (inches) and Average Summer Daily Maximum Temperature (°F)

housing areas, various support buildings, and other infrastructure facilities. The remaining base areas are irrigated lawn, native desert vegetation, and barren ground.

Surface Water Hydrology

The surface water hydrology of the area reflects the low precipitation and high evapotranspiration of the desert environment. No perennial streams flow through or near Luke Air Force Base. The major streams near Luke AFB are the Agua Fria, the Salt, and the Gila Rivers (Figure 2)

REPORT ORGANIZATION

Following this introduction are: (1) a discussion of the hydrology and water resources at Luke Air Force Base and in the Salt River Valley area; (2) an overview of the IWRAPS-AF system and its application to this study; (3) an overview of the Regression Approach used in the study; and (4) a summary of findings. Complete output listings are included in Appendix B.

II. HYDROGEOLOGY AND GROUNDWATER DEVELOPMENT

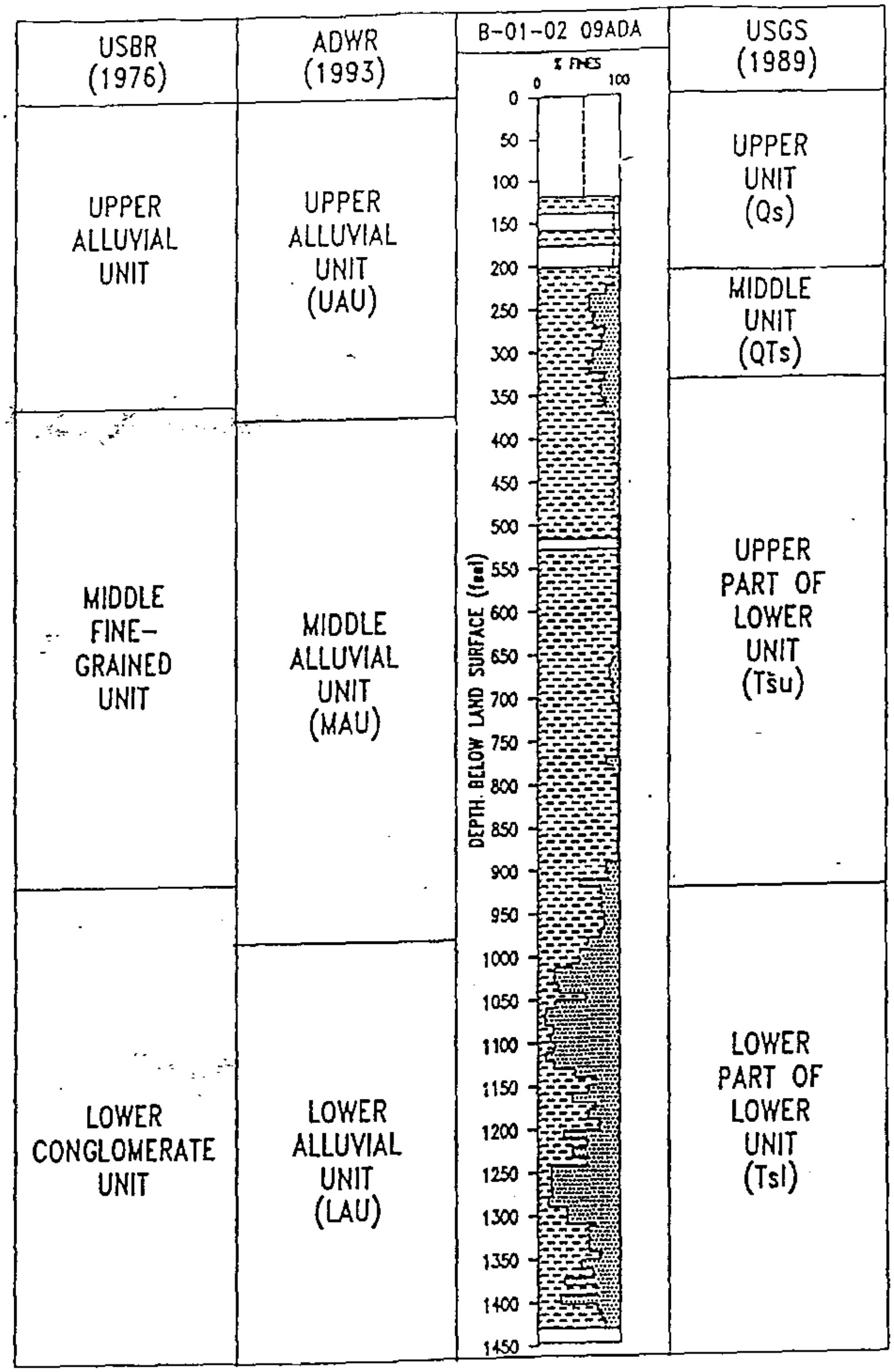
HYDROGEOLOGY OF LAFB

The basin fill deposits in the western Salt River Valley are generally divided into three main layers. These are the lower alluvial unit (LAU), the middle alluvial unit (MAU), and the upper alluvial unit (UAU) (Figure 4).

The lower alluvial unit (LAU) overlies or is in fault contact with the bedrock and, where present, the red unit (a reddish-colored unit consisting of well cemented breccia, conglomerate, sandstone, and siltstone that predates Basin and Range extension). The LAU ranges in thickness from 100 feet near its margins to thousands of feet in its center. The LAU is primarily conglomerate and gravel near the basin margins but grades into well cemented sands, siltstone and mudstone and evaporite deposits including anhydrite, gypsum, and halite. The Luke salt body (Figure 5) is part of the LAU but impedes groundwater flow. The depth to the top of the LAU in the LAFB area is about 1,000 ft. Hydraulic conductivity of the LAU ranges from 3 to 60 ft/d. Specific yield ranges from 0.03 to 0.15 suggesting unconfined to leaky confined conditions.

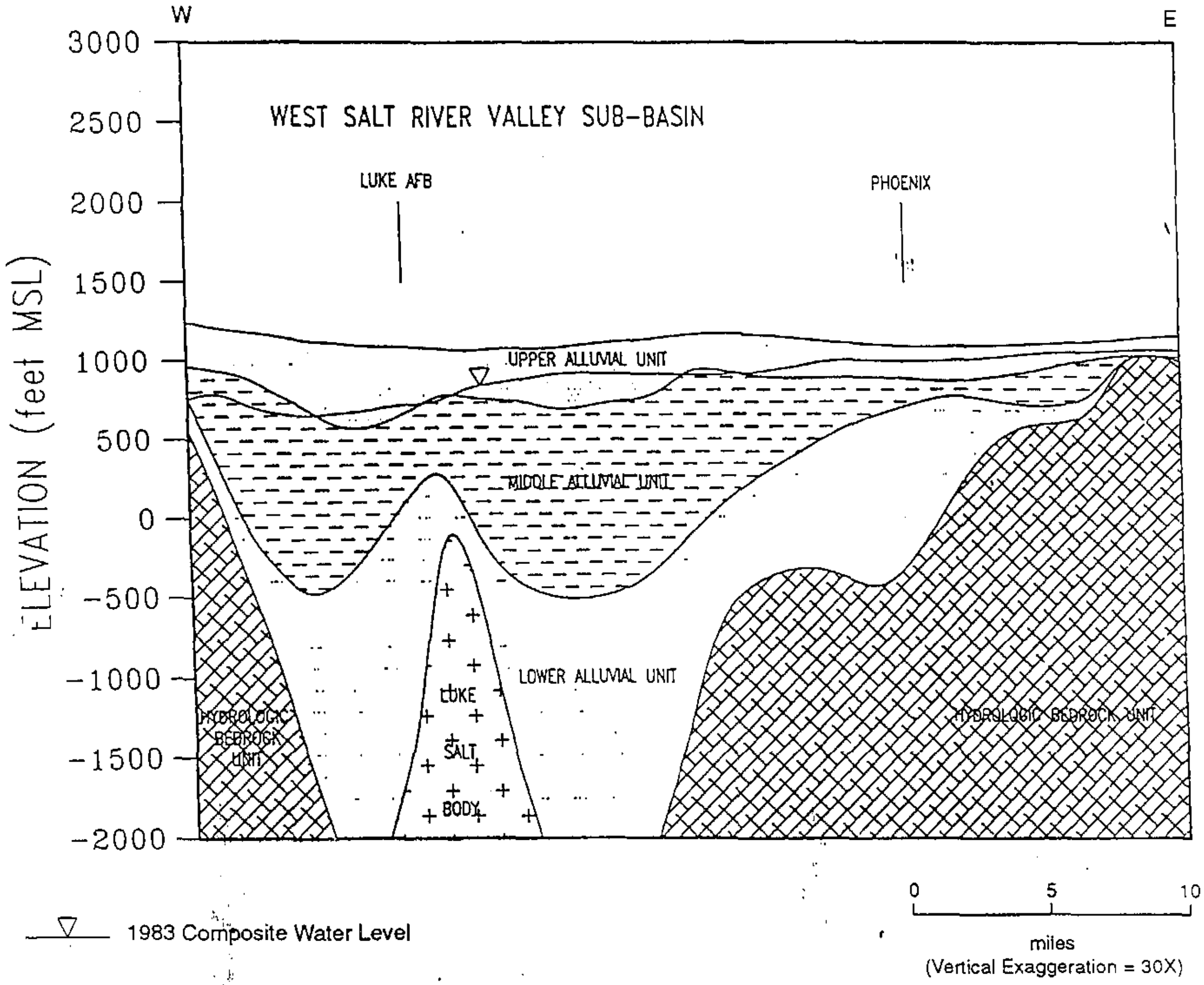
The middle alluvial unit (MAU) overlies the LAU. It is characterized by weakly to moderately cemented clay, silt, mudstone and siltstone with locally interbedded sand and gravel. As with the LAU, the unit is coarser grained near the margins of the basin but in the central portions is a fine-grained unit with some sand and gravel. The MAU ranges in thickness from less than 100 feet near the basin margins to 1600 feet in the deeper parts of the basin. The depth to the top of the MAU near LAFB is about 400 feet. The thickness of MAU in the area is 600 to 1200 feet. Hydraulic conductivity estimates for the MAU range from about 3 to 50 ft/d. Specific yield ranges from 0.03 to 0.14 suggesting unconfined to leaky confined conditions.

