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HYDROLOGY and WATER RESOURCES in ARIZONA and the SOUTHWEST

*Proceedings of the 1988 Meetings
of the*

**Arizona Section
American Water Resources Association**

and the

**Hydrology Section
Arizona-Nevada Academy of Science**

April 16, 1988, University of Arizona
Tucson, Arizona

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INTRODUCTION

The Arizona Section of the American Water Resources Association and the Hydrology Section of the Arizona-Nevada Academy of Science met at the University of Arizona on April 16, 1988. The annual meeting provides a forum to discuss water issues and present current research results. This document is made up of the proceedings of that meeting.

Papers presented at the meeting were submitted camera-ready by their authors for this publication.

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A MODEL OF SNOWPACK DYNAMICS IN FOREST OPENINGS

Peter F. Ffolliott, D. Phillip Guertin, and William O. Rasmussen
School of Renewable Natural Resources, University of Arizona
Tucson, Arizona 85721

Introduction

To assist watershed management specialists and land use planners in estimating the impacts of alternative forest management practices on snowpack accumulation and melt patterns, a computer simulation model, called SNOW, has been developed to analyze snowpack dynamics in forested conditions. In structuring SNOW, three simulation options have been defined. The first option is the simulation of snowpack water equivalent (WE) before a change in forest management. The second and third simulation options are estimates of snowpack WE following either (a) reduction in forest densities through a thinning practice or (b) creation of forest openings by a clearing practice. By comparing snowpack WE prior to a forest management change with that predicted following the implementation of the change, the impact of the forest management practice on snowpack WE can be estimated.

The general formulation and application of the simulation option that estimates the impacts of creating forest openings on snowpack WE are described in this paper. Importantly, a prerequisite to the applications of this option of SNOW is that the winter snowpack accumulation period has begun, that is, a snowpack already has accumulated on the ground.

Formulation of Model

Forest openings have been shown to affect snowfall distribution patterns (Hoover and Leaf, 1967; Ffolliott and Thorud, 1974; Gary 1974). However, it is not always known whether a resultant change in snowpack WE has taken place. To help in this determination, SNOW includes a simulation option to assess the spatial and temporal effects of forest openings on a snowpack.

In essence, the effect of forest openings on snowpack WE at a point in time is dependent upon input variables that change in time and space. Variables that change in time include temperature, precipitation, and snowpack albedo; variables that change in space are forest structure, slope-aspect relationships, and dimensions of the forest openings. After a screening of possible input variables, a set of input variables was identified to simulate the effect of a forest opening on snowpack WE. Importantly, all of the selected input variables in SNOW are readily available.

Net Effect of Forest Openings

Earlier studies have reported that the effect of forest openings is insignificant at a distance of 2 to 3H (H = average height of surrounding trees) into the adjacent forest (Anderson, 1963; Hansen and Ffolliott, 1968; Ffolliott, 1983). Measurements of snowpack WE taken beyond 3H generally represent undisturbed forested conditions, that is, conditions before the creation of the forest openings. Therefore, in structuring SNOW, the net effect of forest openings has been defined and calculated as the difference between the mean snowpack WE across the openings and extending 3H, and the mean snowpack WE beyond 3H. Positive differences represent a net increase, while negative differences are a net decrease.

Time-Dependent Variables

Of the variables analyzed that change with time, only the amount of precipitation that accumulated over the interval of time between the initialization of the model and the simulation period was related to the measurement of the net effect of forest openings. Therefore, the use of this variable requires a user to initialize conditions, with precipitation accumulated from that point to the time of simulation.

Space-Dependent Variables

In terms of variables that change in space, forest density, average height of surrounding trees, potential direct-beam solar radiation, and the dimensions of the forest openings are required in the operation of SNOW.

An input of forest density is necessary to index the processes of interception of precipitation, obstruction of short-wave radiation, and re-radiation of long-wave radiation from trees onto a snowpack. Square feet of basal area per acre was selected as the expression of forest density because it is easily determined in the field, readily converted to other expressions of forest density, and numerous multi-resource forest relations have been developed with basal area as the indpendent variable.

To meet specific hydrologic objectives in terms of snowpack profiles in and adjacent to forest openings, the prescribed width of the openings commonly is defined in terms of H (Ffolliott, 1983). However, to convert this measurement to equivalent feet, knowledge of the average tree height is required. Therefore, if a forest opening is 2H in width and the surrounding trees are 65 feet in height, the opening is 130 feet wide.

Values of average potential direct-beam solar radiation (in langleys) received daily throughout a snowpack accumulation and melt season are used to index the slope-aspect combinations at a site. Once calculated, this variable does not change with time. Considering a solar day as the basic time unit at a site, potential direct-beam solar radiation can be obtained from tables with slope and aspect measurements (Frank and Lee, 1966).

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The dimensions of the forest openings, both widths and lengths, are necessary to provide a spatial measure of the effects of the openings on snowpack dynamics.

Flowchart

The flow of activities that are followed in operating SNOW to simulate the effects of forest openings on snowpack WE is outlined in figure 1. Through inputs of precipitation, forest density, height of surrounding trees, potential direct beam solar radiation, and the dimensions of the forest openings, the net effect of creating the forest openings is estimated in terms of snowpack WE gained or lost.

Application of Model

To employ SNOW to predict the effects of forest openings on snowpack WE, a user responds to interactive statements and questions that structure the simulation exercise and provide the required inputs. These statements and questions are offered to the user after the forest type has been specified, a positive response has been made to a question asking whether a forest management change is being proposed, and an appropriate response has been made to the simulation option.

For purposes of illustration, the effects of forest openings 1-1/2H wide and 300 feet long, oriented with their long axis up-and-down slope, will be simulated in terms of increasing or decreasing the snowpack WE at peak seasonal accumulation, prior to the start of runoff. Such an estimate often is one of the better estimators of potential water yields from a melting snowpack in Arizona (Ffolliott and Thorud, 1972).

A ratio of openings to forested areas of 1:3 is prescribed for the hypothetical 2,500-acre watershed. The amount of precipitation accumulated in the interval between the initialization of the model, a time in the winter snowpack accumulation period, and peak seasonal accumulation is 2.4 inches. Forest density, representing the conditions prior to the forest management change, is 100 square feet of basal area. The average height of the surrounding trees is 65 feet. Average potential direct beam solar radiation received daily in the snowpack accumulation and melt season, based on an average slope of 10 percent, southeast aspect, and latitude of 34 degrees north, is 748 langleys.

In comparison to the snowpack WE simulated to represent undisturbed forested conditions, estimated to be 8.6 inches, the simulated net effect of creating the forest openings is to reduce the snowpack WE on the watershed at peak seasonal accumulation, prior to the start of runoff, by 0.08 inch. In other words, the average snowpack WE on the 2,500-acre watershed after implementation of the clearing practice to create the forest openings is estimated to be 8.52 inches. It appears that creating forest openings on the relatively "warm aspect" that characterized the hypothetical watershed will accelerate snow melt during the early winter snowpack accumulation period, with less snowpack WE in and adjacent to the openings at peak seasonal
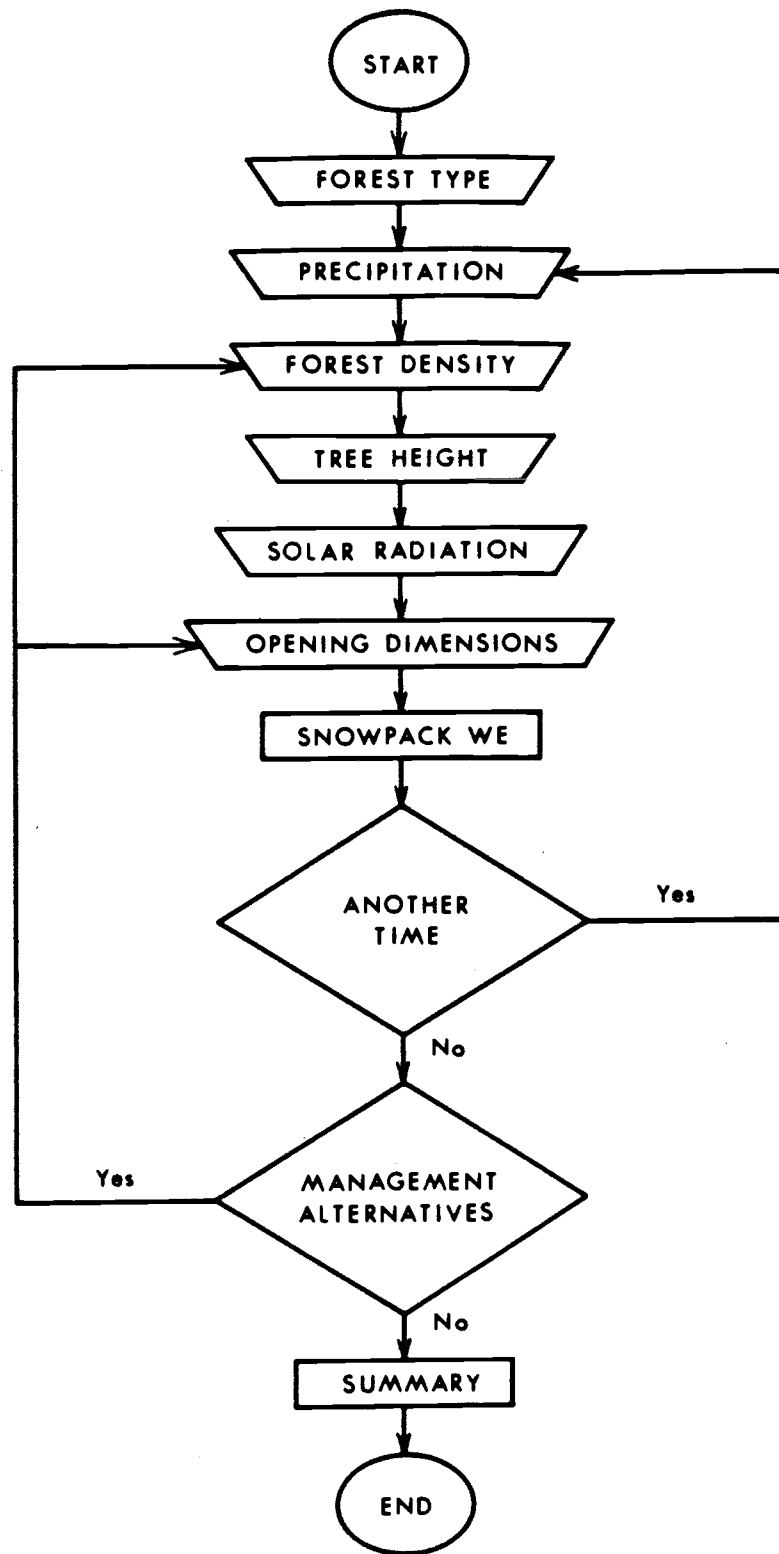
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Figure 1. — Flow of activities in SNOW to estimate the effects
of forest openings on snowpack WE.

accumulation, prior to runoff.

Factors not considered in SNOW must be evaluated by watershed management specialists and land use planners before the implementation of any forest management practice. However, based on the illustrative example presented herein, and assuming that an increase in snowpack WE at peak seasonal accumulation is a planning objective, implementation of an alternative forest management practice appears to be feasible.

Future Developments

To a large extent, SNOW is considered to be a "prototypical" computer simulation model. Developed from source data sets representative of selected southwestern ponderosa pine forests, further testing of the model will be undertaken to determine its applicability to a wide range of conditions encountered in these forests.

Once testing in the ponderosa pine forests has been completed, it is anticipated that the structure of SNOW will be extrapolated to the higher elevation mixed conifer forests, in which the potentials for snowpack management are likely to be greater.

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FACTORS AFFECTING SEASONAL AND ANNUAL
PRECIPITATION IN ARIZONA

Arnon Karnieli and Herbert B. Osborn
U.S. Department of Agriculture, Agricultural Research Service
2000 East Allen Road, Tucson, Arizona 85719

Abstract

Seasonal and annual precipitation vary considerably in Arizona, primarily because of topographic influences. Precipitation data have been analyzed by several investigators over the years. Arizona has been subdivided into precipitation zones, and seasonal and annual precipitation isohyetal maps are available from several sources. Because of a paucity of raingages in the more mountainous regions, however, isohyetal lines in these regions have been largely estimated based on the assumptions of topographic influences. Now, with 158 raingages with 30 or more years of record, topographic factors can be combined with greater knowledge of the sources and paths of moisture into the state to better define annual and seasonal precipitation variability. Elevation and aspect appear to be the principal parameters for analyzing precipitation within the state, with the Mogollon Rim exerting the greatest influence on winter precipitation. Higher than anticipated summer rainfall in southeastern Arizona (based on elevation and aspect) suggest that sources and availability of atmospheric moisture may be a strong parameter in analyzing summer rainfall.

Introduction

The range of elevation (40 to 4200 m) in Arizona leads to a wide range of climatic conditions (Sellers, 1960). Much of the state receives less than 250 mm of annual precipitation. The region of highest precipitation crosses the central part of the state from southeast to northwest along the Mogollon Rim. In Arizona, precipitation is bimodal, with slow moving cold fronts providing lift for winter precipitation, and convective heating of moist tropical air producing summer rainfall. Both the Pacific Ocean and the Gulf of Mexico are now recognized as sources of moisture for precipitation in Arizona (Osborn and Davis, 1977). Winter snow and rain are generally low intensity events associated with slow moving cold fronts, although occasionally surges of

warm moist air can push into Arizona in the winter and produce convective activity within a general storm system. Orographic lifting along the Mogollon Rim in central Arizona (Fig. 1) dominates winter precipitation. Summer rains are primarily high intensity thunderstorms of short duration and limited areal extent, with the influence of elevation and aspect less apparent.

Previous Studies

The climate of Arizona with particular emphasis on precipitation and temperature was categorized by Sellers (1960) and Green (1964). Their publications included the prevalent facts and theories on the reasons for the extreme variability in annual and seasonal precipitation across Arizona. At that time, the Gulf of Mexico was considered the prime source of moisture for summer rain in Arizona. Hales (1973) first suggested that "surges" of moisture from the Pacific Ocean south of Baja California moving into Arizona from the south were important sources of summer thunderstorm rainfall. Osborn and Davis (1977) concluded that both the Pacific Ocean and the Gulf of Mexico could be important sources of moisture for summer rains in Arizona. Also, several investigators, including Sellers (1960) and Osborn (1985), have reported on the importance of tropical storms in pushing moist tropical air into Arizona.

Analysis

An isohyetal map of average annual precipitation for Arizona appeared in the 1941 United States Department of Agriculture (USDA) Yearbook, Climate & Man (Fig. 2). The map, which was developed from relatively few available precipitation records and from topographic considerations, is an excellent starting point for analysis of Arizona precipitation.

Precipitation records from 158 raingages operated more than 30 years (Fig. 3) have been adapted from Sellers et al. (1985) (Appendix A). The data were used to develop a similar isohyetal map of annual precipitation for Arizona (not shown). Although the recent map showed greater detail than the 1941 map, they were very similar. Both showed the strong influence of the Mogollon Rim in increasing precipitation in central Arizona (relative to elevation) and in decreasing precipitation in northeastern Arizona. Both maps showed higher precipitation amounts in the mountainous areas of south-eastern Arizona, although the differences, relative to elevation, were not as extreme as in central Arizona.

Osborn (1984) attempted to separate both seasonal and annual precipitation amounts for Arizona, based on available rainfall records, into zones which were well above (excess) or well below (deficit) average precipitation amounts (as defined by French, 1983) based strictly on elevation. In this paper, we have attempted to redefine the zones
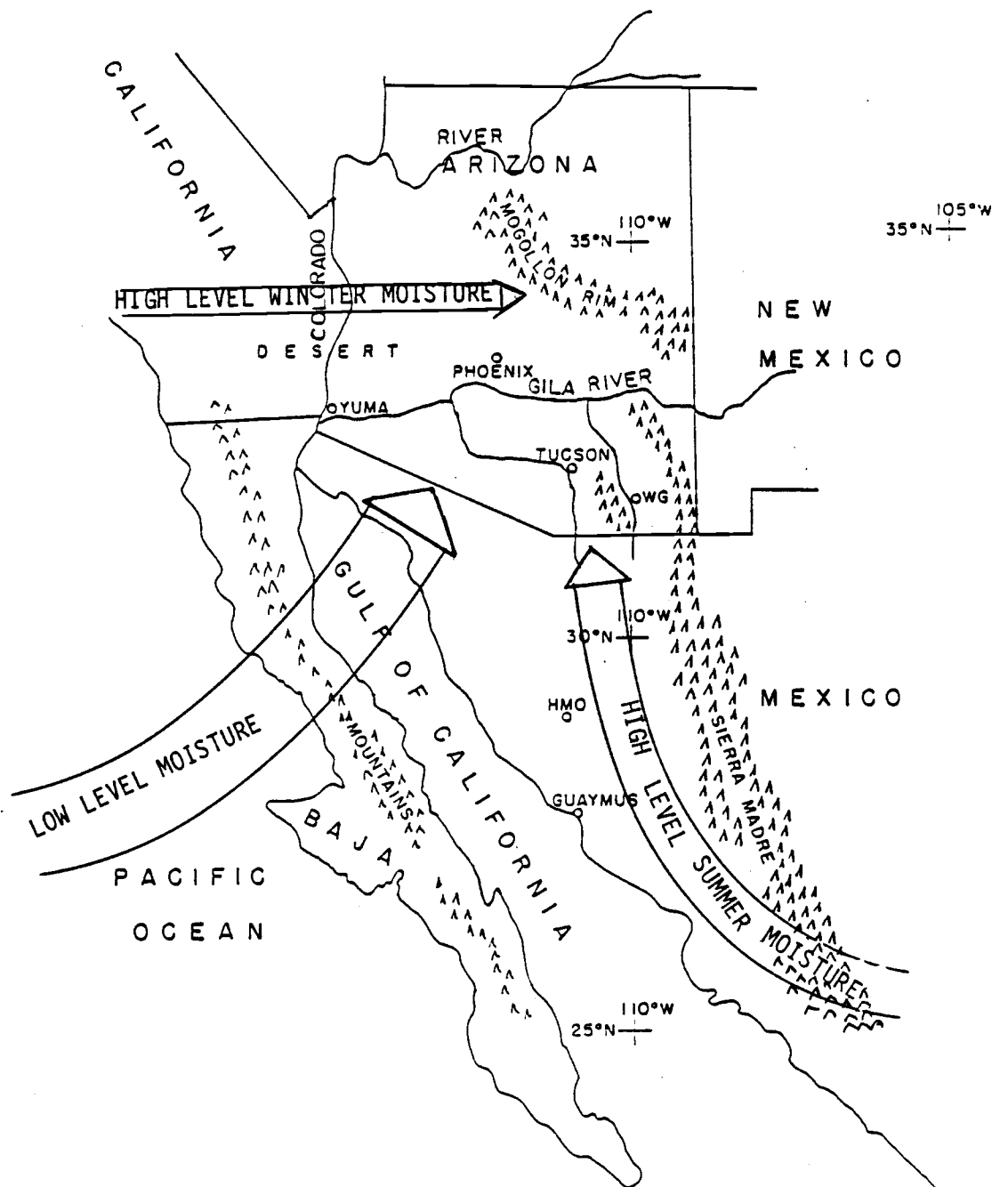
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Figure 1. Sources of moisture for Arizona precipitation.