The upper alluvial unit (UAU) overlies the MAU and is the surficial hydrostratigraphic unit. The UAU is categorized by unconsolidated gravel, sand, and silt. The UAU is coarser near the basin margins and channels of the Salt and Gila rivers, and to a lesser extent the Agua Fria river and other smaller streams. The UAU is more uniform in thickness than the LAU and MAU, typically ranging from 300 to 500 ft. UAU hydraulic conductivity range is 20 - 250 ft/d.



Source: EA Engineering Science, and Technology, Inc. and Woodward-Clyde Federal Services, 1994.

Figure 4. Correlation Between Basin Fill Hydrostratigraphic Units as Defined by USBR, ADWR, and USGS



Source: EA Engineering Science, and Technology, Inc. and Woodward-Clyde Federal Services, 1994.

Figure 5. Generalized East-West Hydrogeologic Cross-Section Through West Salt River Valley and Luke AFB

Storativity estimates for the UAU range from about 0.08 to 0.22 suggesting primarily unconfined conditions. The UAU is not a significant source of groundwater near LAFB due to the partial or complete dewatering of the unit resulting from groundwater withdrawal.

WATER RESOURCES AT LAFB

Groundwater is the only source of water supply at Luke Air Force Base. Water is extracted from the lower Gila River watershed by several wells (Table 2). Well #1 was drilled and started operation in May 1941 to provide water for construction and initial operation of base facilities. The initial well depth was 400 feet. The well had a 16 inch casing and a 1,000 gpm pump capacity. The pump for Well #1 was lowered later to respond to aquifer dewatering. Water from the well was pumped to a 200,000 gallon underground metal storage tank. Water was pumped from this tank into a 500,000 gallon capacity elevated steel storage tank.

Well #2 was completed on 17 December 1941. This well was drilled to the same depth and had the same pump capacity as Well #1. Well #2 was used for emergency fire response. Later, thirteen additional water supply wells were drilled on the base (Figure 6).

LAFB was deactivated from 1947 through 1950. When it was reactivated in early 1951 the pumps in Wells #2 and #3 were above the water table due to the drought in Arizona and the lowering of the water table. The pumps were lowered in these wells to be able to provide water for a potential population of 5,000 at a rate of 575 gallon per capita per day.

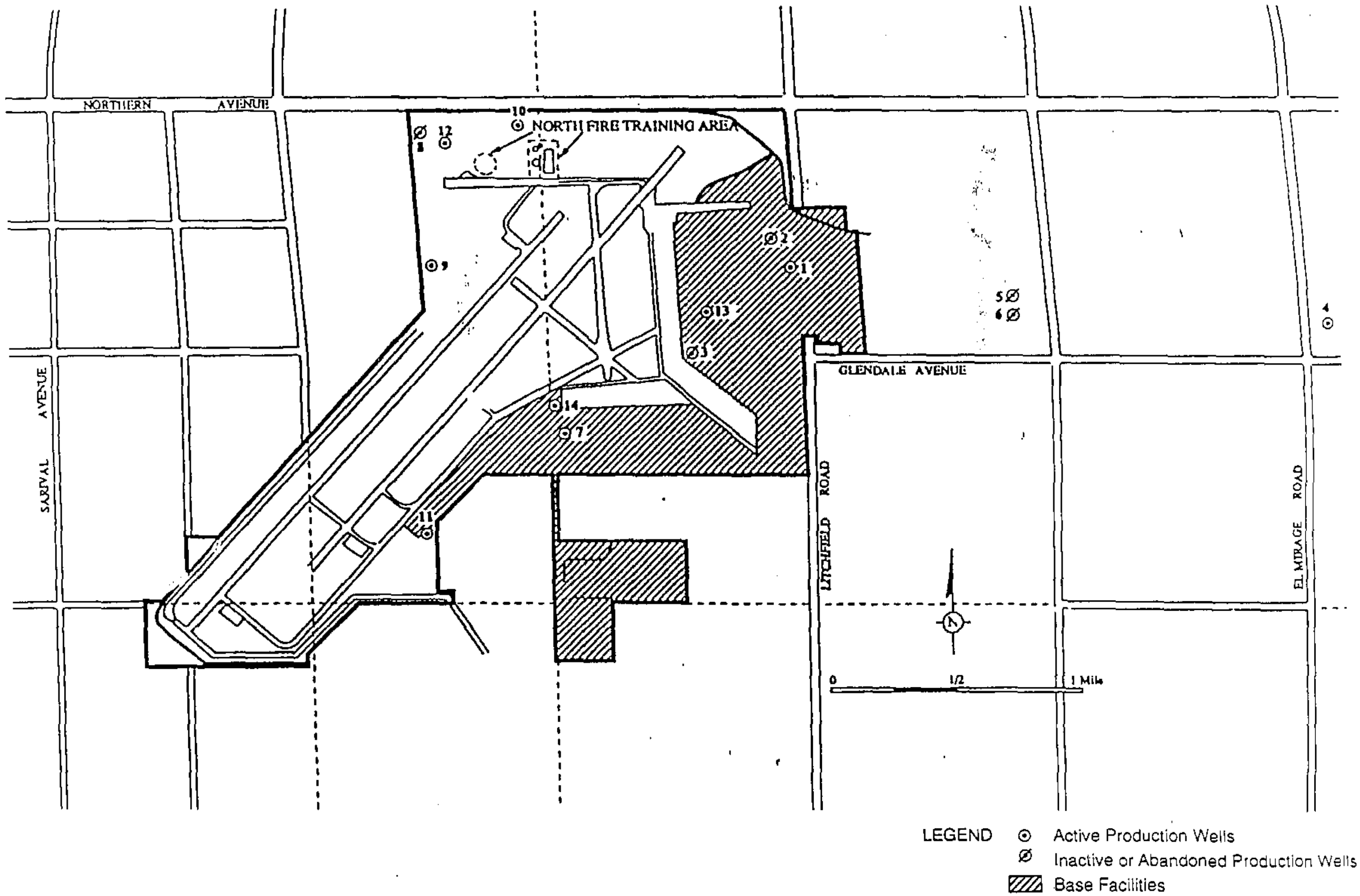
The LAFB well screens range in depth from 598 to 1,200 ft and all probably lie within the MAU or the LAU (Table 3). The production capacity of the wells ranges from 230 to 1200 gpm per well while the specific capacity ranges from 5.9 to 17.7 gpm per foot of drawdown. Well production amounts from 1962 to 1993 are listed in Table 4.

Table 2. Groundwater Wells Serving LAFB (Derhgawen et. al. 1993)

Well #	Average Output (gpm)	Pressure
1	*	
4	150**	
7	700	High
9	900	Low
10	900	Low
11	1100	High
12	1000	Low
13	1200	Low
14	500	High

* For emergency use only (high salt content)

** serves waste water treatment plant and DRMO facility



Source: EA Engineering Science, and Technology, Inc. and Woodward-Clyde Federal Services, 1994.

Figure 6. Location of Luke AFB Water Supply Wells

Table 3. Well information for active water supply wells, Luke Air Force Base

Well	Location	Well Registration #	Year Completed	Elevation at Well (Feet MSL)	Depth of Well (feet)	Production Casing Diameter (Inches)	Screened Intervals(s) (Feet Below Land Surface (BLS))	Pump Setting (Feet BLS)	Producing Hydro-stratigraphic[1] Unit(s)	Production Capacity (Gallons per Minute)	Specific Capacity (Gallons per Minute per Foot of Drawdown)	Static Water Level and Year of Measurement (Feet BLS)	Aquifer Test Results (Transmissivity - Gallons per Day per Foot)
#1[2]	(B-2-1) 4daa	55-609882	1941	1,080	968	18	Unknown	710	Unknown but Assume MAU and/or LAU	520	10.8	320(1988)	-
#4[3]	(B-2-1) 1ccc	55-609883	1960	980	598	8	359 to 588	410	MAU	230	6.1	220(1992)	-
#7	(B-2-1) 9bcb	55-609884	1968	1,082	1,200	18	534-561 564-572 906-975	530	MAU and LAU	625	18	367(1992)	-
#9	(B-2-1) 5bcc	55-609885	1970	1,090	1,010	18	800-968 or 800-1,002	710	LAU	520	10	390(1989)	-
#10	(B-2-1) 5aab	55-609886	1970	1,090	1,007	18	687-1,000	545	LAU	545	11.8	391(1989)	-
#11	(B-2-1) 8cdb	55-609887	1972	1,075	776	18	389-505 555-586 626-658 718-739 749-760	530	MAU and LAU	1,100	17.7	378(1989)	-
#12	(B-2-1) 5abc	55-609888	1973	1,090	971	18	10 Intervals Between 379 and 960	560	MAU and LAU	850	6	384(1990)	-
#13	(B-2-1) 4dcb	55-507978	1984	1,081	1,105	16	505-565 625-745 795-815 845-895 935-1005	492	MAU and LAU	1,200	10.3	390(1990)	35,000[4] and 31,000[5]
#14	(B-2-1) 8ada	55-507977	1984	1,080	910	16	485-555 575-605 685-710 745-765 820-865	472	MAU and LAU	500	5.9	374(1989)	12,000[4] and 13,000[5]

NOTES: [1] MAU - Upper Alluvial Unit; LAU - Lower Alluvial Unit
[2] Well #1 Used for Emergency Supply Only
[3] Well #4 Serves Luke Wastewater Treatment Plant
[4] Transmissivity from Pumping Portion of Test
[5] Transmissivity from Recovery Portion of Test

Source: EA Engineering Science, and Technology, Inc. and Woodward-Clyde Federal Services, 1994.

Table 4. Groundwater Pumping History, LAFB

Part A) Total Monthly and Annual Pumpage (Acre Feet[1])

YEAR	JAN	FEB.	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL[2]
1962	78.6	76.4	107.8	207.8	251.1	283.7	308.5	319.0	234.9	179.3	128.9	101.9	2,278
1963	98.2	119.7	169.8	196.5	280.9	301.2	351.5	223.5	222.0	162.4	111.7	82.3	2,323
1964	87.5	91.2	112.4	157.5	201.1	234.5	279.1	216.4	216.4	180.8	108.7	82.3	1,971
1965	91.5	86.6	109.0	105.0	202.6	239.5	258.5	211.2	211.2	175.6	112.4	80.7	1,961
1966	81.7	75.8	135.1	196.5	229.3	259.1	280.6	191.9	191.9	138.5	111.4	123.4	2,275
1967	90.9	113.3	189.1	202.3	253.9	261.6	274.8	230.2	230.2	176.8	111.4	90.9	2,275
1968	100.7	96.7	118.2	166.1	259.7	282.4	279.7	319.9	285.2	183.9	111.7	90.0	2,294
1969	89.0	83.5	114.5	135.1	226.6	276.0	296.6	237.3	214.0	198.6	110.8	102.2	2,084
1970	104.7	119.7	126.5	177.4	256.7	280.0	256.0	232.7	193.1	155.0	119.1	101.0	2,122
1971	99.5	108.4	183.0	215.8	238.2	283.1	279.4	242.2	246.6	144.9	93.9	91.8	2,227
1972	91.8	135.7	219.2	208.5	241.3	294.4	291.0	310.7	271.7	145.5	115.7	86.0	2,384
1973	93.3	88.1	98.5	172.5	276.6	322.0	319.3	306.1	264.9	191.9	115.4	90.0	2,339
1974	101.3	94.2	105.3	174.1	247.1	299.0	300.0	297.2	244.1	155.6	87.5	82.5	2,270
1975	83.5	82.0	107.8	154.1	254.5	303.6	303.3	320.2	233.9	128.0	128.3	87.5	2,095
1976	90.0	85.0	117.9	160.6	182.7	249.3	270.5	241.6	207.5	132.0	103.2	95.5	1,997
1977	92.1	124.6	141.8	174.4	177.4	216.1	242.5	257.9	201.1	130.2	116.0	114.2	1,961
1978	84.4	68.8	85.7	95.2	227.8	300.9	268.9	208.8	225.0	125.3	95.2	91.2	1,877
1979	90.0	91.5	105.3	114.2	217.7	282.4	291.3	253.6	250.8	175.6	90.9	88.1	2,051
1980	91.8	83.8	91.5	135.7	210.0	277.5	294.7	242.5	199.9	126.2	97.3	83.5	1,934
1981	89.3	76.8	99.5	184.8	226.3	266.8	277.8	253.6	202.6	117.6	93.9	91.8	1,981
1982	99.5	82.6	89.0	119.4	220.4	269.2	268.0	213.7	165.2	123.4	84.1	78.9	1,844
1983	82.6	74.0	80.4	100.1	183.9	231.2	244.1	199.2	167.3	115.7	87.2	66.0	1,632
1984	74.9	73.4	115.1	122.5	214.3	231.8	183.0	154.4	119.4	93.6	69.7	62.9	1,517

NOTES: [1] One Acre-Foot is Equivalent of 3.26×10^5 Gallons.
[2] Annual Totals Do Not Match Exactly Due to Differences in Reporting Data and Conversion of Units.

Source: EA Engineering Science, and Technology, Inc. and Woodward-Clyde Federal Services, 1994.

Table 4. Groundwater Pumping History, LAFB, Cont'd

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	TOTAL[2]
1985	68.8	63.9	78.6	117.6	195.3	254.8	209.7	213.1	176.8	107.4	74.9	69.4	1,630
1986	66.2	66.2	88.7	167.3	201.4	202.9	193.1	197.1	133.2	103.5	79.8	67.5	1,567
1987	71.1	78.2	105.5	160.2	204.8	238.5	243.5	226.0	192.5	132.0	83.8	70.9	1,807
1988	77.2	87.6	128.4	175.1	205.7	241.3	265.6	215.8	176.5	134.8	100.7	82.0	1,891
1989	82.4	92.7	156.9	195.2	265.9	259.1	278.4	263.4	225.6	171.9	103.8	106.5	2,202
1990	102.2	98.5	122.8	162.1	211.8	249.3	210.6	183.6	142.8	123.4	101.9	98.2	1,623
1991	101.9	76.1	76.4	126.5	198.9	218.9	239.2	234.6	172.5	137.8	78.6	63.5	1,730
1992	60.2	60.5	79.5	109.6	143.7	200.2	217.7	160.3	163.9	105.0	82.0	60.2	1,443
1993	63.9	63.9	85.7	113.6	200.5	231.8	–	–	–	–	–	–	–

Part B) Annual Pumpage by Well (Acre Feet[1])

WELL	1984	1985	1986	1987	1988	1989	1990	1991	1992
1	21.3	2	No Data	1.2	0.2	0.01	1.1	0	0
4	31.9	36.5	No Data	31.4	29.4	34.8	30.3	29.2	25.3
7	500	372	No Data	487	55.5	0	0	0	0
9	47.9	38	No Data	19.8	190	218	262	194	156
10	62.7	0.5	No Data	310	297	332	269	189	156
11	441	692	No Data	767	17.1	61.9	120	142	116
12	423	462	No Data	48.9	133	306	5.8	0	91.3
13	–	–	No Data	6.0	1,077	1,082	865	1,128	878
14	–	–	No Data	0	75.2	85.7	68.7	4.5	9.2
TOTAL[2]	1,529	1,603	–	1,671	1,874	2,120	1,622	1,687	1,432

NOTES: [1] One Acre-Foot is Equivalent of 3.26×10^5 Gallons.
[2] Annual Totals Do Not Match Exactly Due to Differences in Reporting Data and Conversion of Units.

Source: EA Engineering Science, and Technology, Inc. and Woodward-Clyde Federal Services, 1994.

III. BACKCAST DEVELOPMENT

IWRAPS-AF CALIBRATION FOR LAFB

Prior to applying IWRAPS-AF for backcasting, it needed to be calibrated for LAFB for a period having reliable real property and water use data. PMCL did this using 1992 data (Derhgawen, U. K. et. al., 1993). PMCL utilized some metered data and both required and actual square footage. The model accounted for 98.0 percent of actual winter water production 107.6 percent of actual summer water production. That demonstrates IWRAPS-AF ability to account for water use. Once calibrated, IWRAPS-AF can be advisedly applied to get historical water use. However, differences in water use practices and missing data limit its accuracy for backcasts outside the calibration period. That caused us to develop the Regression Approach described later in this section.

Trends in Water Use

In the 1970's water planners increasingly turned to water conservation to better use available water supplies while meeting installation requirements. On LAFB high water use fixtures were replaced with low water use equivalents. Individual buildings or activities were metered to help identify unnecessary water use. Leak detection and repair programs were conducted more regularly. As these programs were implemented unaccounted water use decreased and water use efficiency increased.

Water use efficiency is one of the factors embedded within the IWRAPS-AF installation winter water use coefficients. This is accomplished by a coefficient efficiency factor (CEF). The CEF is the ratio of water use in a specific building divided by its use in 1992. To account for the poorer early efficiencies, CEF was assumed to equal 1.33 for 1941-1975 period. This means that a building of specified square footage on LAFB assumedly used 33 percent more water annually from 1941 to 1973 than in 1992.