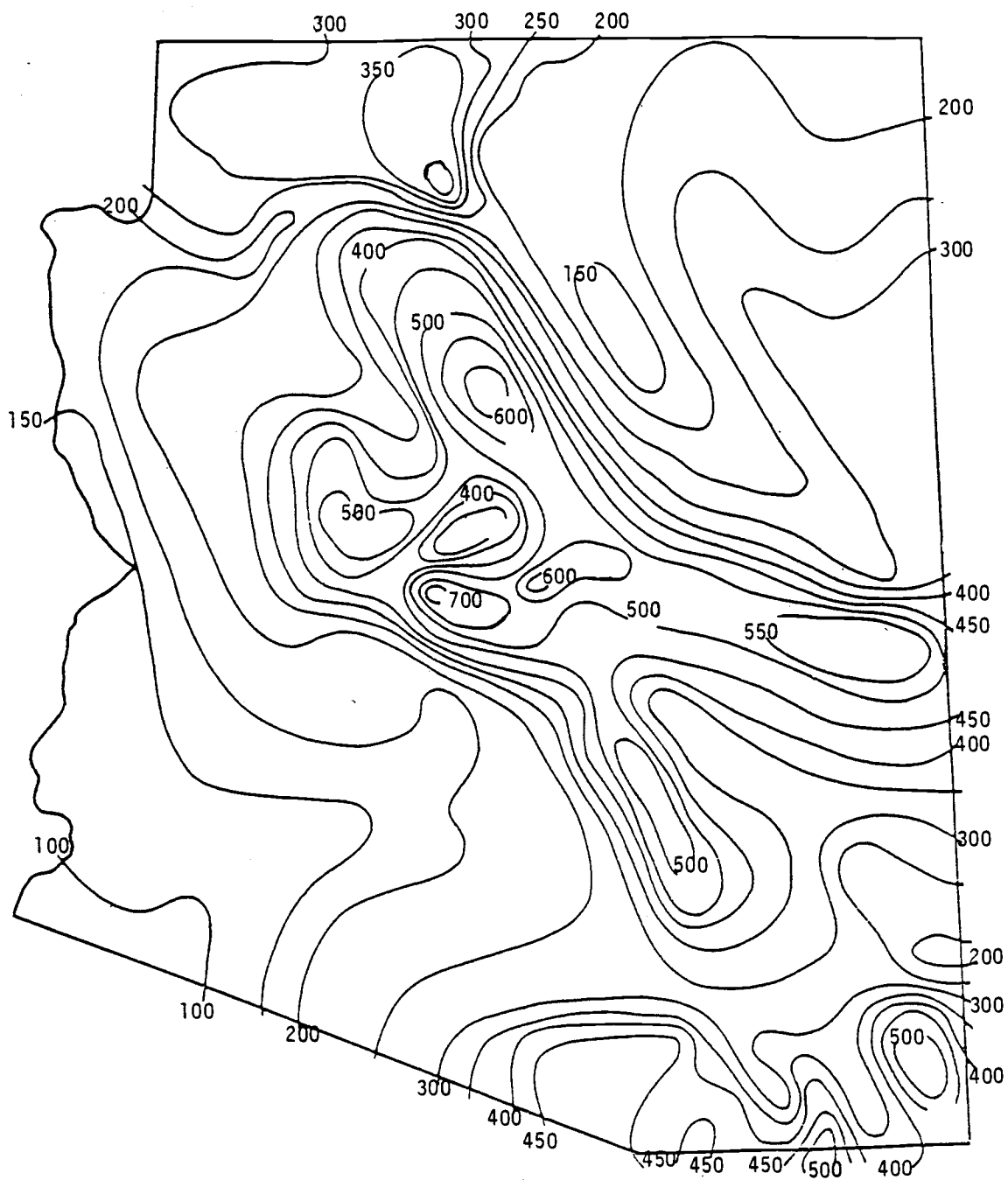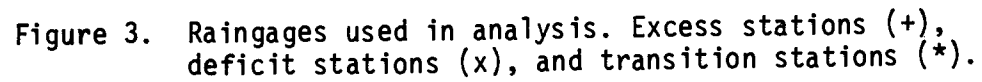Figure 2. Average annual precipitation for Arizona(mm) reproduced from USDA
1941 Yearbook, CLIMATE AND MAN.

STATE OF ARIZONA: LOCATION OF RAINGAGES

Figure 3. Raingages used in analysis. Excess stations (+),
deficit stations (x), and transition stations (*).

of above (excess) and below (deficit) average rainfall as plotted against elevation for winter, annual and summer periods (Figs. 4, 5, 6 and Appendix A).

The excess zone for winter precipitation is clearly defined (Fig. 4). All winter excess stations are located on the south slopes of the Mogollon Rim and other central Arizona ranges. Deficit stations are located north and northeast of the Mogollon Rim. Deficit and excess stations as defined by winter precipitation, are shown on all three maps.

The excess and deficit stations also stand out on the isohyetal map of annual precipitation, but not as clearly as for the winter precipitation (Fig. 5). The ranges in amounts between deficit and excess stations for the same elevations are considerably reduced for annual precipitation, suggesting less variation in summer than in winter precipitation. Also, for annual precipitation, quite a few transition stations could be considered excess stations.

Therefore, as expected, there is considerable overlapping of excess and transition stations in the plot of summer rainfall versus elevation (Fig. 6). About 10 transition stations plot above the best fit line for excess stations. Interestingly, all of these clearly excess stations are located in southeastern Arizona and have a southerly aspect.

Discussion

The relatively higher amounts of summer rainfall as opposed to winter precipitation in southeastern Arizona may be explained by the paths, quantity, and persistence of flows of moist air into Arizona (Fig. 1). Low-level moisture can flow into Arizona from the southwest at any time, depending on the relative position of a low pressure area or trough over California, and a corresponding high pressure ridge east of Arizona. In the winter, such conditions are not as common as in the summer and change more rapidly than in the summer. The exception is when a tropical storm is caught up in the counter clockwise flow around a California low. In these cases, there may be a strong flow of very moist tropical air into Arizona, and heavy rains can occur. However, even when the flow of moist air in the winter is persistent, the upper levels usually are relatively cold and dry. The upper level winter winds from the west tend to be cold and dry throughout the winter.

In the summer, persistent flows of moist low level air from the Pacific and moist high level air from the Gulf of Mexico can combine to provide Arizona with an excellent supply of moisture for rainfall. Higher afternoon air temperatures near the ground along with the broken topography add to the probability of significant thunderstorm rainfall. Southeastern Arizona may be best located for realizing the optimum summer rainfall conditions, and this may account for the increased amounts of summer rainfall respective to Central Arizona and the Mogollon Rim.
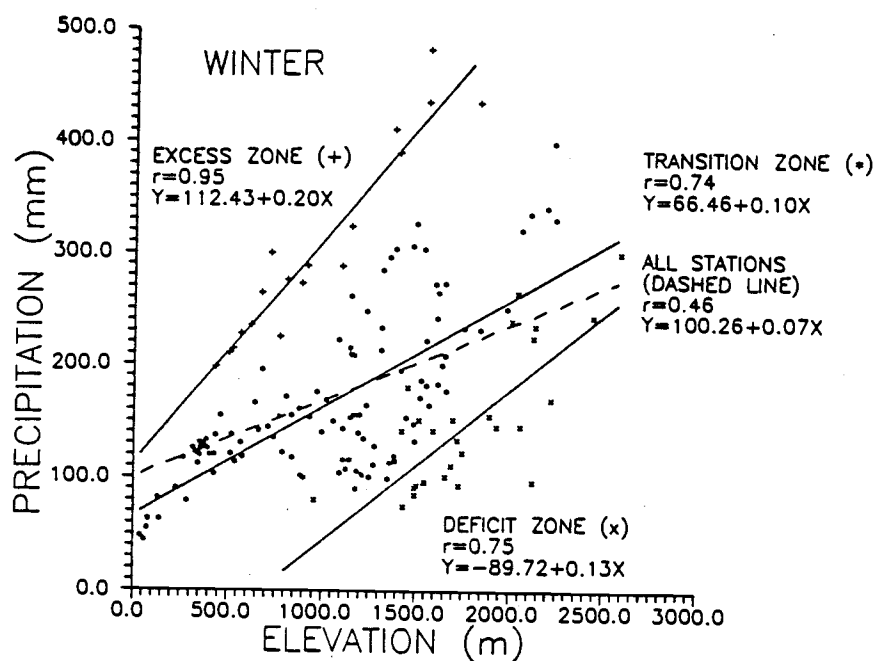
Figure 4. Arizona winter precipitation.
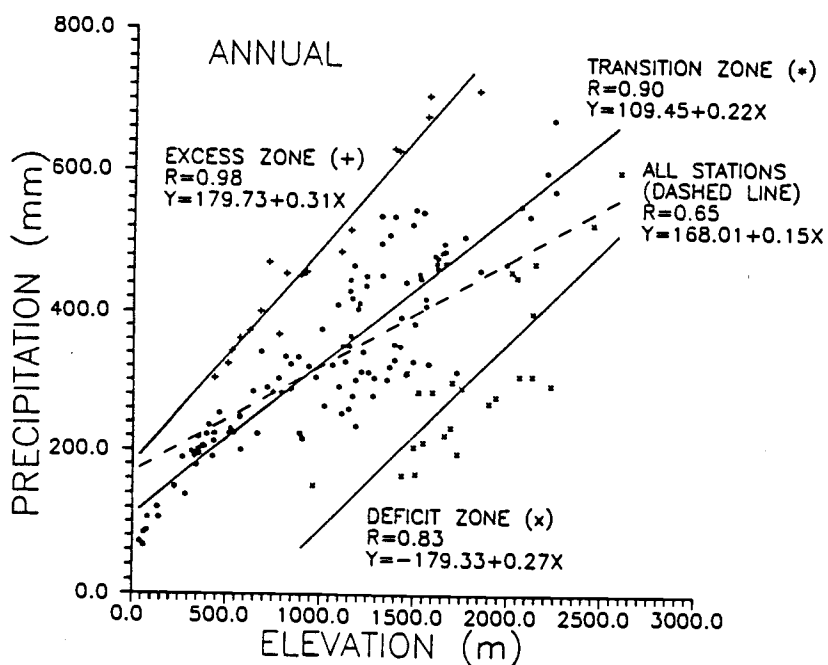
Figure 5. Arizona annual precipitation.
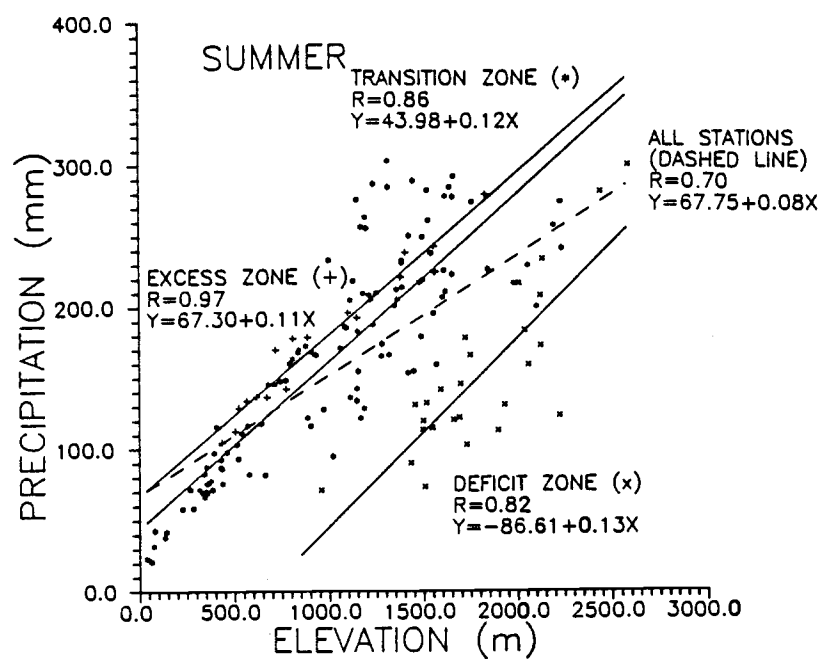
Figure 6. Arizona summer precipitation.

Conclusion

There are a wide range of precipitation amounts for the same elevations for both winter and summer rainfall. The Mogollon Rim and other central Arizona mountain ranges appear to be the dominant factor in establishing both excess and deficit zones for the winter months. Excess stations appear to be the result of aspect (southerly exposure) and orographic lifting, whereas the deficit stations are largely north of the Mogollon Rim in a rain shadow.

A combination of increased high level moist summer air and the relative proximity to both the Pacific Ocean and the Gulf of Mexico may explain why summer rainfall at many stations in southeastern Arizona for the same elevation exceeds summer rainfall along the Mogollon Rim.

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Appendix A: Location and data of climatological stations in Arizona with at least thirty years of record 1900-1982.

No.	Station Name	Period of Record	Longitude	Lati- tude	Elevat- ion (m)	Average Precipitation (mm)		
						Annual	Summer	Winter
1	Aguila	05/24-12/82	110.737	33.95	661.	222.76	81.79	140.97
2	Ajo	05/14-12/92	110.953	32.37	537.	224.23	111.00	113.23
3	Alpine	10/04-12/92	114.787	33.85	2444.	523.49	280.67	242.82
4	Anvil Ranch	07/48-12/82	112.537	31.98	939.	287.27	169.93	117.35
5	Apache Powder Company	07/23-12/92	113.653	31.70	1125.	326.39	218.44	107.95
6	Ash Fork	04/02-09/75	111.437	35.22	1567.	323.34	159.26	164.08
7	Bagdad	05/25-08/78	110.737	34.58	1143.	348.74	133.60	215.14
8	Bartlett Dam	09/39-12/92	112.237	33.82	503.	322.58	112.52	210.06
9	Benson	01/00-05/75	113.620	31.97	1090.	289.56	185.17	104.39
10	Betatakin	07/48-12/82	113.387	36.68	2221.	292.61	123.44	169.16
11	Bisbee	01/00-12/92	114.003	31.45	1658.	468.38	291.34	177.04
12	Black River Pumps	07/48-12/92	114.153	33.48	1841.	457.96	226.31	231.65
13	Blue	11/03-12/82	114.820	33.62	1756.	506.22	273.30	232.92
14	Bouse	01/52-12/82	109.903	33.95	283.	137.92	58.67	79.25
15	Bowie	01/00-12/82	114.437	32.33	1145.	258.57	142.49	116.08
16	Buckeye	01/00-12/82	111.337	33.37	265.	188.72	71.63	117.09
17	Canelo 1 NW	01/10-12/82	113.387	31.55	1519.	452.63	281.69	170.94
18	Casa Grande	01/00-12/82	112.170	32.88	428.	212.34	92.46	119.89
19	Casa Grande Ruins NM	03/06-12/82	112.387	33.00	433.	223.27	86.11	137.16
20	Cedar Glade	02/15-01/54	111.537	34.97	1417.	348.49	153.67	194.82
21	Chandler Heights	07/48-12/82	112.237	33.22	434.	212.09	75.69	136.40
22	Childs	09/15-12/82	112.220	34.35	808.	453.64	177.80	275.84
23	Chinle	12/08-11/70	114.387	36.15	1688.	233.17	122.17	111.00
24	Chino Valley	07/48-12/82	111.470	34.75	1448.	308.10	154.94	153.16
25	Chiricahua NM	01/09-12/82	114.570	32.00	1615.	460.50	277.37	183.13
26	Cibecue	06/27-01/79	113.470	34.05	1615.	475.49	210.82	264.67
27	Clifton	01/00-12/82	114.637	33.05	1056.	320.80	170.94	149.86
28	Cochise Power House	01/00-12/54	114.020	32.07	1274.	277.11	165.35	111.76
29	Cordes	07/48-12/82	111.753	34.30	1149.	363.73	154.43	209.30
30	Crown King	12/14-12/82	111.587	34.20	1829.	711.71	278.64	433.07
31	Deer Valley	01/50-12/82	111.837	33.58	383.	204.22	71.63	132.59
32	Douglas FAA Airport	07/48-12/62	114.320	31.45	1249.	310.64	210.06	100.58
33	Douglas Smelter	12/03-03/73	114.337	31.35	1211.	311.15	208.28	102.87
34	Duncan	05/01-12/82	114.820	32.73	1109.	251.97	136.14	115.82
35	Eagle Creek	01/28-07/73	114.437	33.40	1554.	406.91	225.04	181.96
36	Elgin 5 N	10/12-01/70	113.387	31.73	1494.	381.25	248.92	132.33
37	Fairbank 1 S	07/09-03/73	113.737	31.72	1177.	299.72	209.55	90.17
38	Flagstaff WSO Airport	01/50-12/82	112.253	35.20	2104.	535.18	200.66	334.52
39	Florence	09/08-12/82	112.537	33.03	459.	252.22	97.79	154.43
40	Fort Grant	01/00-09/74	114.070	32.62	1486.	326.64	179.07	147.57
41	Fort Huachuca	02/00-12/81	113.597	31.57	1422.	390.91	249.43	141.48
42	Fort Valley	01/09-12/82	112.197	35.27	2239.	570.74	241.05	329.69
43	Ganado	07/48-12/82	114.353	35.72	1932.	276.61	131.06	145.54
44	Gila Bend	01/00-12/82	111.203	32.95	225.	148.34	58.17	90.17
45	Gisela	01/16-12/92	112.637	34.12	864.	451.36	178.56	272.80
46	Globe	01/31-12/92	113.137	33.38	1082.	408.18	185.93	222.25
47	Gould's Ranch	01/15-08/60	111.353	33.38	351.	194.82	75.67	119.13
48	Grand Canyon HDQRS	09/03-08/67	111.903	36.05	2123.	396.75	172.72	224.03
49	Granite Reef Dam	01/00-09/79	112.220	33.52	404.	235.46	115.82	119.63

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50	Greer	07/48-12/82	114.453	34.02	2598.	598.42	292.70	299.72
51	Griggs 3 W	01/50-12/82	111.437	33.50	354.	193.80	69.09	124.71
52	Heber Ranger Station	08/50-12/82	113.370	34.40	2009.	456.18	216.92	239.27
53	Helvetia Santa Rita Es	06/16-04/50	113.070	31.77	1311.	496.57	283.46	213.11
54	Holbrook	01/00-12/82	113.753	34.90	1545.	211.33	114.81	96.52
55	Horseshoe Dam	07/48-12/82	112.203	33.98	616.	372.11	136.91	235.20
56	Intake	07/06-04/52	112.987	33.62	677.	340.87	145.54	195.33
57	Irving	01/51-12/82	112.303	34.40	1147.	515.11	192.28	322.83
58	Jerome	01/00-12/82	111.803	34.75	1599.	479.04	206.76	272.29
59	Junipine	07/48-06/82	112.170	34.97	1562.	704.34	224.54	479.81
60	Kayenta	06/15-03/78	113.653	36.73	1727.	195.83	102.36	93.47
61	Keams Canyon	08/48-12/82	113.720	35.82	1894.	267.72	113.03	154.69
62	Kelvin	07/48-12/82	112.953	33.10	564.	360.93	133.86	227.08
63	Kingman	05/01-07/67	109.870	35.18	1017.	263.14	94.74	168.40
64	Laveen 3 SSE	07/48-12/82	111.770	33.33	340.	195.07	82.80	112.27
65	Lees Ferry	04/16-12/82	112.337	36.87	957.	150.88	70.87	80.01
66	Leslie Canyon	05/16-01/60	114.353	31.58	1360.	318.77	205.23	113.54
67	Leupp	07/48-04/81	112.953	35.28	1433.	164.59	89.92	74.68
68	Litchfield Park	08/17-12/82	111.553	33.50	314.	197.10	71.37	125.73
69	Maricopa 8 SSE	01/00-12/58	111.820	32.92	427.	189.74	86.87	102.87
70	Marinette	07/13-09/64	111.620	33.63	349.	200.41	70.10	130.30
71	McNary	08/33-12/82	114.070	34.07	2231.	670.81	273.56	397.26
72	Mesa Experiment Farm	01/00-12/82	112.053	33.42	373.	206.50	77.72	128.78
73	Miami	02/14-12/82	113.037	33.40	1098.	484.38	196.09	288.29
74	Mohawk	07/00-05/51	110.387	32.80	138.	105.41	42.16	63.25
75	Montezuma Castle NM	10/38-12/82	112.087	34.62	969.	303.53	127.76	175.77
76	Mormon Flat	08/23-11/82	112.470	33.55	523.	342.65	128.78	213.87
77	Mount Trumbull	10/19-12/77	110.587	36.42	1695.	296.93	145.54	151.38
78	Natural Bridge	01/00-11/72	112.470	34.32	1404.	626.62	238.25	388.37
79	N Lazy H Ranch	07/48-12/82	113.237	32.12	930.	319.53	166.12	153.42
80	Nogales-Post June '48	07/48-12/82	113.003	31.35	1158.	417.32	265.18	152.15
81	Nogales-Thru June '48	01/00-06/48	112.970	31.33	1189.	402.34	262.64	139.70
82	Nogales 6 N	10/52-12/82	112.987	31.35	1145.	427.99	275.08	152.91
83	Oracle	01/00-03/49	113.203	32.57	1356.	508.00	212.09	295.91
84	Oracle 2 SE	02/50-12/82	113.187	32.60	1384.	534.16	230.89	303.28
85	Organ Pipe Cactus NM	07/48-12/82	111.137	31.93	511.	224.03	103.12	120.90
86	Paradise	01/06-08/37	114.703	31.93	1654.	485.14	276.61	208.53
87	Parker	02/00-12/82	109.637	34.17	130.	119.89	38.35	81.53
88	Patagonia	07/21-12/77	113.170	31.55	1233.	449.58	286.00	163.58
89	Payson RS	03/09-02/74	112.587	34.23	1478.	523.24	217.42	305.82
90	Payson	11/40-12/82	112.587	34.23	1497.	544.32	219.20	325.12
91	Peach Springs	07/48-11/82	110.520	35.55	1515.	282.96	132.08	150.88
92	Pearce	03/50-09/80	114.103	31.90	1347.	300.23	200.91	99.31
93	Petrified Forest NP	07/48-12/82	114.053	34.80	1658.	221.74	120.40	101.35
94	Phoenix WSFO Airport	07/48-12/82	111.903	33.43	340.	178.05	66.55	111.51
95	Phoenix City	07/48-12/82	111.853	33.45	330.	190.50	69.09	121.41
96	Pinal Ranch	01/00-05/73	112.937	33.35	1378.	629.92	220.98	408.94
97	Pinedale	06/12-12/68	113.670	34.30	1981.	467.36	216.92	250.44
98	Pinetop Fish Hatchery	07/48-12/82	114.003	34.12	2195.	596.90	257.05	339.85
99	Portal	01/14-03/55	114.753	31.90	1524.	446.53	260.10	186.44
100	Prescott	01/00-12/82	111.470	34.55	1649.	495.81	222.76	273.05
101	Redington	07/48-12/82	113.437	32.60	874.	332.99	172.47	160.53
102	Red Rock 6 SSW	07/08-10/73	112.553	32.50	567.	246.89	116.59	130.30
103	Reno Ranger Station	11/15-04/73	112.603	33.87	715.	469.39	169.67	299.72
104	Roosevelt 1 WNW	07/05-12/82	112.770	33.67	672.	399.30	136.40	263.40