Unaccounted Water Use

The groundwater pumping calculated in the report equals total water use. Total water use is the amount of usage by the different base sectors plus unaccounted water use. Unaccounted water use is normally expressed as a percentage of water produced. Unaccounted water use results from water system losses due to leakage; uncalibrated metering; and fire fighting, street washing, sewer flushing, and other similar activities. Water losses of about 10 to 20 percent are acceptable for current water systems (Willett, J. S., et. al., 1995b). For LAFB a value of 25% was assumed for 1941-1975, 20% was assumed for 1976-1979, 15% was assumed from 1980-1989, and 10% was assumed for 1990-1992 (PMCL assumed 10% for 1992).

Real Property Data

Real property data (sector areas and special purpose sectors) was calculated using a forward-in-time method. This involved assuming that no real property existed before construction commenced in 1941. Sector areas and uses were added as facilities were constructed and utilized according to base records. Areas of facilities were added in the beginning of the year during which they were constructed. Construction records provided to USU are listed in Appendix A.

THE REGRESSION APPROACH

This approach uses the real property data to get a winter water use rate and uses regression analysis to derive the extra water use during the summer months. It uses regression to describe how water use trends and weather affected summer water use during the study period. The developed expression includes all factors that IWRAPS-AF assumes affect LAFB groundwater pumping, plus nonlinear combinations of those. Included factors are winter water use for the different sectors, annual average adjusted square footage (ADJSF), average summer maximum daily temperature (TEMP), and total summer precipitation (PPT).

Annual water use is assumed in IWRAPS-AF to be the sum of: (a) the daily winter water use rate per square foot of facilities (gpdpsf) times the square footage of facilities times 365 days, (b) the daily special purpose water use rate times 365 days, and (c) the extra summer daily use rate due to irrigation and cooling needs per square foot of adjusted square footage times adjusted square footage times 214 days. Figure 7 illustrates how the extra summer water use is added for April through October.

Annual water use is expressed using the following equation:

$$Q = Q_w + (214 \text{ summer days}) \cdot QDIFF \cdot ADJSF \qquad (1)$$

where

Q	= total annual water use (gal)
Q_w	= annual water use without including extra summer use (gal)
$QDIFF$	= extra daily water use per unit building area in the summer (gal/day$\cdot$ ft^2)
$ADJSF$	= total square footage of all building sectors minus the area of maintenance and warehouse sectors (ft^2)

The sum of uses (a) and (b) above equal Q_w :

$$Q_w = 365 \cdot ((\textstyle\sum_{i=1,21} Q_{wi}) + SPEC) \qquad (2)$$

where

$$Q_{wi} = SF_i \cdot GPSFPD_i \qquad (3)$$

where

Q_{wi}	= winter water use rate for building sector i (gal/day)
$SPEC$	= daily water use rate by special sectors (gal/day)
SF_i	= building area of sector i (ft^2)
$GPSFPD_i$	= daily water use per unit building area of sector i adjusted for activity level but not adjusted for summer weather (gal/day$\cdot$ ft^2)

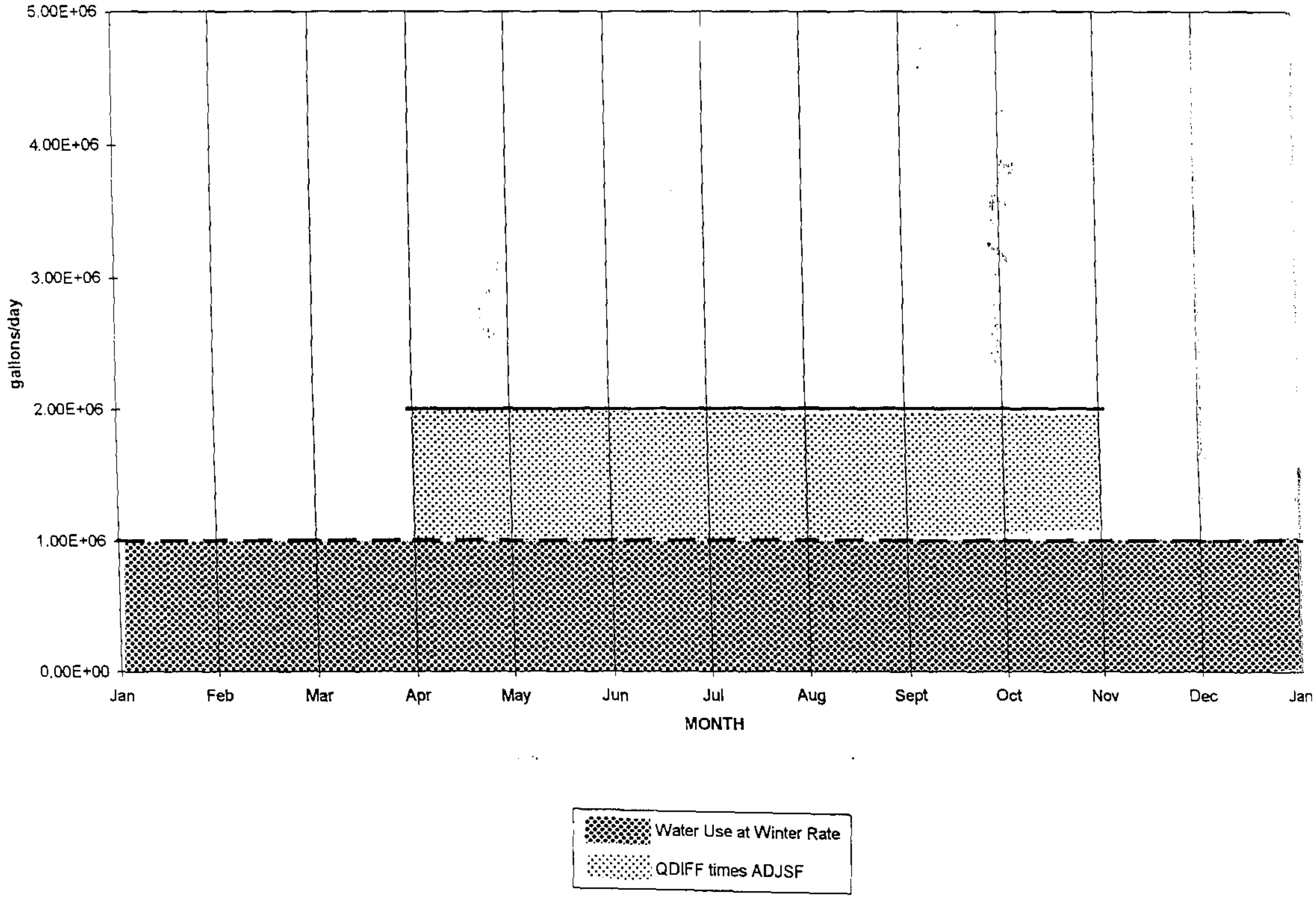


Figure 7. Illustration of Extra Water Use During the Summer Months

Only summer water use is affected by climate in IWRAPS-AF. Thus QDIFF is the extra water used per square foot of buildings in the summer. One way of deriving water use for 1941-1946 and 1951-1961 requires that we be able to get QDIFF in terms of climate and other factors.

To do this, we first rearrange equation 1 to define QDIFF in terms of total pumping (Q) and adjusted square footage (Equation 4).

$$QDIFF = (Q - Q_w) / \{(214 \text{ summer days}) \cdot ADJSF\} \quad (4)$$

Because Q and ADJSF are known for 1962 to 1973 (from LAFB records), we calculate QDIFF for that period using Equation 4. (Table 5). We do not simultaneously use records after 1973 because water use practices apparently change after that. Figure 8 shows that actual groundwater pumping decreased dramatically after 1973 despite increasing building area.

Table 5. QDIFF for 1962 to 1973

Year	QDIFF from Eq 4 (gal/day· ft^2)	QDIFF from Eq 5 (gal/day· ft^2)
1962	4.01	3.88
1963	4.02	3.91
1964	3.20	3.41
1965	2.96	2.90
1966	3.56	3.36
1967	3.56	3.44
1968	3.60	3.49
1969	2.66	2.92
1970	2.39	2.19
1971	2.52	2.40
1972	2.30	2.34
1973	2.23	2.11

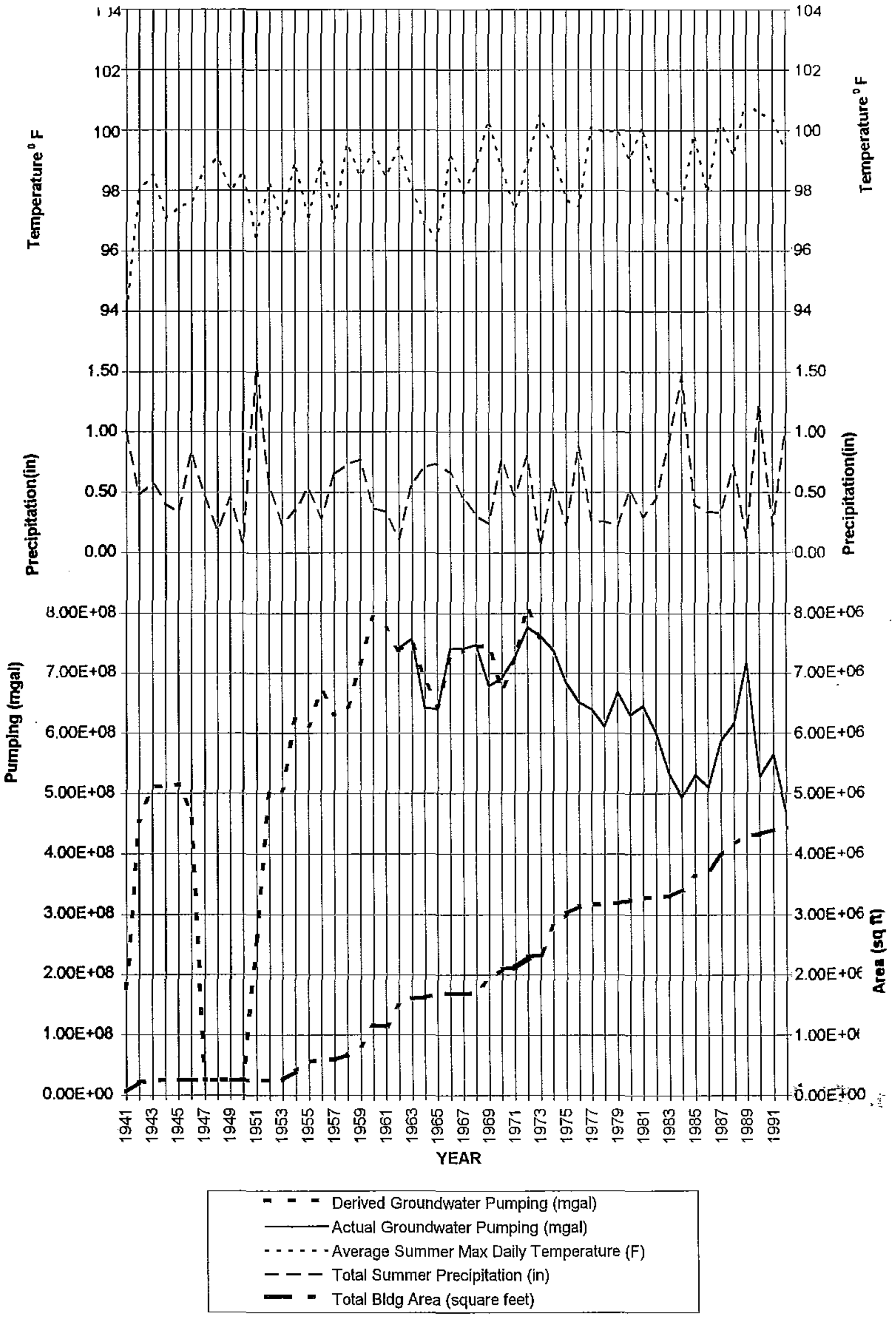


Figure 8. Trends in Climate, LAFB Building Area, and Actual and Historical Analysis Groundwater Pumping.

Next, using data from 1962-1973 (Table 6) we develop a regression equation (Eq. 5) relating QDIFF to year, temperature, precipitation, and adjusted square footage. Table 5 contrasts actual QDIFF (from Equation 4) with that computed by regression Equation 5. Equation 5 acceptably describes QDIFF. The R^2 for the generated regression equation equals 94.9% and the adjusted R^2 equals 86.0% Figure 9 shows how well the computed pumping equals recorded pumping values. Complete listing of the regression model is included in Appendix B.

$$\begin{aligned}\text{QDIFF} = {} & 54.8 + (0.02546 \cdot \text{Year}) - (28.18 \cdot \text{ADJSF} \cdot 10\text{e-}6) + (2.174 \cdot \text{PPT}) \\ & + (0.11947 \cdot \text{TEMP}) + (1.699 \cdot \text{ADJSF} \cdot \text{PPT} \cdot 10\text{e-}6) \\ & + (0.013425 \cdot \text{ADJSF}^2 \cdot 10\text{e-}9) - (4.182 \cdot \text{PPT}^2) \end{aligned} \tag{5}$$

Then we use Equation 5 to derive QDIFF for 1941 to 1961, years for which we have no pumping records. Finally we use Equation 1 to calculate annual water use for that period (Table 7). Q_w is obtained using IWRAPS-AF water use factors. ADJSF values are obtained from LAFB records as discussed previously.

Table 6. Parameters Used to Generate Equation 5

Year	ADJSF (ft^2)	PPT (in)	TEMP (° F)	Actual Groundwater Pumping (MGAL)
1962	701090	0.11	99.40	742.62
1963	702301	0.58	98.03	757.29
1964	712549	0.71	96.88	642.54
1965	758756	0.74	96.34	639.28
1966	762845	0.67	99.21	741.65
1967	762845	0.45	97.91	741.65
1968	762845	0.31	98.82	747.84
1969	872478	0.24	100.30	679.38
1970	970496	0.77	98.75	691.77
1971	980690	0.47	97.37	726.00
1972	1143283	0.80	98.94	777.18
1973	1149116	0.05	100.40	762.51

Table 7. Regression Approach Input and Output for 1941-1961

YEAR	ADJSF (ft^2)	PPT (in)	TEMP (° F)	QDIFF from Eq 5 (gal/day· ft^2)	Pumping Derived by Eq 1 (MGAL)
1941	56293	1.01	94.03	13.09	178.53
1942	145305	0.48	98.03	13.45	451.49
1943	171717	0.57	98.50	12.69	507.73
1944	171717	0.41	97.08	12.77	510.48
1945	171717	0.34	97.44	12.83	512.84
1946	171717	0.84	97.62	11.60	467.40
1947	171717	0.47	98.76	12.81	25.10*
1948	171717	0.19	99.08	12.91	25.70*
1949	171717	0.45	98.01	12.70	25.40*
1950	171717	0.08	98.59	12.65	25.30*
1951	171717	1.56	96.47	5.84	256.10
1952	171717	0.55	98.27	12.48	499.94
1953	171717	0.24	96.98	12.57	503.31
1954	230949	0.35	98.91	11.46	620.11
1955	230949	0.54	97.14	11.00	611.94
1956	258382	0.29	99.00	10.84	669.64
1957	258382	0.65	97.08	10.11	629.18
1958	261142	0.73	99.53	10.07	637.96
1959	373736	0.77	98.49	7.71	710.26
1960	661891	0.37	99.26	4.63	775.11
1961	661891	0.34	98.48	4.50	756.71

* Values for period when the base was relatively inactive derived assuming 5% of normal use

IV. RESULTS SUMMARY

Table 8 summarizes backcast results, detailed output are shown in Appendix B. Winter water use ranged from 8.8 to 50.4 million gallons, Summer water use ranged from 157.79 to 656.40 million gallons, and annual water use ranged from 178.50 to 775.10 million gallons.

The results for 1941 to 1961 and actual groundwater pumping data are shown in Figure 9. Figure 9 shows how water pumping amounts developed via the Regression Approach closely replicated groundwater pumping for 1962-1973. Assuming similar water use practices, the regression model reliably presents water use for 1941-1961.

Table 8. Summary of Output for 1941-1973.

Year	Annual Pumping Values Derived Using Regression (mgal)
1941	178.53
1942	451.49
1943	507.73
1944	510.48
1945	512.84
1946	467.49
1947	25.60
1948	25.78
1949	25.39
1950	25.31
1951	256.10
1952	499.94
1953	503.31
1954	620.11
1955	611.94
1956	669.64
1957	629.18
1958	637.96
1959	710.26
1960	775.11
1961	756.71
1962	723.77
1963	740.82
1964	674.42
1965	629.01
1966	708.80
1967	721.92
1968	730.07
1969	728.44
1970	650.26
1971	702.36
1972	787.33
1973	734.97