105	Ruby Star Ranch	02/50-12/82	112.612	31.92	1109.	348.74	204.93	143.76
106	Rucker Canyon	05/17-12/82	114.503	31.75	1637.	483.36	283.46	199.90
107	Sabino Canyon	07/48-09/82	113.103	32.30	805.	334.01	163.32	170.69
108	Sacaton	04/08-10/82	112.170	33.07	392.	222.25	97.28	124.97
109	Safford	01/00-06/73	114.203	32.93	684.	224.03	122.17	101.85
110	Safford Exp Farm	08/48-12/82	114.237	32.82	900.	215.90	116.08	99.82
111	Saint Johns	08/01-12/82	114.553	34.50	1747.	288.80	166.12	122.68
112	Salome 6 SE	01/03-04/57	110.320	33.78	576.	200.41	82.30	118.11
113	San Carlos Reservoir	07/48-12/82	113.403	33.17	772.	366.27	141.99	224.28
114	San Rafael Ranch	07/23-03/68	113.303	31.35	1445.	440.69	288.04	152.65
115	San Simon	01/00-07/62	114.570	32.27	1183.	234.70	128.52	106.17
116	Santa Margarita	06/17-11/50	112.337	31.68	1196.	410.72	255.02	155.70
117	Santa Rita Exp Range	05/50-11/82	113.070	31.77	1311.	534.92	302.01	232.92
118	Sasabe 7 NW	12/50-12/82	112.320	31.58	1166.	464.57	256.03	208.53
119	Sedona RS	07/48-12/82	112.153	34.87	1317.	450.60	166.12	284.48
120	Seligman	12/04-12/82	111.037	35.32	1591.	282.96	141.48	141.48
121	Sierra Ancha	11/13-09/79	112.953	33.80	1554.	675.64	242.32	433.32
122	Silver Bell	02/06-04/74	112.420	32.38	835.	322.58	167.89	154.69
123	Snowflake	01/00-12/82	113.837	34.50	1720.	311.40	178.05	133.35
124	Springerville	04/11-12/82	114.637	34.13	2123.	305.56	208.53	97.03
125	Stephens Ranch	12/28-03/82	114.720	31.40	1219.	339.85	205.23	134.62
126	Stewart Mountain	07/48-12/82	112.387	33.57	433.	302.26	104.65	197.61
127	Superior	07/20-12/82	112.820	33.30	913.	455.93	167.39	288.54
128	Sycamore RS	07/19-12/59	111.970	34.35	1231.	435.61	187.45	248.16
129	Tempe Veg Res Farm	01/26-12/82	111.987	33.38	360.	201.93	75.95	125.98
130	Tempe	01/05-06/52	111.987	33.43	351.	217.93	87.63	130.30
131	Tombstone	07/00-12/82	113.853	31.72	1384.	351.79	232.41	119.38
132	Truxton Canyon	07/48-03/80	110.253	35.38	1164.	277.11	121.67	155.45
133	Tuba City	01/00-12/75	112.670	36.13	1504.	166.88	73.41	93.47
134	Tucson Campbell Farm	02/49-12/82	112.970	32.28	710.	289.56	145.54	144.02
135	Tucson Magnetic Obsy	07/48-12/82	113.087	32.25	770.	301.75	148.34	153.42
136	Tucson Univ of Ariz	01/00-12/82	112.970	32.25	741.	282.70	147.57	135.13
137	Tucson WSO Airport	07/48-12/82	112.987	32.12	788.	281.69	160.02	121.67
138	Tumacacori NM	07/48-12/82	112.870	31.57	996.	373.13	232.92	140.21
139	Tuweep	07/48-12/82	110.853	36.28	1455.	310.39	130.81	179.58
140	Wallace RS	05/16-04/59	113.003	34.53	2135.	468.12	233.68	234.44
141	Walnut Canyon NM	10/50-12/82	112.403	35.17	2038.	448.06	183.64	264.41
142	Walnut Creek	12/15-12/82	111.103	34.93	1551.	417.07	195.33	221.74
143	Walnut Grove	01/00-12/82	111.370	34.30	1147.	444.25	182.63	261.62
144	Wellton	03/22-12/80	109.787	32.67	79.	105.66	42.93	62.74
145	Whiteriver	02/00-12/82	113.953	33.83	1609.	467.87	225.81	242.06
146	Wickenburg	03/08-12/82	111.187	33.97	639.	283.21	118.11	165.10
147	Willcox	01/00-12/82	114.070	32.30	1277.	302.01	173.74	128.27
148	Williams	07/02-12/82	111.737	35.25	2057.	549.40	229.36	320.04
149	Window Rock 4 SW	03/37-12/82	114.870	35.68	2057.	305.31	159.51	145.80
150	Winslow WSO Airport	01/00-12/82	113.187	35.02	1492.	204.98	113.54	91.44
151	Wittman	12/23-11/66	111.387	33.55	518.	230.38	93.22	137.16
152	Wupatki NM	07/48-12/82	112.553	35.52	1496.	204.47	119.38	85.09
153	Y Lightning Ranch	01/39-12/82	113.720	31.45	1387.	329.93	213.87	115.05
154	Young	07/03-09/64	112.987	34.10	1539.	540.26	237.49	302.77
155	Yuma Citrus Station	09/20-12/82	109.270	32.62	58.	93.82	30.23	53.59
156	Yuma Valley	11/30-12/82	109.203	32.72	37.	71.37	23.37	48.01
157	Yuma WSO Airport	09/48-12/82	109.320	32.67	59.	65.79	21.34	44.45
158	Yuma	01/00-04/74	109.303	32.73	73.	67.12	32.26	54.86

MAPPING THE AREAL PRECIPITATION OVER ARIZONA -
USING KRIGING TECHNIQUE

Arnon Karnieli
U.S. Department of Agriculture, Agricultural Research Service
2000 East Allen Road, Tucson, Arizona   85719
and
University of Arizona, Water Resources Research Center

Abstract

The classical methods for interpolating and spatial averaging of precipitation fields fail to quantify the accuracy of the estimate. On the other hand, kriging is an interpolation method for predicting values of regionalized variables at points (punctual kriging) or average values over an area (block kriging).

This paper demonstrates the use of the kriging method for mapping and evaluating precipitation data for the state of Arizona. Using 158 rain gage stations with 30 years or more of record, the precipitation over the state has been modeled as a realization of a two dimensional random field taking into consideration the spatial variability conditions.

Three data sets have been used: (1) the mean annual precipitation over the state; (2) the mean summer rainy season; and (3) the mean winter rainy season. Validation of the empirical semi-variogram for a constant drift case indicated that the exponential model was appropriate for all the data sets. In addition to a global kriging analysis, the data have been examined under an anisotropic assumption which reflects the topographic structure of the state.

Introduction

Several interpolation techniques such as arithmetic mean, linear interpolation or the nearest neighbor (Thiessen Weight) method, have been widely used for areal mapping of precipitation fields (Hall and Barclay, 1975). Other techniques have been reviewed by Creutin and Obled (1982). A relatively new technique is presented and evaluated in this paper referred to as kriging (after D. G. Krige). This technique was originally developed for geoscience applications. It has been

applied recently in a few cases to the mapping of precipitation fields (Delfiner and Delhomme, 1975; Montmollin et al., 1980; Chua and Bras, 1982; Bastin et al., 1984; Obley and Creutin, 1986).

Matheron (1971) coined the term "regionalized variable" to describe variables which can be characterized from a certain number of measurements which identify spatial structure. The optimal estimator (in the current case for the average areal precipitation) is a linear minimum variance unbiased estimator which requires knowledge of the variogram of the random variable (precipitation) as a function of space. Therefore a theoretical variogram model must be chosen and its parameters have to be estimated prior to the interpolation.

The kriging technique, which was adapted from various resources (Delfiner and Delhomme, 1975; Journel and Huijbregts, 1978; Delhomme, 1978), is briefly introduced below.

Theoretical Background

Let x_1, x_2,...,x_n be the sample locations with given precipitation values of $Z(x_1)$, $Z(x_2)$,...,$Z(x_n)$ and x_0 is the unsampled location. Then the value of precipitation in the unsampled location, $Z(x_0)$, is estimated as a linear weighted combination of n known surrounding data, depending on distance from the unsampled location:

$$Z^* \left(x_0 \right) = \sum_{i=1}^{N} \lambda_1 \, Z \left(x_i \right) \qquad \qquad i = 1...n \qquad (1)$$

where the weights λ_i are determined such that $Z^*(x_0)$ is an unbiased estimate of $Z(x_0)$:

$$E \left[Z^* \left(x_0 \right) - Z \left(x_0 \right) \right] = 0 \qquad (2)$$

and the estimation variance is minimum:

$$E \left[Z^* \left(x_0 \right) - Z \left(x_0 \right) \right]^2 \qquad \qquad \text{minimum} \qquad (3)$$

where $E[\cdot]$ is the expectation. Substituting equation (1) into equations (2) and (3) yields:

$$E \left[\sum_{i=1}^{N} \lambda_i \, Z \left(x_i \right) - Z \left(x_0 \right) \right] = 0 \qquad (4)$$

$$E \left[\sum_{i=1}^{N} \lambda_i \ Z\left(x_i\right) - Z\left(x_0\right) \right]^2 \qquad \text{minimum} \qquad (5)$$

which leads to the following system:

$$\sum_{i=1}^{N} \lambda_i \ C\left(x_i, \ x_j\right) + \mu = C\left(x_0, \ x_j\right) \qquad \sum_{i=1}^{N} \lambda_i = 1 \qquad (6)$$

where $C(x_i)$, $Z(x_i) = E[Z(x_i, \ x_i)]$ is the covariance and μ is a Lagrange multiplier which was employed to obtain the weights.

In the kriging system the estimation variance is written in terms of differences between two sample locations. The minimization yields the replacement of $C(x_i, \ x_j)$ by $\nu(x_i, \ x_j)$:

$$\sum_{i=1}^{N} \lambda_i \ \nu\left(x_i, \ x_j\right) + \mu = \nu\left(x_0, \ x_j\right) \qquad \forall j \qquad (7a)$$

$$\sum_{i=1}^{N} \lambda_i = 1 \qquad (7b)$$

which yields the semi-variogram equations:

$$\nu(h) = \frac{1}{2} E \left[\left(Z \ (x + h) - Z(x) \right)^2 \right] \qquad (8a)$$

or:

$$\nu(h) = \frac{1}{2} \text{var} \left[Z \ (x + h) - Z(x) \right] \qquad (8b)$$

where $\nu(h)$ is the semi-variogram function, h is the distance between sample locations (also called the lag) and var($\cdot$) is the variance. The semi-variogram $\nu(h)$ is a graph which relates the differences or increments of the regionalized variable Z to the distance h between the data points. When there is a trend or drift in the data set, the residuals, R(x), are used in Eq. 8 instead of the realizations, Z(x), to estimate the semi-variogram. An empirical semi-variogram, ν_e, can be calculated from the given set of observations by using the following numerical approximation:

$$\nu_e = 1/ \left[2N\left(h_e\right) \right] \sum_{i=1}^{N} \left(Z \ \left(x_i + h\right) - Z\left(x_i\right) \right)^2 \qquad (9)$$

where $N(h_e)$ is the number of pairs of points a distance h_e apart (Olea, 1975).

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In order to solve Eq. 7, one of several common theoretical forms of Eq. 8 must be used in order to visually fit ν to ν_e (Delhomme, 1979). Once the theoretical semi-variogram has been chosen, four criteria can be used to determine the correctness of the model and to adjust its parameters:

(1) mean kriged estimation error:

$$1/n \sum_{i=1}^{n} \left[Z(x_i) - Z^*(x_i) \right] = 1/n \sum_{i=1}^{n} \epsilon_i \approx 0 \qquad (10)$$

where ϵ_i is the difference between the kriged and the known point value (this term should approach 0).

(2) mean standardized squared estimation error:

$$1/n \sum_{i=1}^{n} \left[\left\{ Z(x_i) - Z^*(x_i) \right\} / s_i^* \right]^2 = 1/n \sum_{i=1}^{n} \left[\epsilon_i / s_i \right]^2 \approx 1 \qquad (11)$$

where s_i^* is the estimation standard deviation (this term should approach 1).

(3) sample correlation coefficient between the estimation values, Z^*, and the standardized estimation values, $(Z - Z^*)/s^*$.

This term should approach 0.

(4) sample correlation coefficient between the estimation values, Z^*, and the known values, Z (this term should approach 1).

Data Collection

Annual average, summer and winter averages of rainfall depth over the state of Arizona has been adapted from Sellers et al. (1985). The summer rainy season includes the months of May to September and the winter rainy season includes the months of October to April.

Each of the three data sets are based on 158 rain gage stations having more than 30 years of record. This reduces the time variability of the precipitation record which is assumed to be very large in Arizona.

Figure 1 illustrates the location and the spatial distribution of the 158 raingage stations over the state.
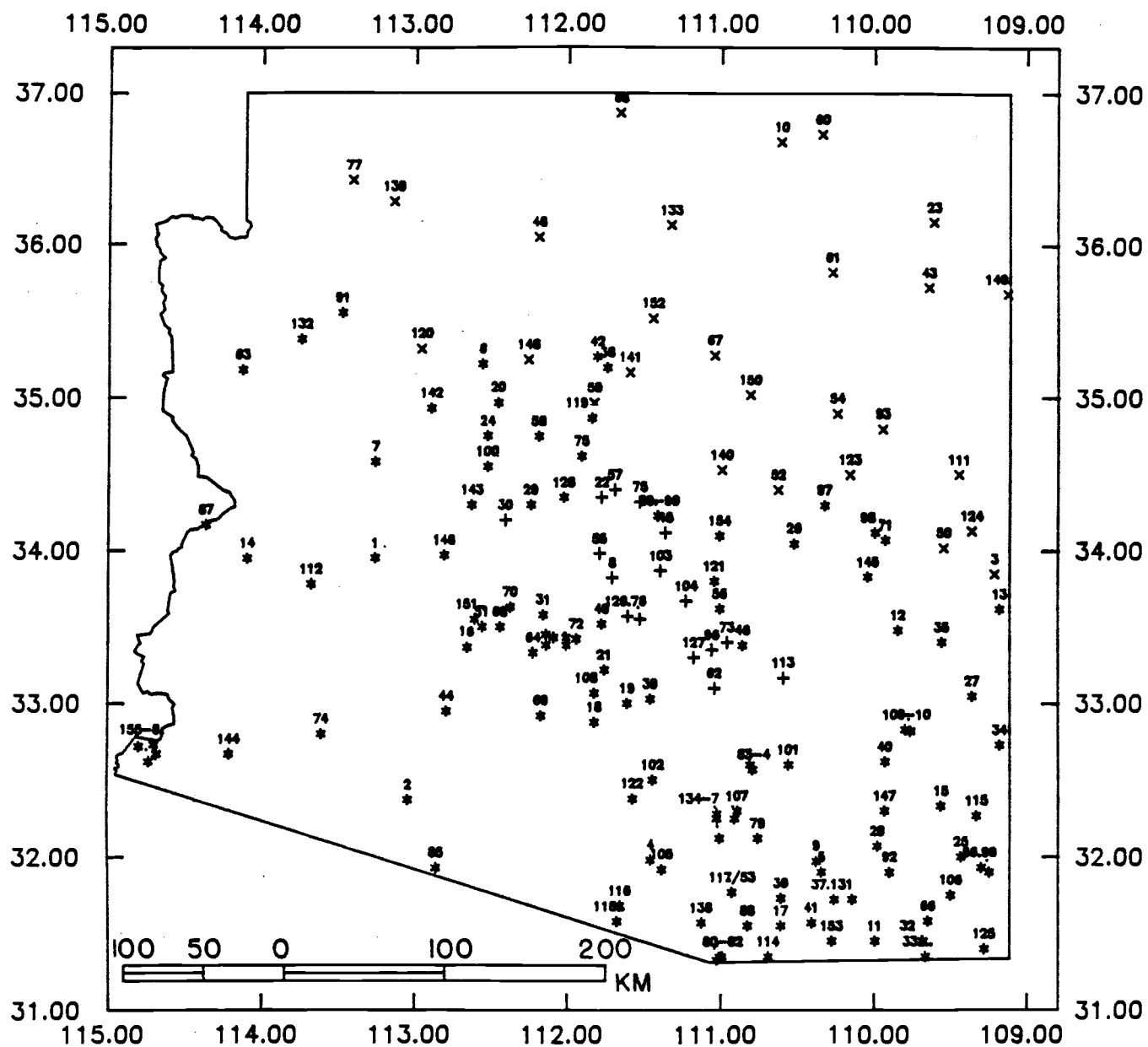
Figure 1: The State of Arizona - location of raingages.

Methods

All the variogram and kriging calculations under were computed by using the BLUEPACK-3D software package implemented on a VAX 11/780 at the University of Arizona Computer Center. The BLUEPACK-3D is an integrated geostatistic program, written in FORTRAN, which was developed jointly by the Center de Geostatistique - Fontainebleau, France and the BRGM (French Geological Survey).

The variograms were fitted and plotted using VPLOT - a graphic package developed for the IBM-PC by D. E. Myers and G. J. Jalkanen, the University of Arizona, Tucson. The kriging maps have been produced by SURFER - a graphic computer package for two or three dimensional plotting.

Structural Analysis and Results

The first step in the kriging analysis was to establish the semi-variograms. The empirical variograms for all three cases (annual, summer and winter) are shown in Figure 2. Each plot includes the variogram for the four principal directions of the grid (North-South; East-West; NE-SW; and NW-SE) and the Onmi direction which is the average of the former four. For an isotropic phenomenon it is assumed that the varigram is not a function of the angle of the direction between the data points. As a result, the theoretical semi-variogram, assuming isotropy, is calculated only on the Onmi direction. From these plots the absence of detectable nugget variance can be recognized. All four semi-variograms start from the origin.