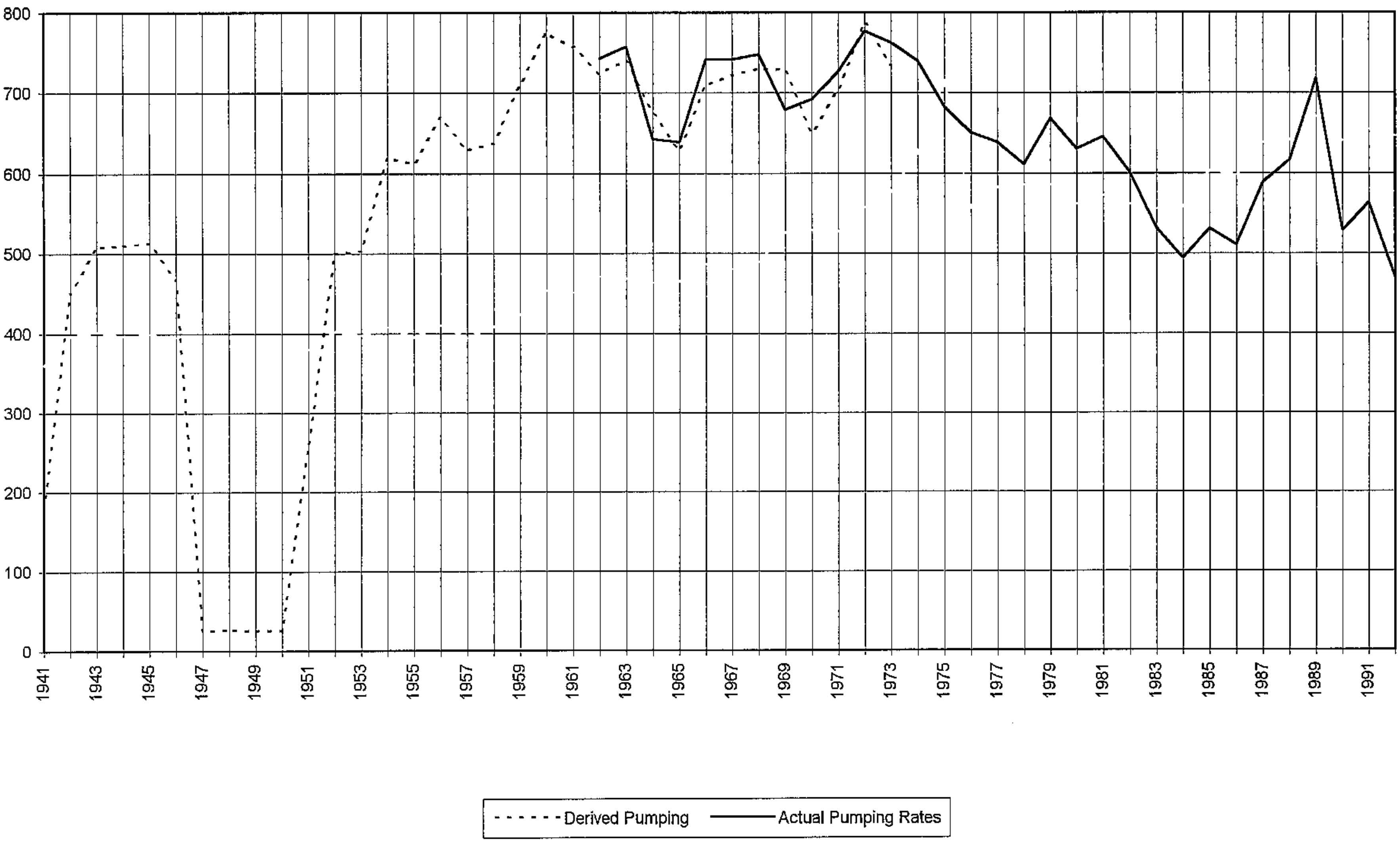


Figure 9. Actual and Historical Analysis Annual Groundwater Pumping

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APPENDIX A

REAL PROPERTY DATA PROVIDED TO USU

Table A-1. Real Property Data Provided to USU.

Year	FCC	Building Area (SF)
1941	510713	12080
1941	510713	9955
1941	610915	5017
1941	721315	7733
1941	722351	2125
1941	724417	7733
1941	724417	7733
1941	730771	3917
1941	842249	742
1942	171211	9356
1942	219946	21922
1942	219946	18478
1942	442769	10760
1942	442769	10000
1942	610122	3444
1942	610243	14930
1942	610243	6012
1942	610243	5012
1942	610249	13500
1942	724417	8109
1942	730443	1000
1942	730717	5032
1942	730835	10888
1942	730835	8194
1942	740255	2694
1942	740387	2934
1942	740883	1841
1943	131111	9312
1943	171617	3015
1943	219946	11865
1943	510713	8550
1943	510713	5535
1953	219946	4051
1954	131111	1230
1954	131115	1054
1954	171617	31041
1954	171617	26961
1954	211152	13344
1954	211177	46802
1954	211177	26400
1955	211152	11338
1955	211177	44170
1955	211177	27232
1955	217712	34702
1955	217712	20697
1955	218868	8254

Table A-1. Real Property Data Provided to USU, cont'd

Year	FCC	Building Area(SF)
1955	442758	5751
1955	740672	8395
1956	141753	7233
1956	141753	3633
1956	141753	12967
1956	610249	3600
1958	211157	28880
1958	211161	548
1958	218712	12670
1958	442758	30934
1958	442758	4800
1958	740383	2760
1959	211157	41550
1959	422258	5000
1959	721312	25944
1959	721312	26072
1959	721312	25800
1959	722351	14884
1959	740316	19894
1959	740672	264
1960	171621	7969
1960	171623	20675
1960	171623	9956
1960	216642	6351
1960	422257	553
1960	510125	2750
1960	610111	700
1960	610112	8800
1960	610119	3240
1960	610128	34889
1960	610142	4838
1960	610144	640
1960	610243	121518
1960	610243	12492
1960	610249	5120
1960	610282	1380
1960	610286	22305
1960	610911	3980
1960	723155	4701
1960	730441	14610
1960	730832	2134
1960	740672	1329
1960	740717	1000
1960	740884	4200
1960	811149	27934
1960	841169	258

Table A-1. Real Property Data Provided to USU, cont'd

Year	FCC	Building Area(SF)
1961	842249	720
1962	211152	14397
1962	211159	20630
1962	211177	37886
1962	211177	23489
1962	218852	10989
1962	218852	8209
1962	442257	1000
1962	442758	94404
1962	442758	77289
1962	610122	17115
1962	730839	46
1962	740618	22038
1963	211154	2210
1963	211177	42870
1963	211177	42690
1963	211177	40480
1963	610811	1211
1964	131111	9245
1964	211152	3800
1964	442257	3760
1964	750811	1003
1965	171443	5292
1965	171813	5722
1965	442758	5880
1965	610129	22560
1965	610129	8654
1965	610243	2304
1965	723392	264
1965	750811	1411
1966	121111	144
1966	141489	1964
1966	171618	1981
1966	217722	5792
1966	219946	2554
1968	219944	11040
1968	422265	4800
1968	442257	351
1969	121111	1635
1969	141383	3404
1969	141743	8716
1969	141743	5312
1969	211152	8230
1969	211157	42542
1969	211157	34312
1969	215552	14767

Table A-1. Real Property Data Provided to USU, cont'd

Year	FCC	Building Area(SF)
1969	442768	14614
1969	442768	7614
1969	610311	3500
1969	610718	3500
1969	721312	24855
1969	721315	24720
1969	723392	912
1969	724417	16728
1969	730773	13918
1969	740618	2433
1970	131117	2787
1970	131117	2004
1970	141753	20640
1970	171475	4784
1970	171712	6272
1970	171815	25030
1970	171815	8833
1970	211152	6948
1970	211177	32089
1970	211177	12233
1970	217762	783
1970	218852	1600
1970	219946	400
1970	219946	4000
1970	610129	11308
1970	610243	2521
1970	610243	10280
1970	730831	8343
1971	216642	2960
1971	217722	3804
1971	219944	184
1971	422257	545
1971	422265	960
1971	422265	960
1971	610142	9760
1971	730839	45
1971	740665	389
1971	811149	184
1971	842249	54
1971	842249	54
1972	123335	1166
1972	218712	1261
1972	219943	4638
1972	219944	20483
1972	610122	17602
1972	721312	21093

Table A-1. Real Property Data Provided to USU, cont'd

Year	FCC	Building Area (SF)
1972	721312	14062
1972	721312	20181
1972	721312	21808
1972	721312	21093
1972	721312	21093
1972	721315	7031
1972	740457	4174
1972	740457	4174
1972	740457	4174
1972	740457	4174
1972	740459	384
1972	740459	384
1973	134375	5833
1973	171476	3390
1973	211153	1447
1973	219947	5200
1973	422265	84
1973	432283	5970
1973	442257	666
1973	442257	387
1973	740672	978
1973	900001	1750
1974	219946	8240
1974	510001	125109
1974	510125	5917
1974	510126	960
1974	510143	504
1974	510147	2260
1974	510148	2490
1974	510149	4060
1974	510175	6930
1974	510212	6730
1974	510275	28921
1974	510342	4934
1974	510411	21842
1974	510672	7372
1974	510712	1715
1974	510713	8690
1974	510915	2905
1974	530155	2520
1974	530634	500
1974	540243	16359
1974	740266	102075
1974	740266	101575
1974	740671	22834
1974	821117	5843

Table A-1. Real Property Data Provided to USU, cont'd

Year	FCC	Building Area(SF)
1975	141753	10800
1975	171211	18300
1975	171212	67133
1975	211157	3200
1975	212213	10599
1975	215552	10500
1975	510175	21600
1975	510175	10800
1975	610129	1358
1975	724417	17105
1975	724417	17105
1975	740873	10136
1976	442758	2400
1976	610142	1000
1976	723392	264
1976	723392	120
1976	740381	1748
1976	740387	9750
1976	740388	52270
1976	740388	31932
1976	740389	8840
1976	811149	186
1977	211179	15379
1977	217722	1020
1977	740884	7360
1978	131118	69
1978	141165	5400
1978	171621	6000
1978	211152	1320
1978	217722	7373
1978	219944	2760
1978	610913	6573
1978	824462	326
1978	842249	226
1978	842249	226
1980	211154	1681
1980	218712	1174
1980	610122	960
1980	740253	9284
1980	740674	37827
1980	740883	6120
1981	141753	1427
1981	211153	960
1981	216642	780
1981	216642	780
1981	219944	324

Table A-1. Real Property Data Provided to USU, cont'd

Year	FCC	Building Area(SF)
1981	610913	1363
1981	740664	12541
1981	740664	8637
1981	740672	3904
1982	131118	150
1982	141753	1920
1982	211154	3680
1982	214425	1000
1982	442758	11600
1982	610243	2200
1982	723155	1296
1982	730832	576
1982	730839	280
1983	211161	740
1983	610144	3373
1983	730841	1415
1984	121111	3700
1984	131118	10456
1984	211154	8800
1984	211154	9600
1984	211154	8800
1984	211154	5600
1984	211154	5600
1984	211154	5600
1984	211154	5600
1984	211161	260
1984	442257	1045
1984	442628	27
1984	510176	3525
1984	610122	3456
1984	610129	1458
1984	610129	2780
1984	610144	3480
1984	610711	10940
1984	730717	3465
1984	730835	10192
1984	740386	6545
1984	740386	3080
1984	740672	625
1984	740883	525
1985	121111	900
1985	141753	7000
1985	211152	14373
1985	211152	749
1985	211154	4650
1985	214425	19126

Table A-1. Real Property Data Provided to USU, cont'd

Year	FCC	Building Area(SF)
1985	215552	32000
1985	215552	9400
1985	215552	10630
1985	217712	10095
1985	218868	1126
1985	219946	300
1985	442257	400
1985	442257	400
1985	442257	400
1985	442257	400
1985	442257	400
1985	442257	400
1985	442257	600
1985	442257	400
1985	442257	400
1985	442257	121
1985	610121	5670
1985	610122	6781
1985	610129	15420
1985	610243	4600
1985	610243	30000
1985	610243	23000
1985	610284	4080
1985	740382	4134
1985	740884	2300
1986	141455	240
1986	171212	11280
1986	211157	2267
1986	214428	3300
1986	214428	2360
1986	214428	5800
1986	217712	28855
1986	217712	22670
1986	219944	2400
1986	442257	600
1986	442758	6000
1986	442758	6185
1986	610243	5167
1986	740381	3636
1986	890123	400
1987	121111	256
1987	141753	23650
1987	211152	20000
1987	211152	7000
1987	211154	8021
1987	211154	7000

Table A-1. Real Property Data Provided to USU, cont'd

Year	FCC	Building Area(SF)
1987	211177	30000
1987	211177	16000
1987	216642	7000
1987	218712	20000
1987	422258	5000
1987	422258	5000
1987	442257	600
1987	442758	9436
1987	610122	500
1987	610249	5333
1987	721312	26052
1987	721312	26052
1987	723155	448
1987	724417	1560
1987	724417	1560
1987	730142	15700
1987	740388	6720
1987	824462	900
1988	141753	12000
1988	141753	12000
1988	171621	9250
1988	211153	4800
1988	211177	25350
1988	211177	32250
1988	211177	23000
1988	211179	14305
1988	218712	8100
1988	422265	5000
1988	422265	5000
1988	422265	5000
1988	422265	5000
1988	442257	7749
1988	442515	8200
1988	610243	12000
1988	722345	2000
1988	730142	2920
1988	841169	90
1988	841169	90
1988	842249	600
1988	900002	1050
1989	141453	17238
1989	171443	4800
1989	171618	28000
1989	171618	15000
1989	211159	600
1989	211177	21028

Table A-1. Real Property Data Provided to USU, cont'd

Year	FCC	Building Area(SF)
1989	211179	11000
1989	217712	5300
1989	442257	120
1989	442257	400
1989	442257	100
1989	510125	5140
1989	510125	5750
1989	740675	13000
1989	900003	5000
1990	171211	24400
1990	442257	480
1990	730839	1380
1990	823248	800
1991	171618	24000
1991	219946	4225
1991	219946	3475
1991	610122	750
1991	610243	12610
1991	740617	25500
1991	900004	468
1992	442257	2385
1992	442257	160
1992	442257	320
1992	442257	1530
1992	442257	252
1992	510147	2927
1992	510713	1800
1992	721312	26052
1992	900005	1090
1993	171617	825
1993	214467	5000
1993	723392	264
1993	740665	8000
1993	740665	900
1993	740884	2000
1993	750811	3770
1993	900006	1800
1994	141753	2990
1994	141753	13000
1994	442257	144
1994	442257	190
1994	442257	1900
1994	723392	185
1994	730441	5040
1995	510125	2878

APPENDIX B

INPUT AND OUTPUT USED IN THE REGRESSION APPROACH

TABLE B-1. INPUT TO THE REGRESSION

YEAR	ADJ SF	PPT	TEMP	QDIFF
1962	701090	0.11	99.40571429	4.010724
1963	702301	0.58	98.03	4.020143
1964	712549	0.707142857	96.88571429	3.201195
1965	758756	0.74	96.34	2.963892
1966	762845	0.667142857	99.21714286	3.569493
1967	762845	0.45	97.91857143	3.569493
1968	762845	0.311428571	98.82	3.60015
1969	872478	0.242857143	100.3	2.663578
1970	970496	0.774285714	98.75285714	2.390417
1971	980690	0.47	97.37857143	2.521543
1972	1143283	0.804285714	98.94	2.307359
1973	1149116	0.051428571	100.4871429	2.230943

Table B-2. INPUT FOR CONFIDENCE INTERVAL PREDICTION

YEAR	SF/10E6	PPT	TEMP	SF**2/10E9	PPT**2	PPT*SF/10E6
1941	0.056293	1.01	94.03429	3.168902	1.0201	0.056856
1942	0.145305	0.48	98.03714	21.11354	0.2304	0.069746
1943	0.171717	0.572857	98.5	29.48673	0.328165	0.098369
1944	0.171717	0.408571	97.08714	29.48673	0.166931	0.070159
1945	0.171717	0.337143	97.44714	29.48673	0.113665	0.057893
1946	0.171717	0.838571	97.61857	29.48673	0.703202	0.143997
1947	0.171717	0.472857	98.76429	29.48673	0.223594	0.081198
1948	0.171717	0.185714	99.07857	29.48673	0.03449	0.03189
1949	0.171717	0.454286	98.01286	29.48673	0.206376	0.078009
1950	0.171717	0.077143	98.59571	29.48673	0.005951	0.013247
1951	0.171717	1.562857	96.46857	29.48673	2.442522	0.268369
1952	0.171717	0.552857	98.26857	29.48673	0.305651	0.094935
1953	0.171717	0.242857	96.98714	29.48673	0.05898	0.041703
1954	0.230949	0.35	98.90857	53.33744	0.1225	0.080832
1955	0.230949	0.538571	97.14	53.33744	0.290059	0.124383
1956	0.258382	0.285714	99	66.76126	0.081633	0.073823
1957	0.258382	0.651429	97.08714	66.76126	0.424359	0.168317
1958	0.261142	0.731429	99.53	68.19514	0.534988	0.191007
1959	0.373736	0.771429	98.48857	139.6786	0.595102	0.288311
1960	0.661891	0.37	99.25857	438.0997	0.1369	0.2449
1961	0.661891	0.335714	98.48429	438.0997	0.112704	0.222206
1962	0.70109	0.11	99.40571	491.5272	0.0121	0.07712
1963	0.702301	0.58	98.03	493.2267	0.3364	0.407335
1964	0.712549	0.707143	96.88571	507.7261	0.500051	0.503874
1965	0.758756	0.74	96.34	575.7107	0.5476	0.561479
1966	0.762845	0.667143	99.21714	581.9325	0.44508	0.508927
1967	0.762845	0.45	97.91857	581.9325	0.2025	0.34328
1968	0.762845	0.311429	98.82	581.9325	0.096988	0.237572
1969	0.872478	0.242857	100.3	761.2179	0.05898	0.211888
1970	0.970496	0.774286	98.75286	941.8625	0.599518	0.751441
1971	0.98069	0.47	97.37857	961.7529	0.2209	0.460924
1972	1.143283	0.804286	98.94	1307.096	0.646876	0.919526
1973	1.149116	0.051429	100.4871	1320.468	0.002645	0.059097
1974	1.501209	0.594286	99.34	2253.628	0.353176	0.892147
1975	1.675546	0.231429	97.71571	2807.454	0.053559	0.387769
1976	1.77172	0.885714	97.46429	3138.992	0.78449	1.569238
1977	1.77908	0.254286	100.0771	3165.126	0.064661	0.452395
1978	1.791653	0.262857	99.93714	3210.02	0.069094	0.470949
1979	1.791653	0.22	99.99857	3210.02	0.0484	0.394164
1980	1.845844	0.527143	99.04429	3407.14	0.27788	0.973023
1981	1.869812	0.305714	100.09	3496.197	0.093461	0.571628
1982	1.876084	0.435714	98.05286	3519.691	0.189847	0.817437
1983	1.880872	0.897143	97.90857	3537.679	0.804865	1.687411
1984	1.934018	1.462857	97.57714	3740.426	2.139951	2.829192
1985	2.037903	0.404286	99.83857	4153.049	0.163447	0.823895
1986	2.057986	0.34	97.95571	4235.306	0.1156	0.699715
1987	2.150117	0.332857	100.3686	4623.003	0.110794	0.715682
1988	2.197547	0.727143	99.17714	4829.213	0.528737	1.597931
1989	2.286475	0.127143	100.8771	5227.968	0.016165	0.290709
1990	2.312255	1.23	100.605	5346.523	1.5129	2.844074
1991	2.375115	0.224286	100.376	5641.171	0.050304	0.532704
1992	2.405894	1.04	99.33143	5788.326	1.0816	2.5021