Eq. 9 was used to calculate the isotropic empirical semi-variogram for a constant drift case. Few theoretical models (Delhomme, 1978) have been examined. The final model was chosen as a result of the cross validation procedure. The exponential and the spherical models produce about the same results. All three empirical variograms were fitted with an exponential model of the form:

$$\nu(h) = C_0 + C_1 \left[1 - \exp\left(-|h|/a\right)\right] \tag{12}$$

where a is the range, h is the lag, C_0 is the nugget variance and $C_0 + C_1$ equals the sill. The fitted exponential models are illustrated in Figure 3 and the value of the parameters together with the cross validation results are presented in Table 1.

In the next step the kriging interpolation for the maps was performed. Figures 4, 5 and 6 show the final product of the analysis as isohyetal maps. One can find these maps very similar to other average precipitation maps of Arizona (e.g. the map in Sellers et al., 1985). However, the advantage of the proposed kriging technique is in its by product.
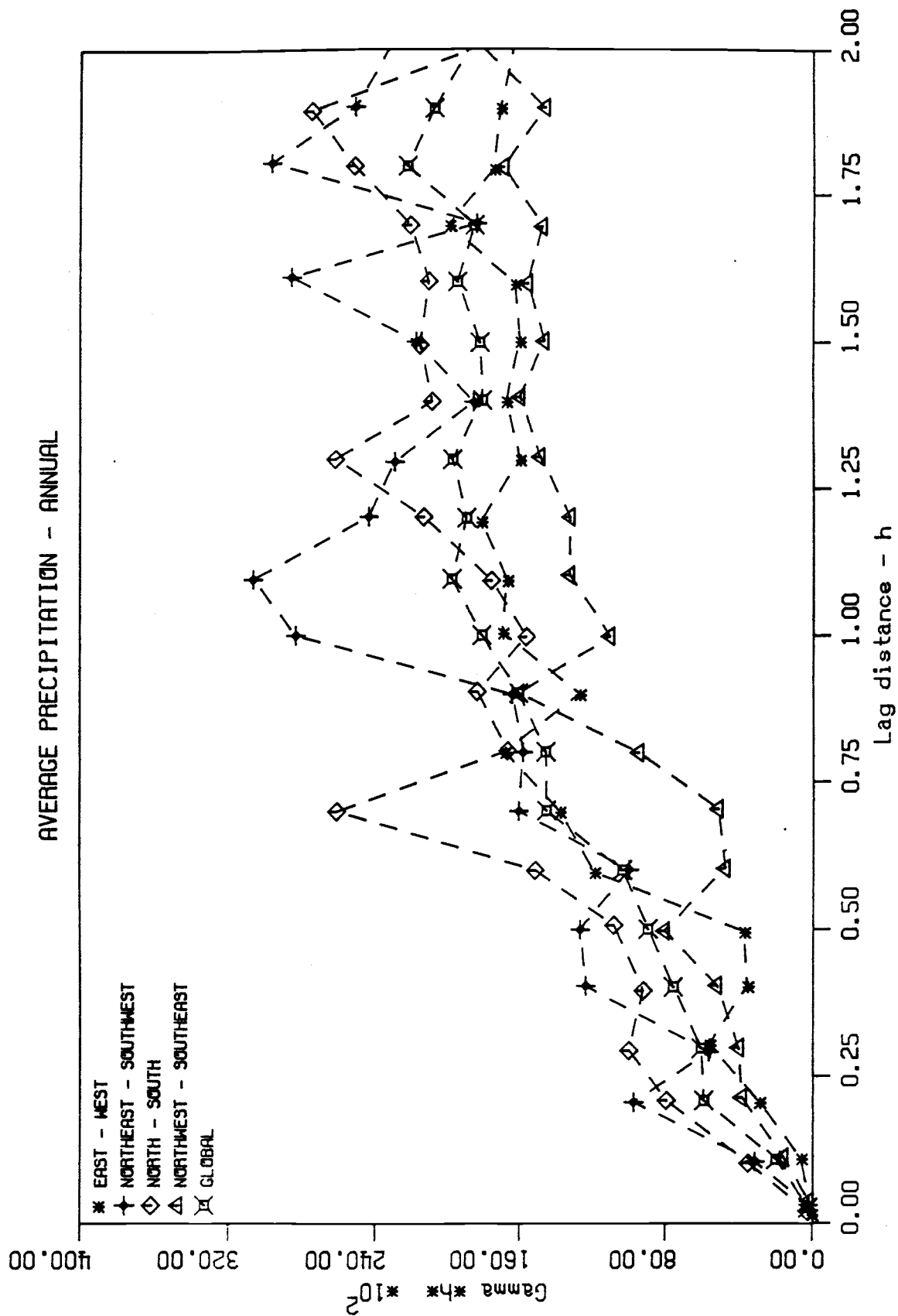
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Figure 2.1: Empirical semi-variogram of the average precipitation depth for the four principle directions and global – annual.
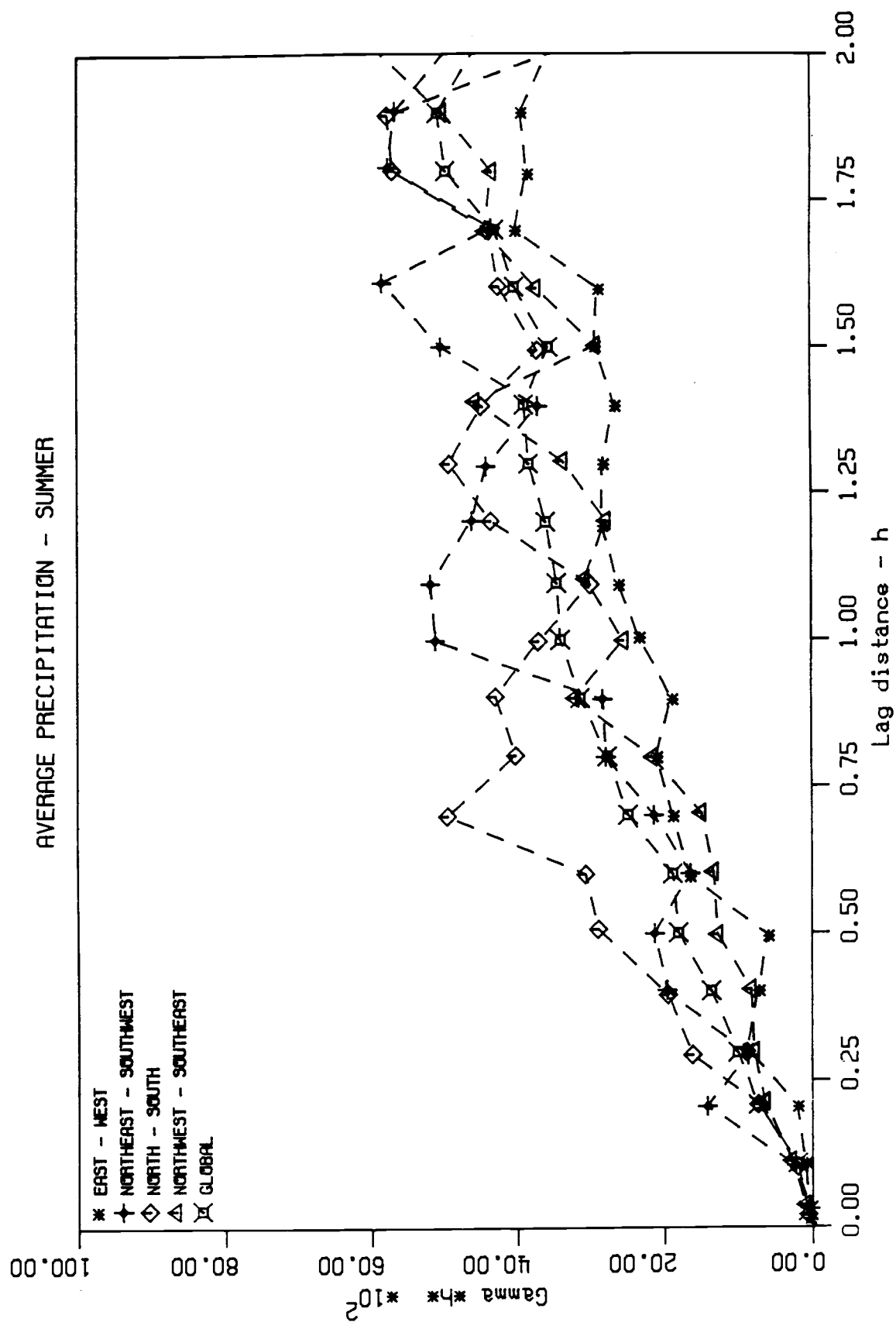
25

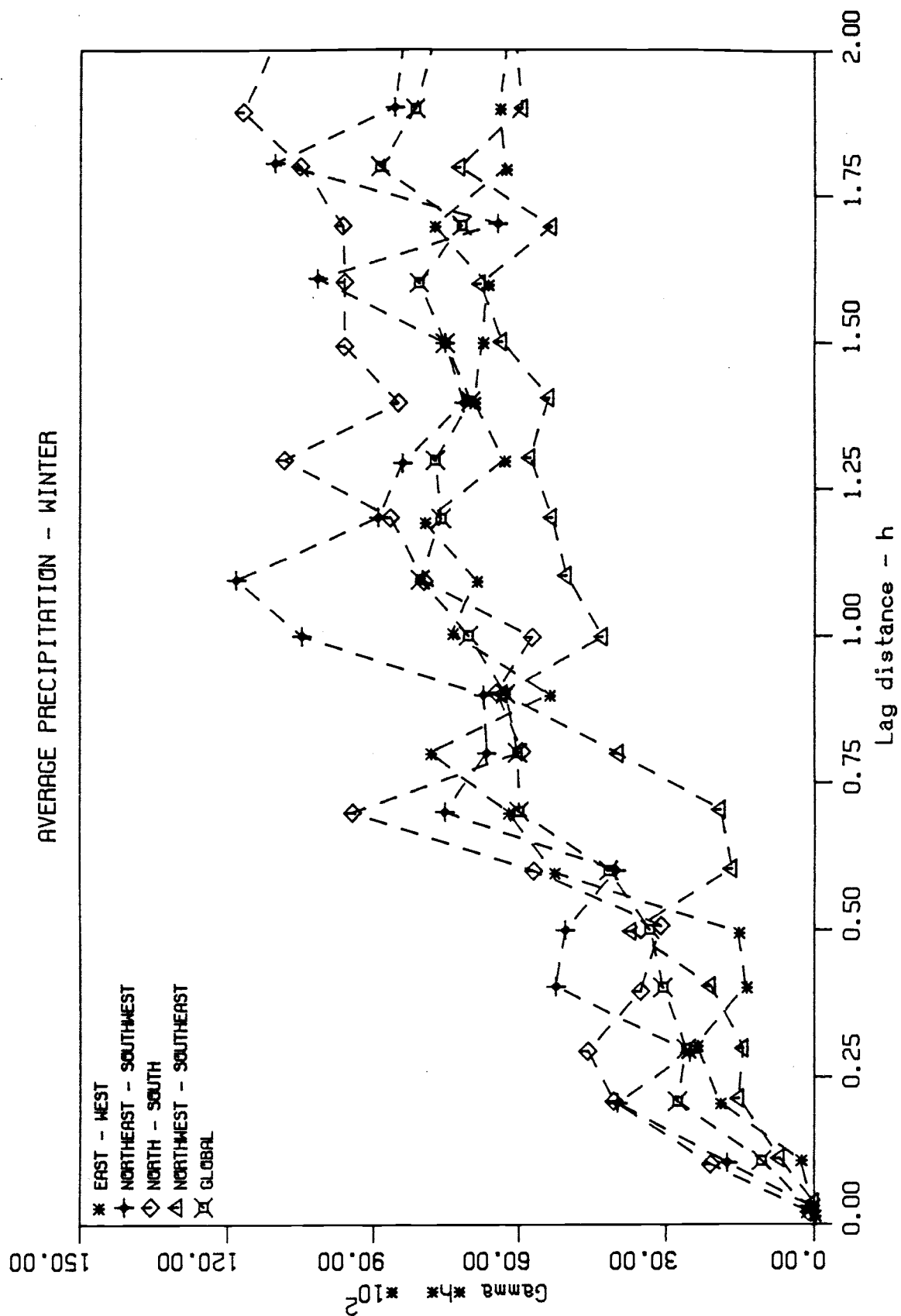Figure 2b: Empirical semi-varigram of the average precipitation depth for the four principle directions and global – summer,

Figure 2c: Empirical semi-variogram of the average precipitation depth for the four principle directions and global - winter.
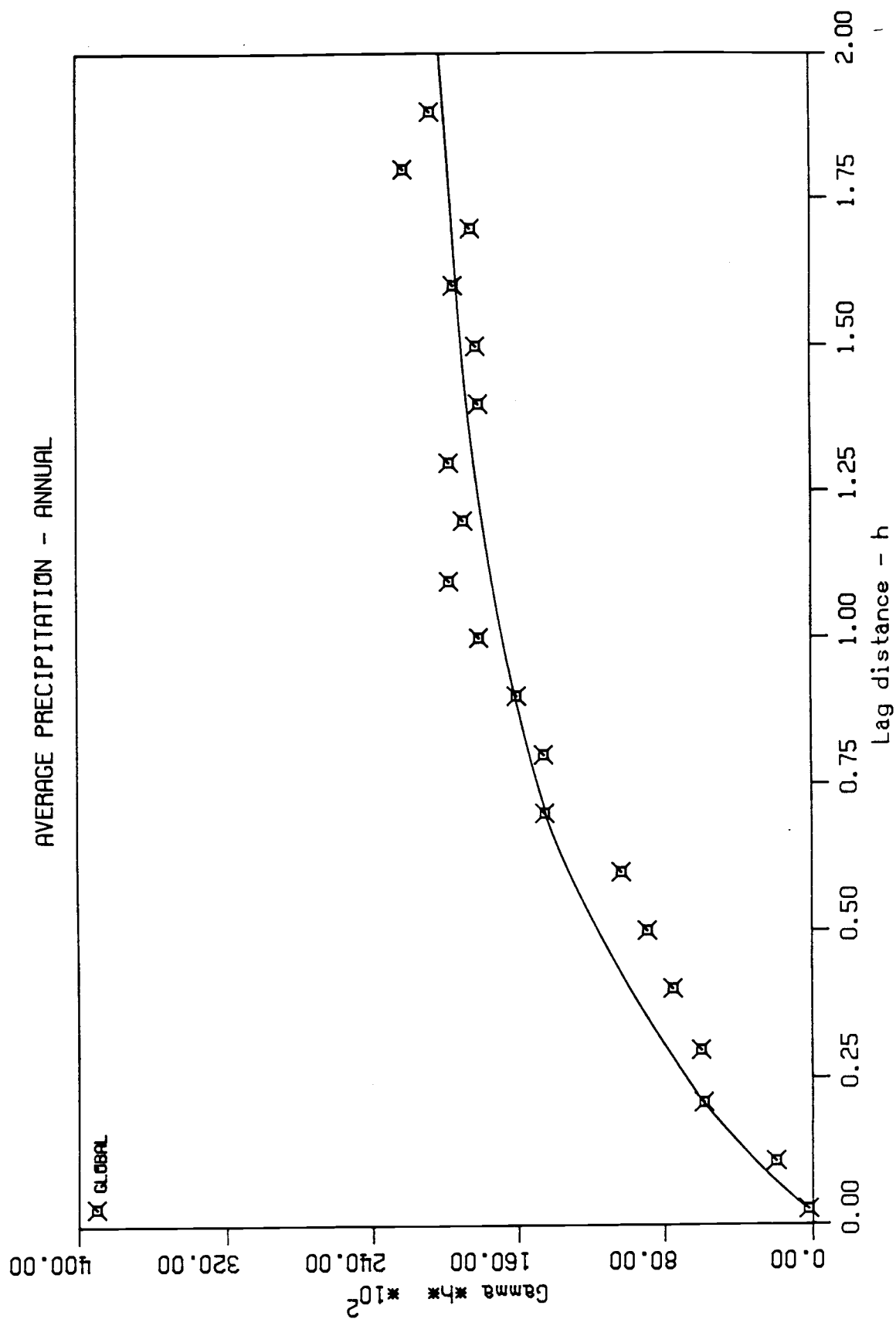
AVERAGE PRECIPITATION – ANNUAL

Gamma *h* *10²

Lag distance – h

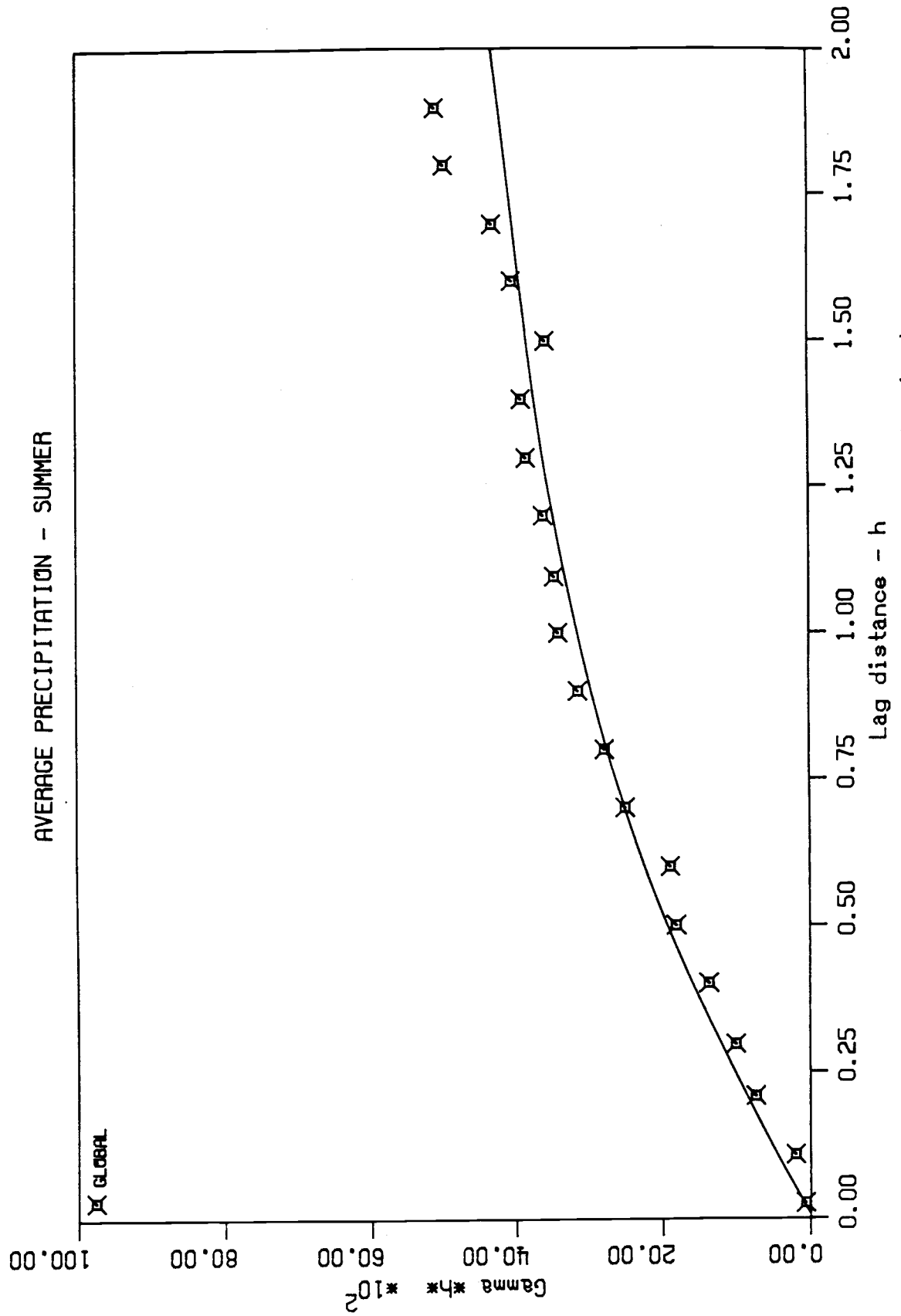. . . . . model of average precipitation depth – annual.