Table B-3. OUTPUT FROM MINITAB INCLUDING CONFIDENCE INTERVALS

```
-----------------------------------------------------------
MTB > READ 'frWRD1.DAT' C1-C5
     12 ROWS READ

 ROW     C1        C2          C3         C4         C5

   1   1962    701090   0.110000    99.406   4.01072
   2   1963    702301   0.580000    98.030   4.02014
   3   1964    712549   0.707143    96.886   3.20120
   4   1965    758756   0.740000    96.340   2.96389
  .  .  .

MTB > READ 'frWRD2.DAT' C21-C27
     52 ROWS READ

 ROW    C21        C22        C23        C24        C25        C26        C27

   1   1941   0.05629   1.01000   94.034      3.17   1.02010   0.05686
   2   1942   0.14530   0.48000   98.037     21.11   0.23040   0.06975
   3   1943   0.17172   0.57286   98.500     29.49   0.32816   0.09837
   4   1944   0.17172   0.40857   97.087     29.49   0.16693   0.07016
  .  .  .

MTB >
MTB > LET C6 = C1*C1
MTB > LET C7 = C2*C2/1000000000.00
MTB > LET C8 = C3*C3
MTB > LET C9 = C4*C4
MTB > LET C10 = C2*C3/1000000.00
MTB > LET C11 = C2*C4
MTB > LET C12 = C3*C4
MTB > LET C13 = C2*C3*C4
MTB > LET C14 = C2/1000000.00
MTB >
MTB >
MTB > LET C15 = C5*C5
MTB >
MTB >
MTB >
MTB >
MTB > NAME C1 'YEAR'
MTB > NAME C2 'ADJSF'
MTB > NAME C3 'PPT'
MTB > NAME C4 'TEMP'
MTB > NAME C5 'QDIFF'
MTB >
MTB >
MTB > REGRESS C5 7 C1 C14 C3 C4 C7 C8 C10 ;
SUBC> PREDICT C21-C27.
* NOTE *      C14 is highly correlated with other  predictor variables
* NOTE *      PPT is highly correlated with other  predictor variables
* NOTE *       C7 is highly correlated with other  predictor variables

The regression equation is
QDIFF = 55 - 0.0255 YEAR - 28.2 C14 + 2.17 PPT + 0.119 TEMP + 0.0134 C7
           - 4.18 C8 + 1.70 C10
```

Table B-3. OUTPUT FROM MINITAB INCLUDING CONFIDENCE INTERVALS, cont'd

Predictor	Coef	Stdev	t-ratio	p
Constant	54.8	188.3	0.29	0.785
YEAR	-0.02546	0.09891	-0.26	0.810
C14	-28.18	11.94	-2.36	0.078
PPT	2.174	3.063	0.71	0.517
TEMP	0.11947	0.09271	1.29	0.267
C7	0.013425	0.005706	2.35	0.078
C8	-4.182	2.562	-1.63	0.178
C10	1.699	1.621	1.05	0.354

s = 0.2471   R-sq = 94.9%   R-sq(adj) = 86.0%

Analysis of Variance

SOURCE	DF	SS	MS	F	p
Regression	7	4.56187	0.65170	10.68	0.019
Error	4	0.24419	0.06105		
Total	11	4.80607			

SOURCE	DF	SEQ SS
YEAR	1	3.58831
C14	1	0.22382
PPT	1	0.15358
TEMP	1	0.07110
C7	1	0.24000
C8	1	0.21807
C10	1	0.06699

Fit	Stdev.Fit	95% C.I.	95% P.I.	
13.1509	3.5105	(3.4014,22.9003)	(3.3773,22.9244)	XX
13.5086	2.8041	(5.7210,21.2961)	(5.6909,21.3263)	XX
12.7482	2.5959	(5.5386,19.9578)	(5.5061,19.9904)	XX
12.8232	2.6237	(5.5366,20.1098)	(5.5043,20.1420)	XX
12.8873	2.6620	(5.4943,20.2804)	(5.4626,20.3121)	XX
11.6533	2.6299	(4.3495,18.9571)	(4.3173,18.9893)	XX
12.8687	2.7328	(5.2791,20.4583)	(5.2481,20.4893)	XX
12.9636	2.8048	(5.1740,20.7531)	(5.1439,20.7833)	XX
12.7542	2.8084	(4.9545,20.5539)	(4.9244,20.5841)	XX
12.7066	2.9396	(4.5427,20.8705)	(4.5139,20.8993)	XX
5.9004	4.0214	(-5.2679,17.0687)	(-5.2890,17.0897)	XX
12.5363	2.9387	(4.3747,20.6979)	(4.3459,20.7267)	XX
12.6249	3.0510	(4.1515,21.0984)	(4.1237,21.1261)	XX
11.5139	2.5288	(4.4909,18.5369)	(4.4575,18.5704)	XX
11.0604	2.5479	(3.9843,18.1365)	(3.9511,18.1697)	XX
10.9004	2.4102	(4.2066,17.5942)	(4.1715,17.6293)	XX
10.1687	2.4123	(3.4692,16.8682)	(3.4341,16.9033)	XX
10.1264	2.4698	(3.2672,16.9856)	(3.2329,17.0199)	XX
7.7643	1.6334	(3.2280,12.3006)	(3.1764,12.3522)	XX
4.6873	0.3984	(3.5808, 5.7937)	(3.3853, 5.9892)	XX
4.5574	0.2959	(3.7356, 5.3792)	(3.4867, 5.6280)	X
3.9383	0.2393	(3.2736, 4.6029)	(2.9830, 4.8935)	
3.9636	0.2053	(3.3935, 4.5338)	(3.0715, 4.8558)	
3.4634	0.1546	(3.0340, 3.8927)	(2.6539, 4.2728)	
2.9538	0.1893	(2.4280, 3.4796)	(2.0893, 3.8183)	
3.4215	0.1784	(2.9261, 3.9169)	(2.5751, 4.2678)	
3.5019	0.1367	(3.1222, 3.8817)	(2.7176, 4.2862)	

Table B-3. OUTPUT FROM MINITAB INCLUDING CONFIDENCE INTERVALS, cont'd

```
---------------------------------------------------------

  3.5446      0.2104   ( 2.9604, 4.1288)  ( 2.6434, 4.4458)
  2.9798      0.1784   ( 2.4842, 3.4754)  ( 2.1334, 3.8263)
  2.2440      0.1917   ( 1.7116, 2.7764)  ( 1.3755, 3.1125)
  2.4625      0.2226   ( 1.8443, 3.0808)  ( 1.5389, 3.3862)
  2.4026      0.2375   ( 1.7430, 3.0621)  ( 1.4508, 3.3543)
  2.1730      0.2448   ( 1.4931, 2.8529)  ( 1.2070, 3.1390)
  5.7462      1.7123   ( 0.9907,10.5017)  ( 0.9414,10.5509) XX
  7.6567      2.8122   (-0.1534,15.4667)  (-0.1834,15.4968) XX
  9.7145      3.7377   (-0.6660,20.0951)  (-0.6886,20.1177) XX
  9.8853      3.7338   (-0.4843,20.2548)  (-0.5070,20.2775) XX
 10.1231      3.8758   (-0.6410,20.8872)  (-0.6628,20.9091) XX
  9.9679      3.8840   (-0.8190,20.7548)  (-0.8408,20.7767) XX
 11.6391      4.5307   (-0.9436,24.2219)  (-0.9623,24.2405) XX
 11.8668      4.7301   (-1.2699,25.0036)  (-1.2878,25.0215) XX
 12.0337      4.8724   (-1.4981,25.5656)  (-1.5155,25.5830) XX
 12.0064      5.0863   (-2.1194,26.1322)  (-2.1360,26.1489) XX
 10.7514      6.3323   (-6.8350,28.3379)  (-6.8484,28.3512) XX
 16.1668      6.7496   (-2.5785,34.9122)  (-2.5911,34.9247) XX
 16.3042      6.9982   (-3.1314,35.7398)  (-3.1435,35.7520) XX
 19.2075      8.1993   (-3.5640,41.9790)  (-3.5743,41.9893) XX
 21.0795      9.0397   (-4.0260,46.1850)  (-4.0354,46.1943) XX
 22.7233     10.0559   (-5.2045,50.6511)  (-5.2129,50.6595) XX
 24.0057     11.0745   (-6.7509,54.7624)  (-6.7586,54.7701) XX
 26.1415     11.5386   (-5.9040,58.1871)  (-5.9114,58.1945) XX
 27.9052     12.4997   (-6.8094,62.6198)  (-6.8162,62.6266) XX

X  denotes a row with X values away from the center
XX denotes a row with very extreme X values


MTB >
MTB >
MTB > STOP
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February 6, 1997

Mr. Mike Cianci
JACE/AFWRAT
7383 N. Litchfield Rd, STE 3006
Luke AFB, AZ 85309

Dear Mike

Enclosed are the results of our backcasting of Luke AFB groundwater pumping. We feel we have addressed all your comments and hope you are pleased with the final product.

We have enjoyed the opportunity to work for you. Please let me know if I can hlep further.

Sincerely,

Richard C. Peralta, PE, PhD.
Professor

cc:
Jim Williams AFCEE/ERC
BEM Systems