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Figure 3b: Semi-variogram with exponential model of average precipitation depth – summer.
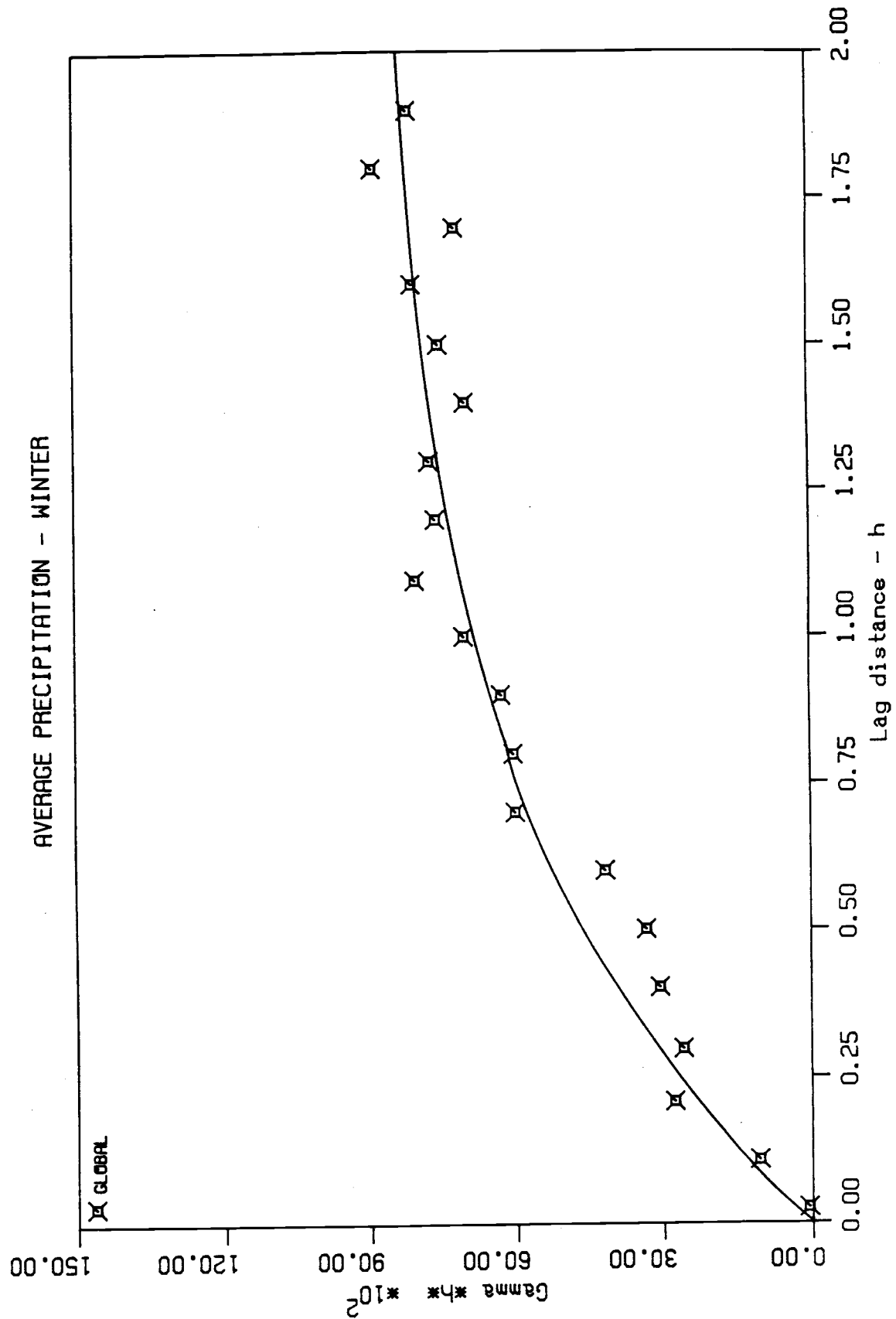
Figure 3c: Semi-variogram with exponential model of average precipitation depth - winter.
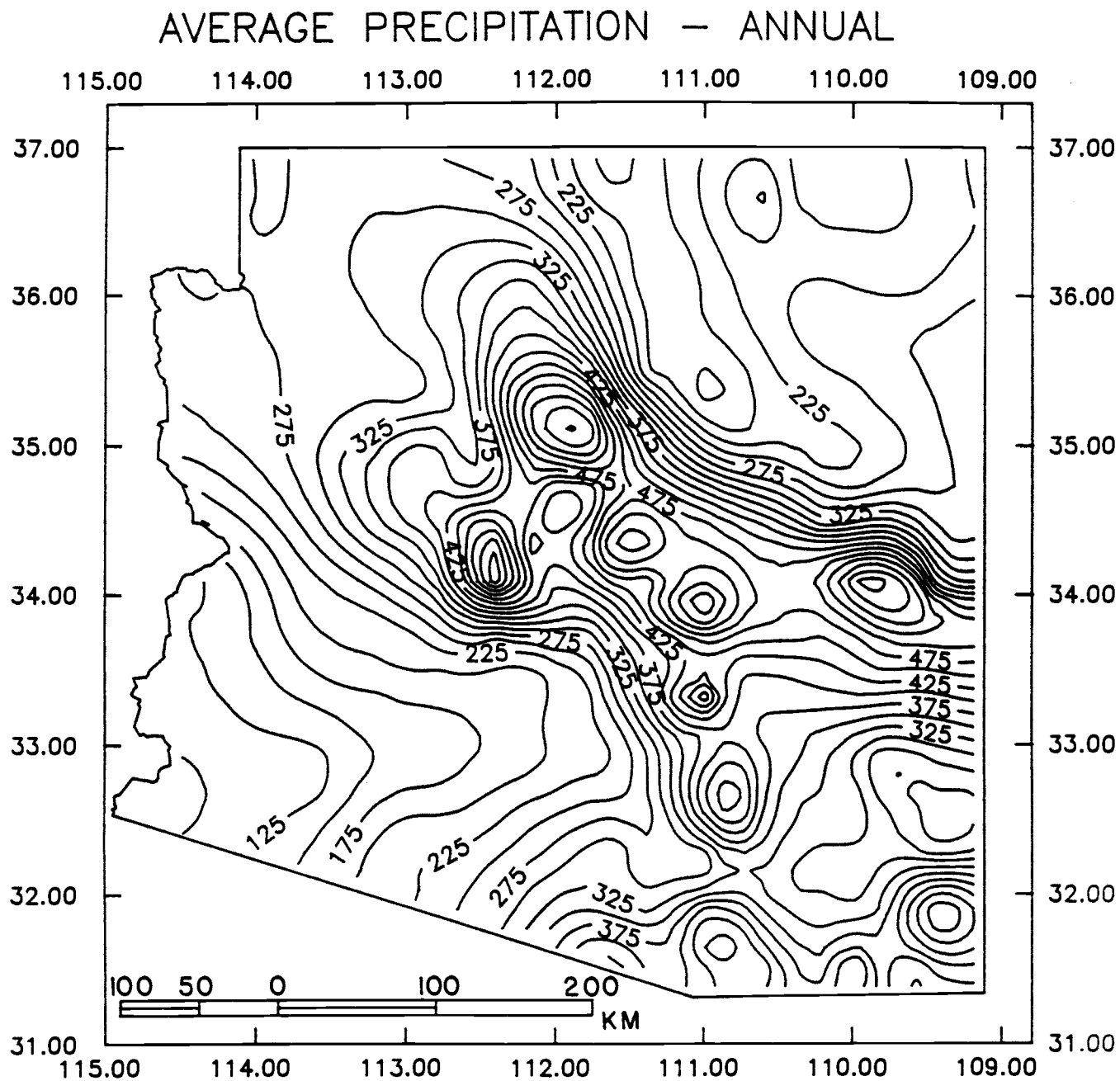
Figure 4: Isohyetal map of the annual average precipitation depth of Arizona produced by kriging technique.

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AVERAGE PRECIPITATION — SUMMER

Figure 5: Isohyetal map of the summer average precipitation depth of Arizona produced by kriging technique.

AVERAGE PRECIPITATION — WINTER

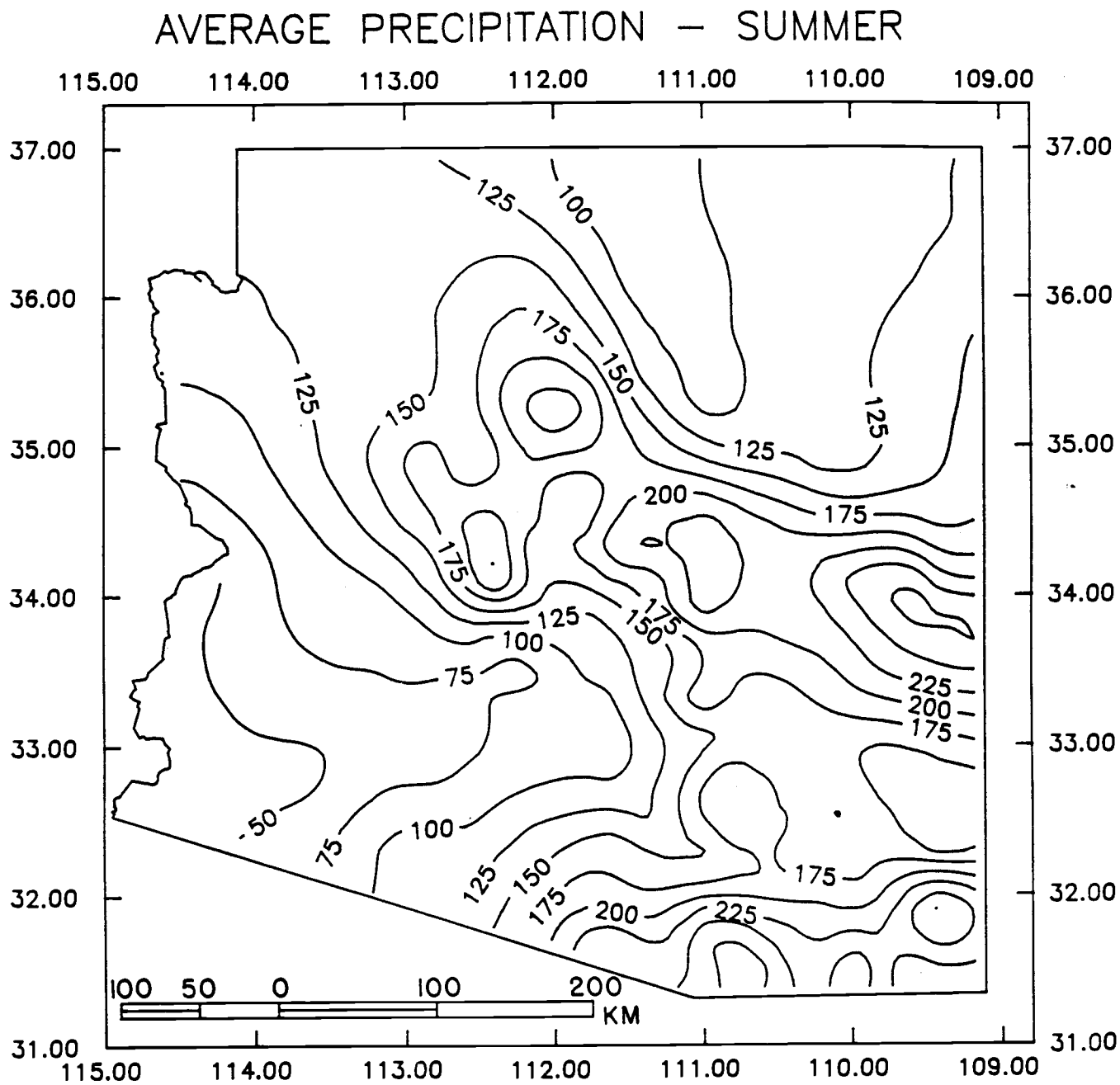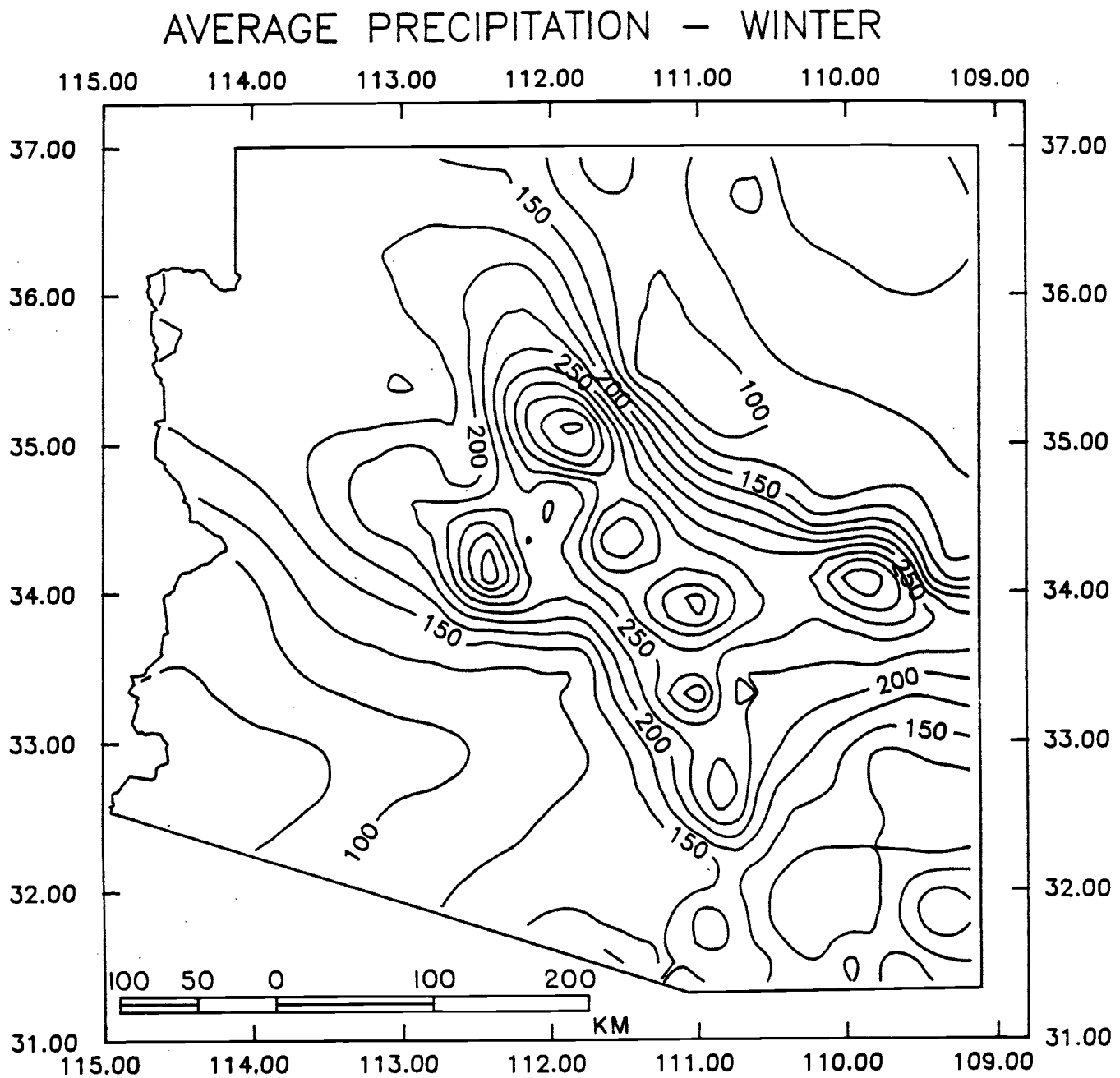Figure 6: Isohyetal map of the winter average precipitation depth of Arizona produced by kriging technique.

TABLE 1: Parameters and cross validation results for exponential model
semi-variogram fitting.

| | MODEL PARAMETERS | | | | CROSS VALIDATION RESULTS | | | |
	NUGGET	RANGE	SILL	LAG	1	2	3	4
ANNUAL	0.0	0.8	0.18E5	0.1	0.02	0.61	0.03	0.84
SUMMER	0.0	1.0	0.50E4	0.1	0.01	0.76	0.08	0.91
WINTER	0.0	0.7	0.90E4	0.1	0.02	0.47	0.05	0.81

1 - mean kriged estimation error.
2 - mean standarized squared estimation error.
3 - correlation coefficient between the estimation values and the
    standarized estimation values.
4 - correlation coefficient between the estimation values and the known
    values.

Figure 7 presents the associated kriging errors map in terms of
kriging variance. The kriging errors are a function of the sample site
density and depend only on the geometrical location of the measured
points. Errors are common when using an irregular grid such as rainfall
gage stations and are a good measure of the precision of the
interpolation (Delhomme, 1978). In this study the kriging variance is
generally greater than 50 and less than 125. It can be seen that the
kriged map is relatively precise in the middle of the state, however the
errors become greater towards the edges of the map specially towards the
north-west corner of the state as a result of fewer data points close to
the state borders (refer to Figure 1).
    Bastin et al., (1984) suggested to look on the variance as
depending exclusively on the location of the rain gages. Thus, it is
possible to compute the error variance associated with any set of
hypothetical data points without getting actual data at these points.
The above authors demonstrate the use of the kriging variance as an
efficient tool for solving rain gage allocation problems.
    So far discussed, it was assumed that the variation of the
precipitation over the state was much the same in all directions.
However, one of the features of the experimental semi-variograms
presented in Figure 2, is evident anisotropy because of the semi-
variograms sill. In all cases, annual, summer and winter, the sill
differs appreciably within the four principal directions. When the
variability is not the same in every direction and there is a greater
spatial dependence in one direction the phenomenon is said to be
directional (or zonal) anisotropic (Journel and Huijbregts, 1978).
    Table 2 summarized the structural analyses of the anisotropic
cases. Only those pairs of points lying within a particular interval
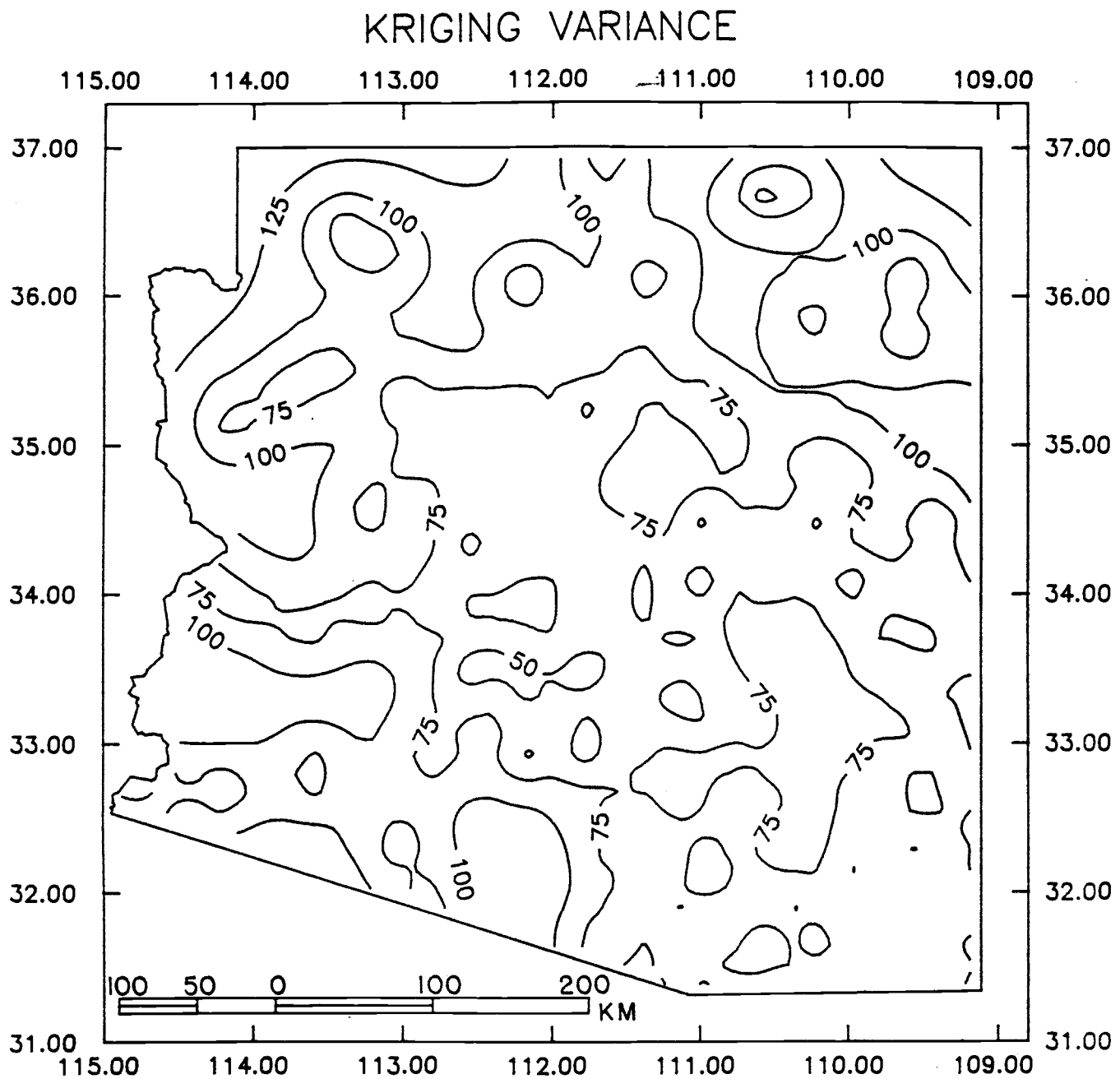
KRIGING VARIANCE

Figure 7: Error map in kriging variance of the average precipitation depth of
Arizona.

are used in Eq. 9 to calculate empirical semi-variogram for that corresponding angle-of-direction interval. A separate theoretical semi-variogram is fitted for each direction. As can be recognized from Table 2, the semi-variograms can be grouped into two; the N-S and the NE-SW semi-variograms indicate lower sill, and the E-W and the NW-SE semi-variograms are characterized by higher sill. Note that in all the three cases the exponential model has been used and that all the other variogram parameters: the range, nugget and lag remain unchanged.

TABLE 2:   Parameters of anisotropic semi-variograms.

DIRECTION	MODEL PARAMETERS			
	NUGGET	RANGE	SILL	LAG
ANNUAL				
EAST - WEST	0.0	0.8	0.18E5	0.1
NORTHEAST - SOUTHWEST	0.0	0.8	0.22E5	0.1
NORTH - SOUTH	0.0	0.8	0.25E5	0.1
NORTHWEST - SOUTHEAST	0.0	0.8	0.18E5	0.1
GLOBAL	0.0	0.8	0.21E5	0.1
SUMMER				
EAST - WEST	0.0	1.0	0.40E4	0.1
NORTHEAST - SOUTHWEST	0.0	1.0	0.60E4	0.1
NORTH - SOUTH	0.0	1.0	0.60E4	0.1
NORTHWEST - SOUTHEAST	0.0	1.0	0.50E4	0.1
GLOBAL	0.0	1.0	0.50E4	0.1
WINTER				
EAST - WEST	0.0	0.7	0.07E4	0.1
NORTHEAST - SOUTHWEST	0.0	0.7	0.10E4	0.1
NORTH - SOUTH	0.0	0.7	0.12E4	0.1
NORTHWEST - SOUTHEAST	0.0	0.7	0.07E4	0.1
GLOBAL	0.0	0.7	0.09E4	0.1

Figure 8 presents the theoretical semi-variogram for both the N-S and E-W directions. The unisotropic phenomenon of the precipitation fields in Arizona can be explained by the topographic structure of the state disregarding the storms origin and direction (for more detailed discussion see Karnieli and Osborn in this issue). This can be concluded also by the similar unisotropic structure for the annual, summer and the winter cases. The Mogollon Rim which stretches in the middle of the state, oriented from NW to SE provides a significant orographic effect on the precipitation. Consequently, the variation of the precipitation is greater in the N-S and NE-SW directions (perpendicular to the Mogollon Rim) than in the E-W and NW-SE directions.

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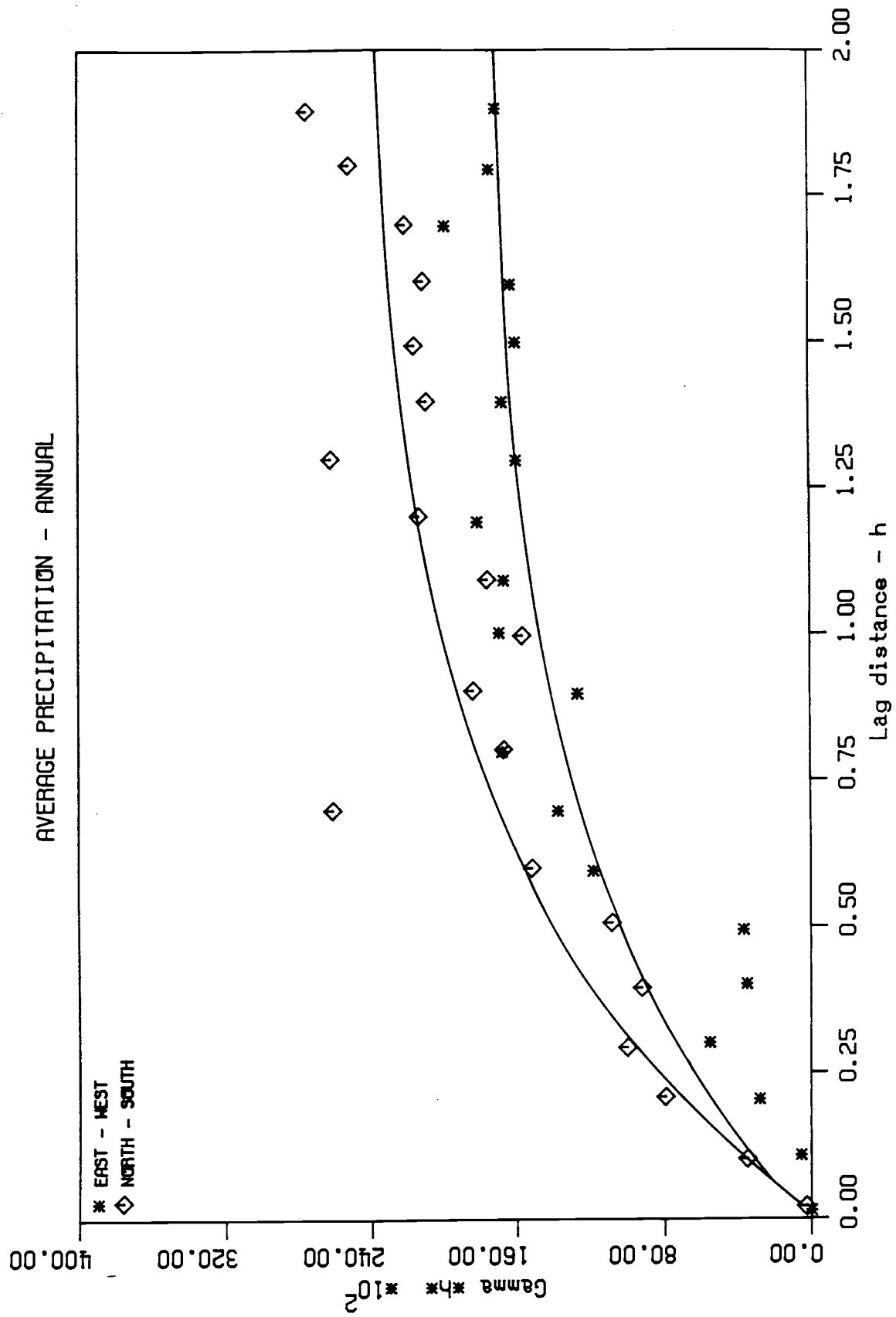
Figure 8a: Zonal (directional) anisotropic of the average precipitation in Arizona - annual.

AVERAGE PRECIPITATION - SUMMER

EAST - WEST
NORTH - SOUTH

Lag distance - h

Gamma *h* $*10^2$

Figure ... of the average precipitation in Arizona - summer.
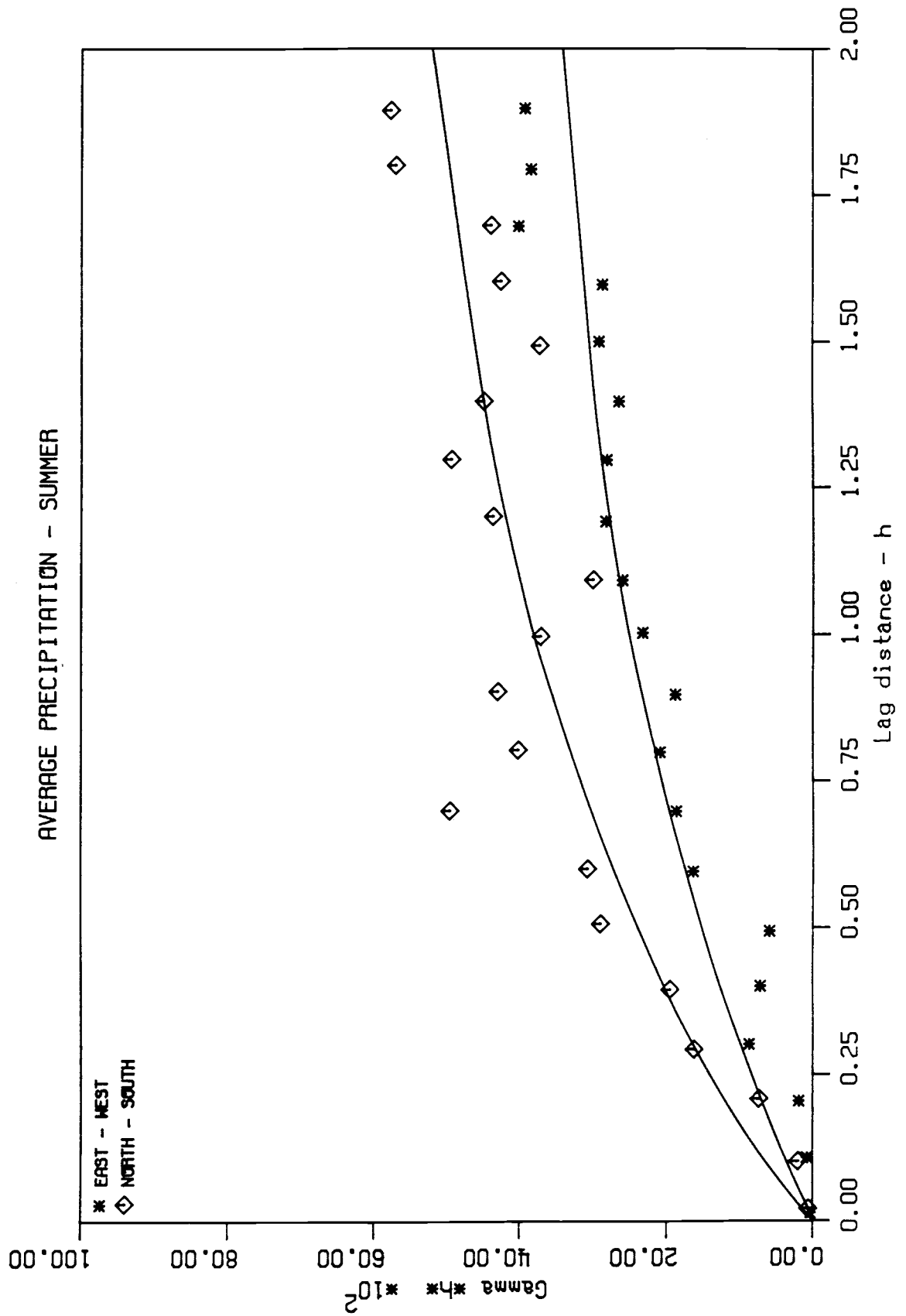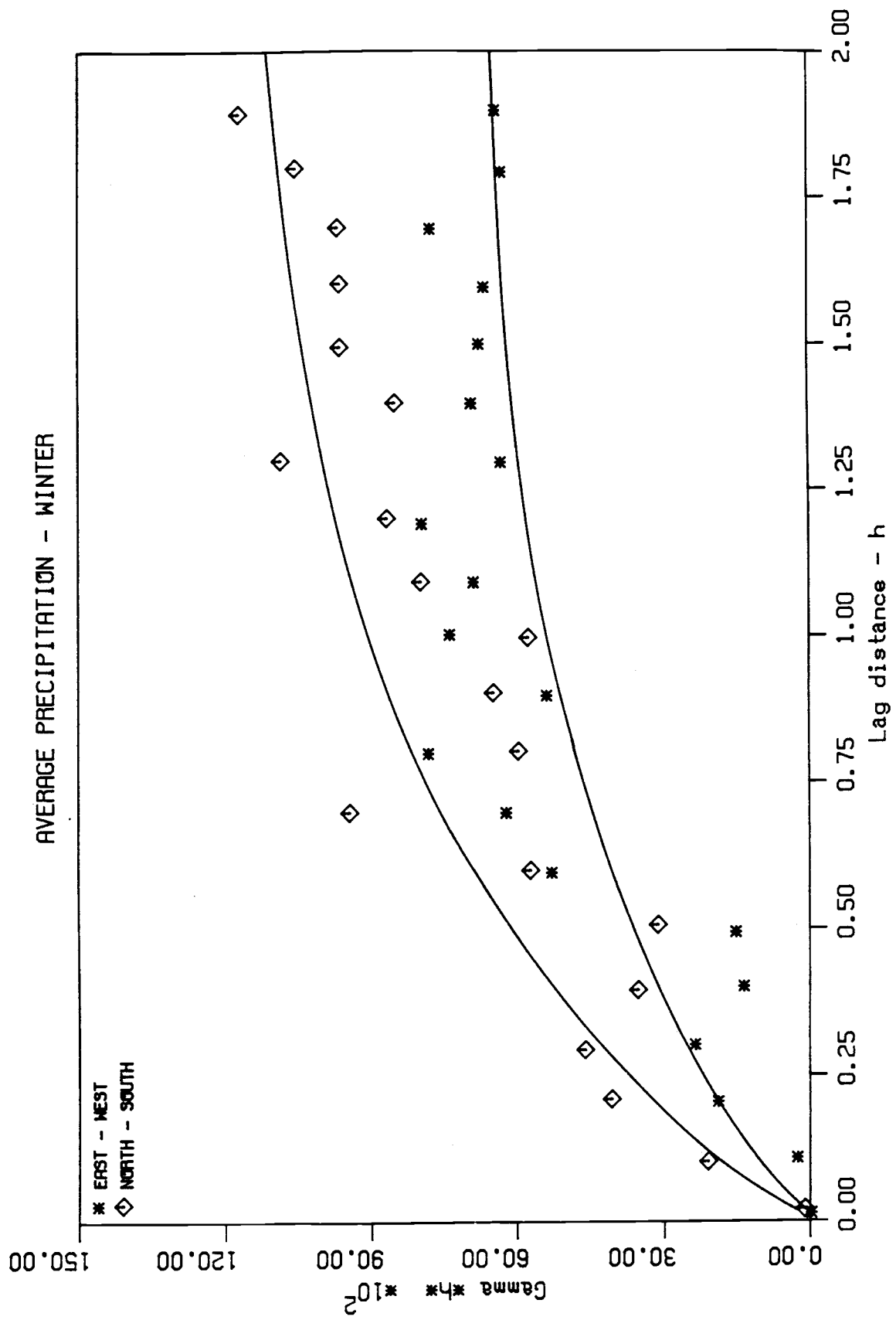
Figure 8c: Zonal (directional) anisotropic of the average precipitation in Arizona – winter.

On the other hand, the presented zonal unisotropic can be interpreted as a spatial drift which have not been observed by the current computer package. In this case a polynomial drift should be fitted in order to be eliminated from the kriging algorithm. Chua and Bras (1982) and Neuman and Jacobson (1984) describe various of methods for dealing with this problem.

Conclusions

Kriging is an advanced interpolation technique in which the estimator is a linear minimum variance unbias estimator. This paper has proposed the application of kriging method for contour mapping as well as for estimating the average areal rainfall over large regions such as the State of Arizona with irregular rain gage network.

The kriging variance contour map (Figure 7) indicates that the predicted spatial structure agrees fairly well with the actual spatial structure. However, for better results stations surrounding the state borders, have to be taken into consideration. Furthermore, the error map can help the National Weather Service in selecting the optimal location of additional rain gages in order to increase the network accuracy.

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INITIAL SURVIVAL AND GROWTH OF TREE SEEDLINGS IN A WATER HARVESTING AGRISYSTEM

Peter F. Ffolliott
School of Renewable Natural Resources, University of Arizona
Tucson, Arizona 85721

Introduction

Water harvesting is a technique for developing surface water resources that subsequently can be utilized to provide water for livestock and domestic use, and small-scale subsistence agriculture and forestry practices. Water harvesting systems are artificial methods that collect and store precipitation until it can be utilized beneficially. These systems include a catchment area, usually treated to improve surface runoff efficiency, and a storage facility for the harvested water, unless the water is to be applied immediately for the growing of drought-hardy plants (Frasier and Myers, 1983). For systems established for irrigation purposes, a water distribution scheme also is required.

The purpose of water harvesting is to either augment the existing water supplies, or to provide water where other sources are not available or too costly to develop. A principal aim is to furnish water in sufficient quantity and of suitable quality for the intended use. The technology of water harvesting can be applied in almost any arid region of the world.

In this paper, the initial survival and growth of tree seedlings planted in two catchments of a water harvesting system, located in Avra Valley, 40 kilometers west of Tucson, Arizona, is reviewed. This water harvesting system, developed by the University of Arizona in cooperation with the City of Tucson, was established to demonstrate a potential use for retired farmland, with rainfall as the only source of water for irrigation.

Study Area

The water harvesting system, consisting of a gravity-fed sump, a storage reservoir, sixteen catchments, and an irrigation system, occupies nearly 2 hectares in Avra Valley. Elevation of the system is about 600 meters, the terrain is relatively level, and the soil is sandy clay loam. Annual precipitation is 300 millimeters, occurring in a bimodal summer-winter distribution pattern. Summer temperatures reach 45 degrees Celsius, with winter temperatures rarely below 0 degrees Celsius.

As mentioned above, the study area originally was farmland. However, the City of Tucson began to purchase and retire farmland in the vicinity, including the study area, in 1975, utilizing the groundwater to augment its

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water needs. The native vegetation was disturbed by the earlier farming activities, with the area currently occupied by invading "weed" species.

The Water Harvesting System

The combined design capacity of the gravity-fed sump and the storage reservoir is approximately 2,400 cubic meters of water (Karpiscak et al., 1984). The sump and the storage reservoir were treated with NaCl to decrease infiltration, and the main reservoir is covered with 250,000 empty plastic film cans to decrease evaporation.

Sixteen catchments, also treated with NaCl to decrease infiltration, are used to concentrate rainfall runoff around planted agricultural crops and tree species in untreated planting areas at the base of the catchments (Karpiscak et al., 1984). Excessive runoff flows directly into a collecting channel and then into the sump. Each catchment, about 1.6 hectares in size, is approximately 90 meters in length, varies from 6 to 18 meters in width, and slopes about 0.5 percent.

The irrigation system consists of a 6,000 Watt centrifugal pump, an 8-centimeter pipeline connecting the sump and the storage reservoir to the pump, two 5-centimeter PVC pipelines connecting the pump to the field plots, and 2-centimeter polyethylene driplines equipped with 0.01-cubic meter per hour drip emitters (Karpiscak et al., 1984). The valving system permits the movement of water from the sump to the storage reservoir, from the storage reservoir to the sump, and from either the sump or the storage reservoir to the field. A water meter records the amount of water applied to the plants.

Description of the Study

On July 28, 1984, 103 tree seedling of Aleppo pine (Pinus halepensis) and Brutia pine (Pinus brutia), grown in containers for 8 months in a greenhouse, were hand-planted in two of the 16 catchments in the water harvesting system. Fifty-two tree seedlings were planted in Catchment No. 8, and 51 tree seedlings were planted in Catchment No. 10. Spacing between the tree seedlings was approximately 2 meters along the planting lines. Measurements of survival and growth of the tree seedlings, made annually in an initial three-year evaluation period, form the basis for this paper.

The two tree species selected for this study commonly are found in arid environments in the world. Aleppo pine is a common tree species throughout southern Europe to Asia Minor. It occurs in the eastern Mediterranean region in mixed stands, with several species of oak; it also grows mixed with several broad-leaved shrubs to form the upper-story of these stands. Aleppo pine typically is found on shallow sedimentary soils. It is reported that the tree species is resistant to soil salinity, drought, and a limited amount of frost (Abido, 1986). Because of its ability to endure severe climatic and edaphic conditions, Aleppo pine has been utilized in reclaiming poor soils and for afforestation purposes in many Mediterranean countries. The tree species also has been introduced into many arid regions of the world.

Brutia pine, once recognized as a variety of Aleppo pine, currently is considered a separate tree species (Abido 1986). Unlike Aleppo pine, the natural range of Brutia pine is restricted to the eastern Mediterranean regions. It is found from Greece to Iraq, concentrated principally in Turkey and Cyprus. The tree species, typically a fast-grower in its early stages, is found on most soil types.

It has been reported by many investigators that Aleppo pine and Brutia pine are the most important tree species in afforestation, control of erosion, and sand dune fixation in the arid regions of the world (Abido, 1986). However, defining the minimal rainfall regimes required for initial survival is a frequent problem when attempting to introduce these two tree species.

Results and Discussion

Approximately six weeks after the planting, on September 8, 1984, the first measurement of tree seedling survival was made, the results of which are summarized below:

Catchment No. 8

Species	Total	Live	Dead	Percent Survival
Brutia pine	26	22	4	84.6
Aleppo pine	26	21	5	80.1
Total	52	43	9	82.7

Catchment No. 10

Species	Total	Live	Dead	Percent Survival
Brutia pine	26	17	9	65.4
Aleppo pine	25	14	11	56.0
Total	51	31	20	60.8

A second measurement of tree seedling survival was made on October 13, 1984, with the results presented below:

Catchment No. 8

Species	Total	Live	Dead	Percent Survival
Brutia pine	26	17	9	65.4
Aleppo pine	26	17	9	65.4
Total	52	34	18	65.4

Catchment No. 10

Species	Total	Live	Dead	Percent Survival
Brutia pine	26	13	13	50.0
Aleppo pine	25	9	16	36.0
Total	51	22	29	43.0

On October 13, 1984, a replacement planting of tree seedlings also was made. Brutia pine seedlings, the same age as those in the original planting, were planted for every dead tree seedling recorded on this date, regardless of the tree species originally planted.

Two years after the original planting, on July 26, 1986, a third measurement of tree seedling survival was made. The results of this survey are summarized below:

Catchment No. 8

Species	Total	Live	Dead	Percent Survival
Brutia pine	17	15	2	88.2
Aleppo pine	35	28	7	80.0
Total	52	43	9	82.7

Catchment 10

Species	Total	Live	Dead	Percent Survival
Brutia pine	13	7	6	53.8
Aleppo pine	38	21	17	55.3
Total	51	28	23	54.9

A fourth measurement of tree seedling survival was made on August 8, 1987, three years after the original planting. These measurements indicated the following:

Catchment No. 8

Species	Total	Live	Dead	Percent Survival
Brutia pine	17	15	2	88.2
Aleppo pine	35	27	8	77.1
Total	52	42	10	80.7

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Catchment No. 10

Species	Total	Live	Dead	Percent Survival
Brutia pine	13	6	7	46.2
Aleppo pine	38	19	19	50.0
Total	51	25	26	49.0

Throughout the three-year evaluation period, survival within a catchment has been essentially the same for the two tree species. However, overall survival of the tree seedlings consistently has been higher in Catchment No. 8 than in Catchment No. 10 throughout the evaluation period. At the present time, the reason for this difference in survival rates is unknown.

Initial growth of the tree seedlings, regardless of the species, has been relatively slow. At the end of the three-year evaluation period, the average height of the surviving tree seedlings was 12.5 centimeters, ranging from less than 10 to over 16 centimeters. Diameter growth of the tree seedlings has been insignificant. Once established, it is presumed that the growth rate of the tree seedlings will increase.

Conclusions

Initial survival and growth of the tree seedlings, over a three-year evaluation period, suggest that Aleppo pine and Brutia pine can be planted with relative success in a water harvesting system, such as the one utilized in this study. Although growth has been relatively slow, survival after three years has ranged from nearly 50 to 80 percent. Long-term survival and growth of these tree seedlings will continue to be monitored, with the results utilized in determining the feasibility of planting Aleppo pine and Brutia pine in the arid environments of southeastern Arizona.

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Mapping and Characterization of the Soils on the University of Arizona Maricopa Agricultural Center

Donald F. Post, Chris Mack, Philip D. Camp, and Ahmed S. Suliman
University of Arizona and USDA Soil Conservation Service

Department of Soil and Water Science
Room 429 Shantz Building
Tucson, AZ 85721

INTRODUCTION

The Maricopa Agricultural Center (MAC) is a University of Arizona research and demonstration farm located three miles east of Maricopa and three miles north of the Casa Grande-Maricopa Highway in Pinal County, Arizona. The farm is 770 hectares (2100 acres) in size, and the elevation is 358 meters (1175 feet). Figure 1 is a field map of MAC Farm which lists the legal description for the land and gives the Universal Transverse Mercator (UTM) grid notations for the section corners (half-section corners for part of the farm). This map also shows field numbers and field boundaries.

Data collected on MAC farm should be spatially referenced to the UTM coordinates. The numbers reported in this paper are averages of several measurements made by us to identify farm boundaries. UTM coordinate numbers are expressed in meters north and east of reference points noted on U.S. Geological Survey Topographic Maps. It is difficult to absolutely identify coordinates to the nearest meter; however we believe these are accurate. All soils data collected by these authors are referenced to the coordinates listed in Figure 1.

The response of crops grown on this farm are greatly affected by the physical, chemical and biological characteristics of the soils. Therefore, it is essential that the nature, properties, and distribution of the soils be known. This paper presents soil characterization data about MAC Farm soils that should be very useful in helping researchers understand plant responses on the farm.

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The MAC Farm was acquired in January, 1983 and field studies and collection of soil samples to map and characterize the soils began in May, 1984 and continued until January, 1987. We initially sampled and described five (5) soil profiles on the research part of farm (Section 20), and they were sent to the National Soil Survey Laboratory in Lincoln, NE for detailed analyses. In January of 1987 six (6) additional soil profiles were described and sampled on the demonstration part of the farm (Sections 17, 18, and 19), and selected analyses were completed on these pedons. The lab procedures used to characterize these soils are described in Soil Survey Investigation Report #1.

Many soil borings to depths of 1.0-1.5 meters were made throughout the farm and appropriate notes and observations recorded. Over 800 Ap surface horizon samples (0 to 30cm depth) were collected on a grid system, and selected analyses were completed on these samples. The soil map of the farm and a display of soil properties, notably the texture of the surface soil horizon, is presented in this paper. The methodology and terminology used to prepare the soil map follows the National Cooperative Soil Survey guidelines as presented in the National Soils Handbook, the Soil Survey Manual, and Soil Taxonomy.

The Soil Map of MAC

Three soil series, Casa Grande, Trix, and Shontik have been mapped on the farms. Table 1 lists the soil map unit name and the taxonomic classification for each soil series. Two of the mapping units are identified as an association of two soil series, which means the soils are geographically associated but we were not able to map them separately at the mapping detail used to complete the map presented in this paper.

Table 1.   List of soil mapping unit names and the taxonomic classification of the soil series.

Map Unit Symbol and Name	Classification of the Soil Series
CG Casa Grande soils, reclaimed	Casa Grande - fine-loamy, mixed, hyperthermic Typic Natrargids
SH-CG Shontik-Casa Grande association, reclaimed	Shontik - fine-loamy, mixed, hyperthermic Natric Camborthids
TR Trix soils, reclaimed	Trix - fine-loamy, mixed (calcareous), hyperthermic Typic Torrifluvents
TR-CG Trix-Casa Grande association, reclaimed	

Many factors affect soil formation and ultimately the physical, chemical, and biological properties of a soil. Two factors in particular have greatly affected the properties of the MAC farm soils: 1- the geologic history of these soils and 2- the agricultural development, especially land-leveling and soil reclamation activities.

Soils of the MAC Farm have formed on a relict basin floor of Pleistocene age, which has been partly affected by Holocene age (recent) alluvium deposited adjacent to the Santa Cruz Wash. Water movement through this area in the recent past was very slow and of low energy, resulting in a depositional rather than erosional environment near the Santa Cruz channel. Fine textured recent alluvium makes up the upper horizons of the Trix soil, which has been deposited on older soil material. The Casa Grande soil has not been affected by the deposition of recent alluvium, and it's characteristics are different from the Trix. The historic shallow, braided channels of the Santa Cruz Wash have subsequently been channelized into one large channel, and it now serves as a drain for irrigation tail waters as well as carrying overland flood waters.

All soils on the farm were strongly saline and sodic prior to agricultural development. Evidence of this chemical toxicity can be found adjacent to the farm in native areas where the sodium absorption ratios range from 20 to 40, and the electrical conductivity of the saturation extract range from 15 to 40 deciSiemens per meter. Salinization of this area probably occurred during early or mid-Holocene, and it appears to be a function of a fluctuating water table present in these soils during that time period. Although these soils have been successfully reclaimed, they retain some residual characteristics that require continuous monitoring. For this reason the taxonomic classification reflects this situation, but our soil map unit names does indicate that they have been reclaimed.

We identified four mapping units on the farm (Figure 2), and this map may suggest that the soils are uniform in properties. This is somewhat misleading because the soils have been significantly altered from their original conditions through extensive land leveling operations and various soil reclamation treatments. The Casa Grande (CG) and Trix (TR) mapping units are the most uniform; however the other two units are an association of two major soils. Additional field work would be required to determine which soil is present at a given location in these two mapping units. We estimate that the composition of the Trix-Casa Grande (TR-CG) association, reclaimed mapping unit is about 65% Trix soil, 25% Casa Grande soil, and 10% inclusions of other similar soil series. The Shontik-Casa Grande (SH-CG) association, reclaimed mapping unit is 70% Shontik soils, 15% Casa Grande soils, and 15% inclusions of other similar

soil series. The Casa Grande soils, reclaimed and the Trix soils, reclaimed are comprised 85 to 90% of these soils, with minor inclusions of other similar soil series.

The texture of the surface Ap horizons on MAC farm (0-30 cm depth) are sandy loam, sandy clay loam, or clay loam. Figure 3 shows the distribution of these three classes on the farm. The linear boundaries are related to existing field boundaries, and abrupt changes in surface textures have been created through the land-leveling process. The Trix soil has either a clay loam or sandy clay loam surface, and it is higher in organic matter and therefore darker in color than the other two soils. The Casa Grande surface is usually a sandy loam or sandy clay loam texture, whereas the Shontik soil has a sandy loam surface. The Shontik soil surface is more sandy than the Casa Grande, usually having from 65-75% (or more) sand content. Figures 4 and 5 are maps showing the absolute percentages of sand and clay in the surface horizon (0-30 cm) for the entire farm.

Description of the Soil Series

A soil map does not preclude the need for site-specific evaluations of the soil which are commonly needed on research study plots. However, it is useful to have some general descriptive information about the three soils mapped on the farm.

Presented below are some descriptive information about each soil, and Table 2 summarizes selected soil characterization data for each soil. Future papers will include more detailed information on these soils, but these numbers can be helpful, if used judiciously. We have included data for the major horizons and ranges are given rather than specific numbers. If a single number is required, an average of the two values would be an appropriate number to use.

The Casa Grande soil is a deep, well drained slowly permeable soil formed in old alluvium. On the MAC Farm this soil typically has a brown to reddish brown sandy loam or sandy clay loam surface horizon from 0-30 cm deep. The subsoil horizon from 30 to 60 cm is usually a reddish brown sandy clay loam, which increases in calcium carbonate content with depth. Below this horizon at a depth of 60 to 100 cm is a horizon enriched with calcium carbonate (calcic horizon), which also has a sandy clay loam texture. The depth to the calcic horizon varies from 25 to 100 cm in depth, but commonly occurs between 50 and 80 cm in depth.

The Trix soil is a deep, well drained very slowly permeable soil whose upper horizons are formed in fine textured recently deposited alluvium, which in turn overlies Casa Grande soil material.

Typically this soil has a dark brown clay loam or sandy clay loam surface horizon 0-30 cm deep. The upper subsurface horizon ranges from 30 to 100 cm deep, and it typically averages about 75 cm deep. It has similar characteristics as the surface horizon (Table 2). Underlying this horizon is Casa Grande soil material, and it has properties similar to that described for the subsurface horizons of the Casa Grande soils.

The Shontik soil is a deep, well drained moderately to moderately rapid permeable soil found in sandy alluvium. It has a brown sandy loam surface horizon 0-30 cm deep, and is usually higher in sand content than the Casa Grande surface horizon. The subsoil horizons extend from 30 to 100 cm or more, and are very similar to the surface horizons, also having a sandy loam texture (Table 2). There are no enrichments of calcium carbonate in this soil above 100 cm; however it is present at deeper depths.

SUMMARY

This paper has presented a soil map and described the characteristics of the MAC Farm soils. Because characteristics of a soil are strongly related to soil texture, we have summarized the MAC Farm data in relationship to soil horizon textural properties. Table 2 gives the numerical ranges of selected soil properties for the major soil horizons, and it does this by soil series and by soil depth. Therefore, if one knows the textural properties of the study site and the soil depth, it is possible to get reasonable numerical values for the bulk density and soil porosity, water holding capacity, organic matter, cation exchange capacity, and calcium carbonate content. We have not included data on pH, soluble salt content, and the sodicity condition of MAC soils. These parameters are highly variable from year to year and even within a growing season, so site-specific analyses must be made if these parameters are needed. Future papers will further describe and characterize MAC soils, as there is much yet to be learned.

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illus.

ACKNOWLEDGEMENTS

Table 2. Soil characterization data for the MAC Farm soils.

SOIL MAPPING UNIT SYMBOL	TEXT. CLASS	Depth cm	Sand %	Clay %	Bulk Density g/cm³	Total Pore Space %	% Water-Weight Basis*			Organic Matter %	CaCO₃ %	CEC meq/100g
							-.1 Bar	-.33 Bar	-.15 Bar			
SH	SL	0- 30	65-75	10-15	1.40-1.60	40-47	17-23	14-19	6.6- 7.0	.4- .6	2- 5	8-10
SH	SL	30-100	65-75	10-15	1.40-1.60	40-47	17-23	14-19	6.6- 7.0	.1- .2	4- 6	7- 9
CG	SL,SCL	0- 30	55-65	15-22	1.40-1.60	40-47	16-22	12-18	7.0- 9.0	.5- .7	3- 5	9-13
CG	SL,SCL	30- 70	55-65	15-22	1.50-1.65	38-43	16-22	12-18	7.0- 9.0	.1- .3	4-20	8-12
CG	SCL	0- 30	45-55	22-27	1.45-1.55	42-45	18-23	16-19	10 -10.5	.8-1.2	3- 5	13-16
CG	SCL	30-100	45-55	22-27	1.45-1.55	42-45	18-23	16-19	10 -10.5	.2- .4	5-20	12-15
TR	SCL	30-100	45-55	22-27	1.45-1.55	42-45	18-23	16-19	10 -10.5	.6- .8	3- 6	15-18
TR	CL	0- 30	25-45	27-40	1.40-1.55	42-47	21-27	18-24	13.5-15.5	1.2-1.5	2- 3	24-27
TR	CL	30- 70	25-45	27-40	1.40-1.55	42-47	21-27	18-24	13.5-15.5	.5-1.0	2- 3	22-26

*Note: % Water (Weight Basis) X Relative Bulk Density = % Water on Volume Basis
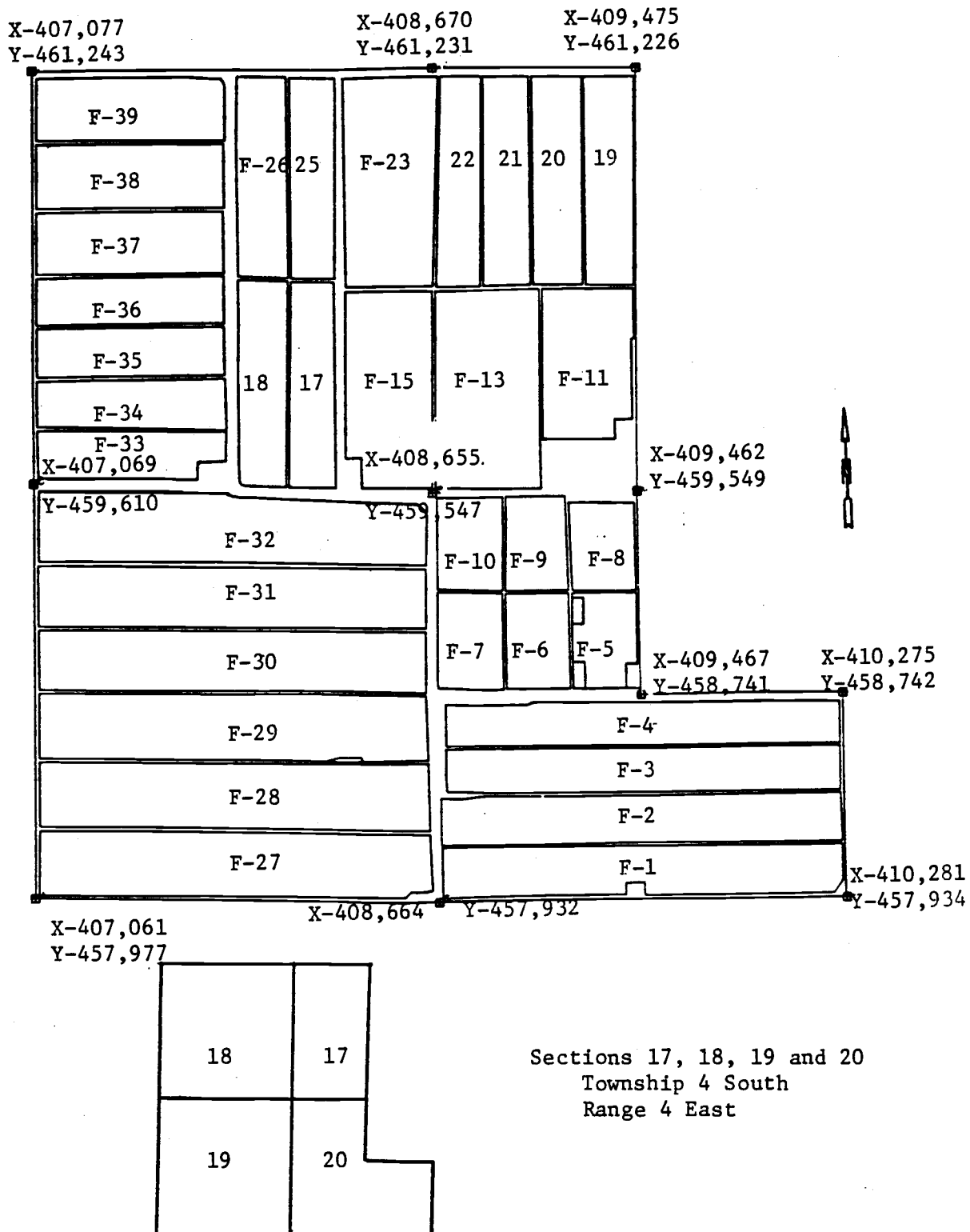
Figure 1. Field map of the Maricopa Agricultural Center.
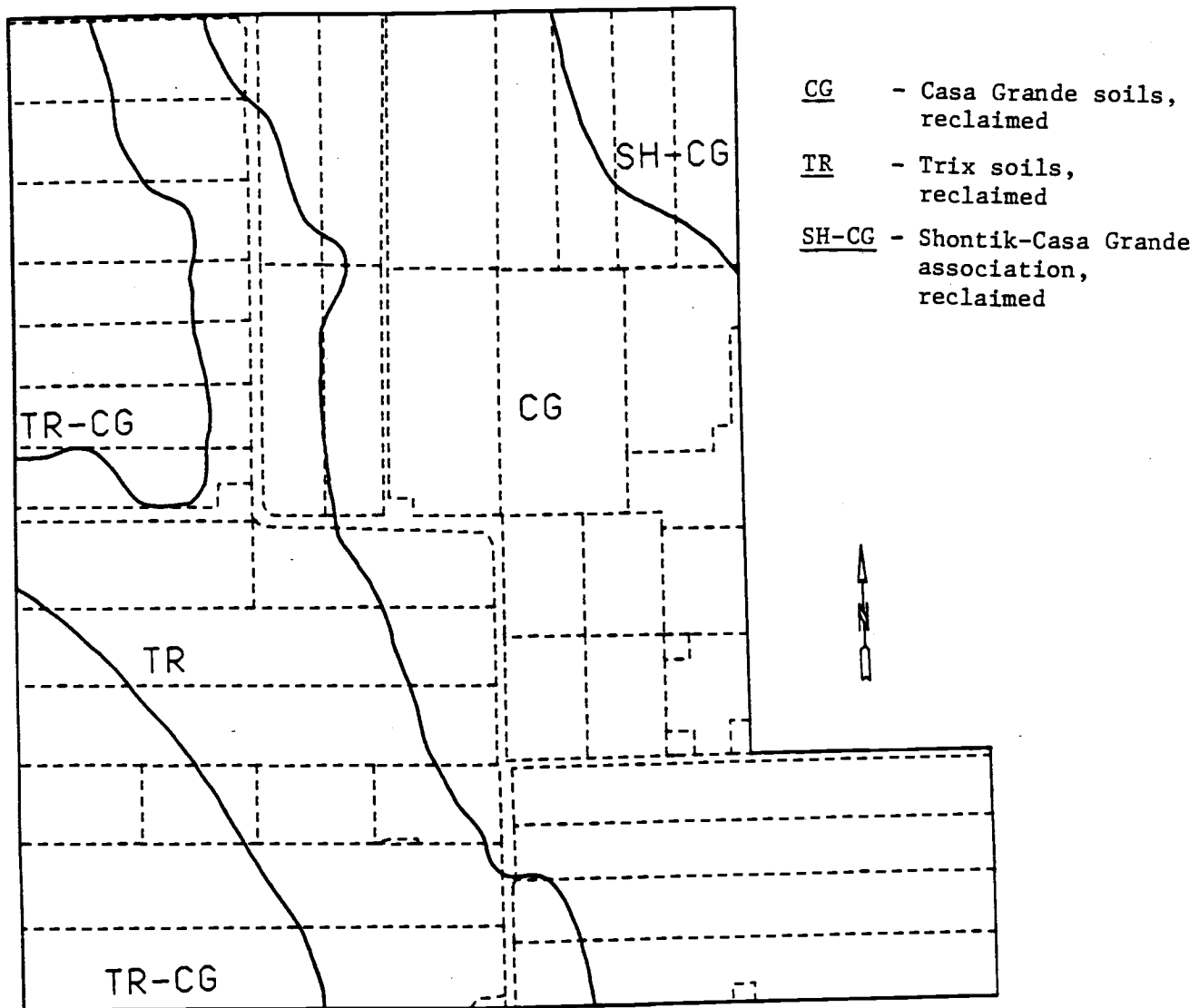
Figure 2.   Soil map of the Maricopa Agricultural Center.
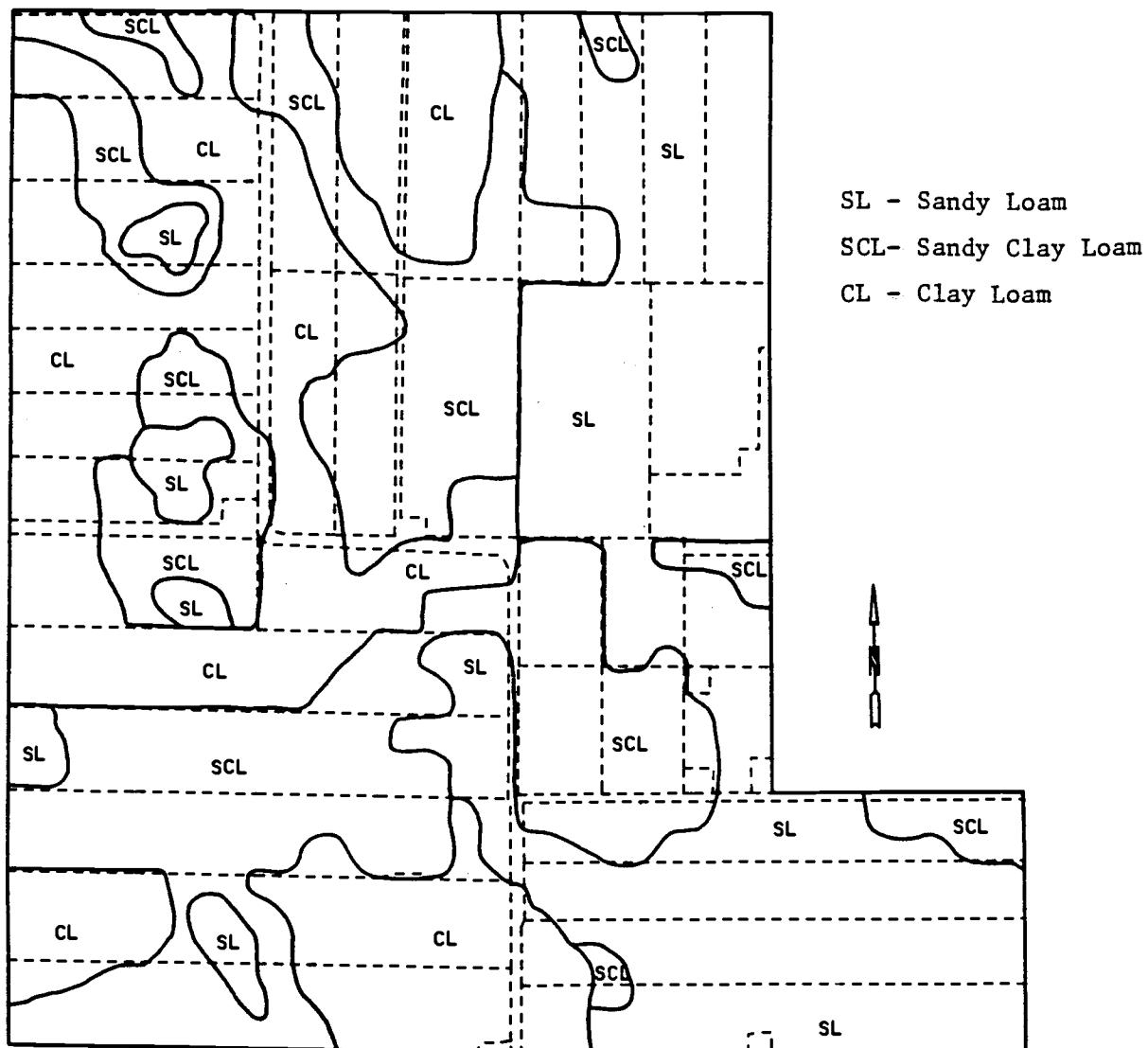
SL — Sandy Loam
SCL— Sandy Clay Loam
CL — Clay Loam

Figure 3. Surface textural map of the Maricopa Agricultural
Center.
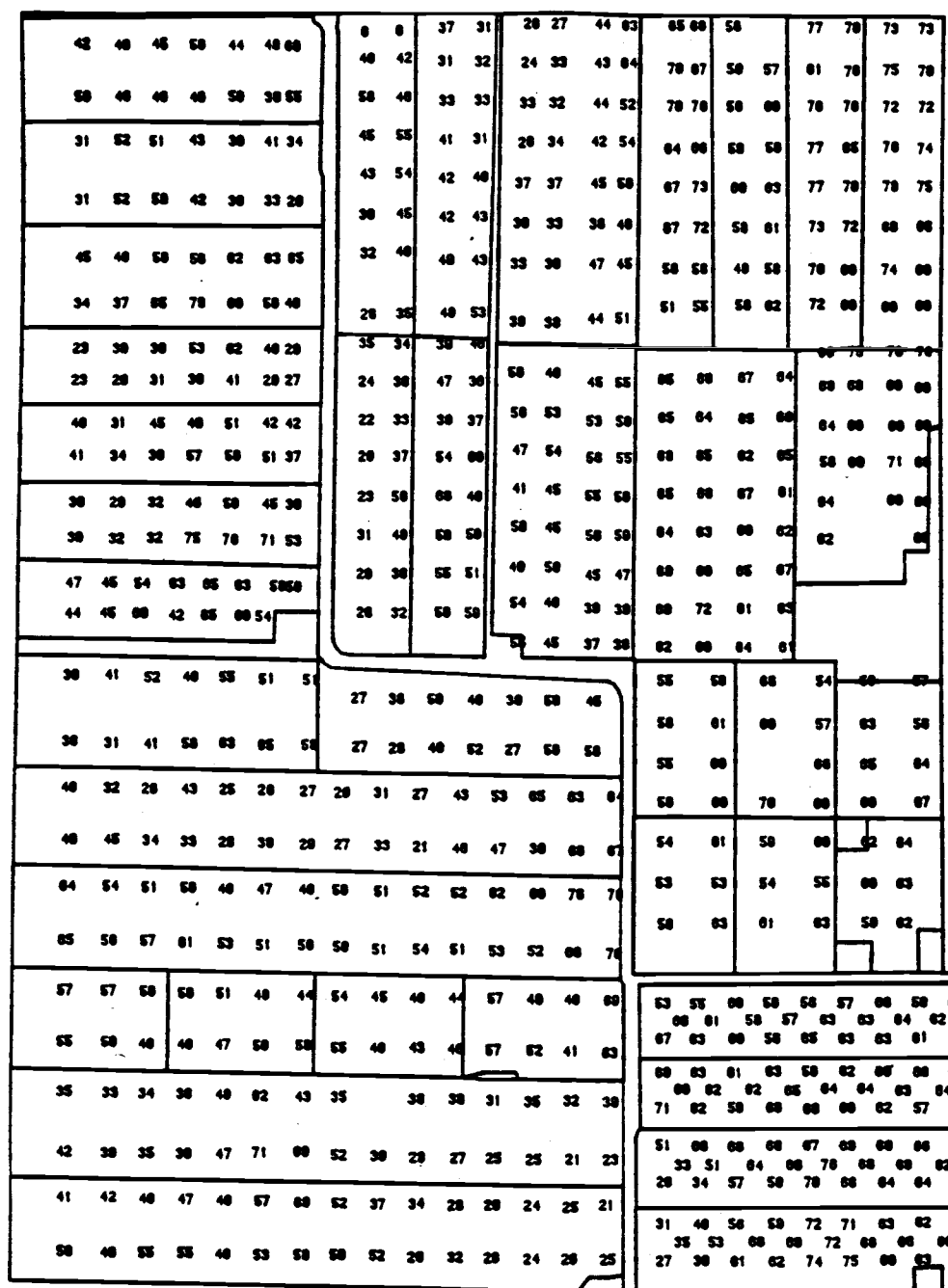
Figure 4. Percent sand in the surface Ap horizon (0 - 30 cm depth).

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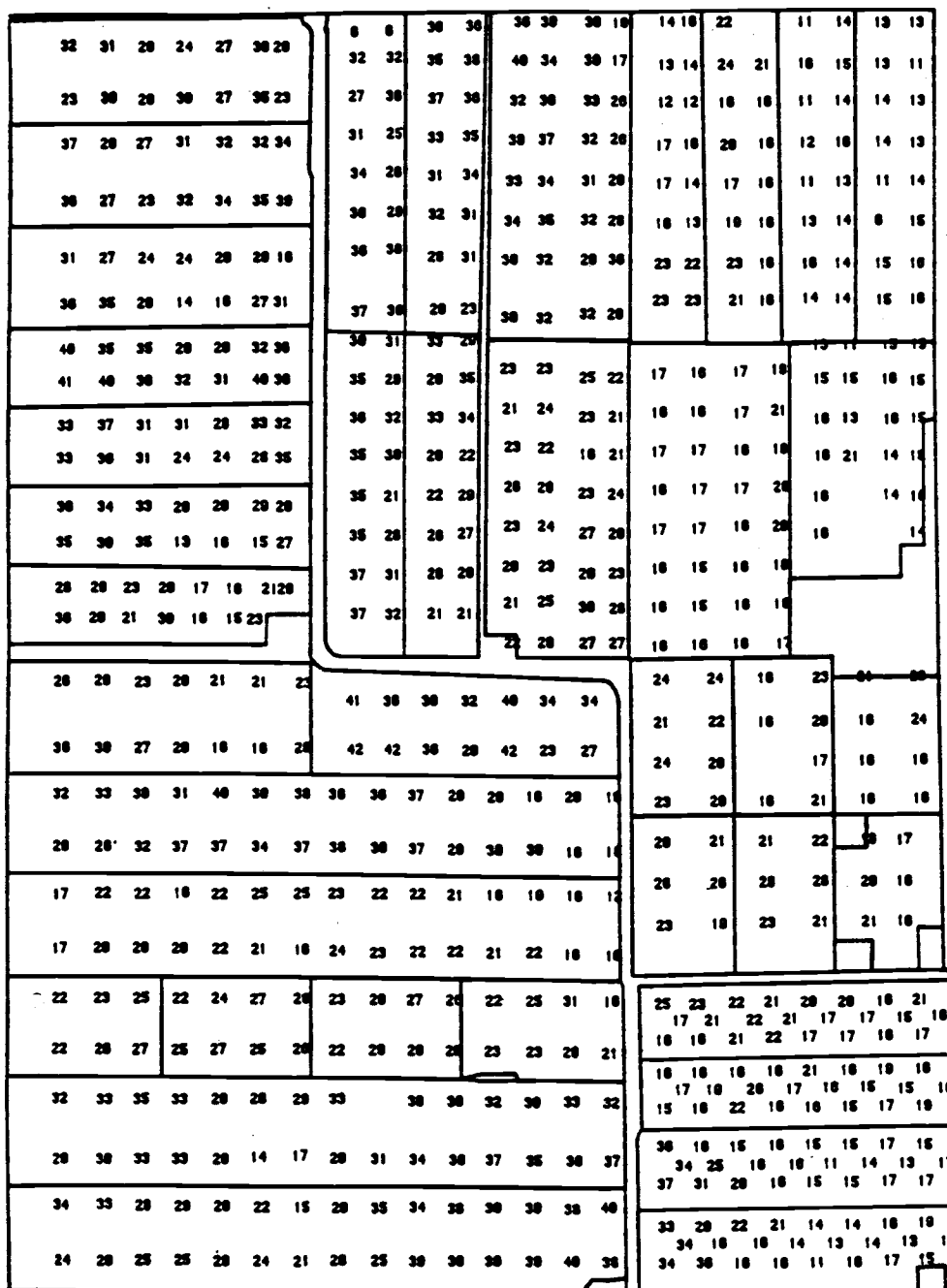
Figure 5. Percent clay in the surface Ap horizon (0-30 cm depth).

Relationship Between Soil Spectral Properties and Sand, Silt and Clay Content of the Soils on the University of Arizona Maricopa Agricultural Center

Ahmed S. Suliman and Donald F. Post
University of Arizona

Department of Soil and Water Science
Room 429 Shantz Building
Tucson, AZ 85721

INTRODUCTION

The spectral reflectance properties of 552 Ap surface horizon soil samples collected from the MAC farm were measured using a Barnes Modular-Multiband Radiometer. All samples were passed through a 2mm sieve, mixed, and uniformly placed in 50 x 50 cm black trays. The data were collected on cloudless days, the sun Zenith angle was between 29 and 43 degrees, and ten readings per sample were taken and averaged. Reflectances were made with both dry and wet soil conditions.

RESULTS

Table 1 presents the % reflectance mean and standard deviation for all samples in each band, and correlates it to the sand, silt, and clay percentages. The correlation coefficients were negatively correlated to silt and clay and positively correlated to sand, with the highest correlations being between the .63 - .69 (red) and .76-.90 (near infrared) bands.

Step-wise multiple linear regression equations were computed (95% C.I.) relating the three soil separates to % reflectance in each band, and they are presented in Table 2. Three of the seven bands were significant for dry conditions (.76-.90, .45-.52, and 1.15-1.30) and two bands for wet conditions; however, the two significant bands were different for the sand, silt, and clay separates. The following were significant: sand .63-.69 and .52-.60; silt -.45-.52 and .76-

.90, and clay -.52-.60 and .63-.69. A correlation matrix to show the co-variance among the seven bands is presented in Table 3.

SUMMARY

The sand, silt, and clay content of MAC Farm soils are related to soil reflectance; however, reflectance may also be related to other soil characteristics. Other researchers have shown organic matter, iron, calcium carbonate content, and soil color to be correlated to reflectance. Additional research is being completed to investigate these relationships, and results of these studies will be presented in future papers.

Table 1. Percent reflectance mean and standard deviation and its linear relationship to sand, silt, and clay.

| Band (μm) | % Reflectance | | Linear Correlation (r) | | | | | |
| | | | Sand | | Silt | | Clay | |
	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
.45 - .52 (blue)	12.7(1.8)	5.0(1.2)	.16	.63	-.11	-.58	-.20	-.62
.52 - .60 (green)	18.0(2.5)	8.2(2.2)	.31	.67	-.25	-.62	-.34	-.65
.63 - .69 (red)	25.3(3.4)	12.9(3.5)	.45	.69	-.38	-.65	-.47	-.67
.76 - .90 (NIR)	31.0(3.9)	17.4(4.4)	.46	.69	-.40	-.65	-.48	-.67
1.15 - 1.30 (NIR)	38.5(4.1)	22.9(5.0)	.41	.66	-.36	-.63	-.43	-.64
1.55 - 1.75 (MIR)	39.8(4.3)	21.7(4.6)	.43	.62	-.37	-.59	-.44	-.60
2.08 - 2.35 (MIR)	36.2(4.1)	15.1(3.4)	.43	.58	-.37	-.54	-.45	-.56

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Table 2.   Multiple linear regression equations relating sand, silt, and clay to % reflectance in the various band wavelengths.

Dry Conditions:

% Sand = 12.98 + 675.31 (% Refl .76-.90) - 731.92 (% Refl .45-.52) - 206.91 (% Refl 1.15-1.30)

$$r^2 = .46 \quad F = 155$$

% Silt = 40.73 - 295.79 (% Refl. .76-.90) + 368.16 (% Refl .45-.52) + 74.48 (% Refl 1.15-1.30)

$$r^2 = .40 \quad F = 124$$

% Clay = 46.29 - 379.52 (% Refl .76-.90) + 363.76 (% Refl .45-.52) + 132.44 (% Refl 1.15-1.30)

$$r^2 = .45 \quad F = 147$$

Wet Conditions:

% Sand = 8.33 + 1081.29 (% Refl .63-.69) - 1209.40 (% Refl .52-.60)

$$r^2 = .50 \quad F = 270$$

% Silt = 48.30 + 421.53 (% Refl .45-.52) - 256.38 (% Refl .76-.90

$$r^2 = .44 \quad F = 215$$

% Clay = 48.46 + 574.22 (% Refl .52-.60 - 536.12 (% Refl. 63-.69)

$$r^2 = .47 \quad F = 242$$

Table 3. Correlation matrix to show the relationship among the seven spectral bands of MAC Farm soils.

	.45-.52 DRY	.45-.52 WET	.52-.60 DRY	.52-.60 WET	.63-.69 DRY	.63-.69 WET	.76-.90 DRY	.76-.90 WET	1.15-1.30 DRY	1.15-1.30 WET	1.55-1.75 DRY	1.55-1.75 WET	2.08-2.35 DRY	2.08-2.35 WET
.45-.52	1.00	1.00	.97	.99	.89	.97	.87	.96	.87	.92	.85	.82	.83	.76
.52-.60			1.00	1.00	.97	.99	.96	.99	.95	.95	.93	.86	.92	.80
.63-.69					1.00	1.00	.99	.99	.97	.96	.96	.88	.95	.81
.76-.90							1.00	1.00	.98	.96	.97	.88	.97	.82
1.15-1.30									1.00	1.00	.99	.97	.99	.91
1.55-1.75											1.00	1.00	.99	.97
2.08-2.35													1.00	1.00

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ACCUMULATION OF HEAVY METALS AND PETROLEUM HYDROCARBONS IN URBAN LAKES: PRELIMINARY RESULTS

Frederick A. Amalfi and Milton R. Sommerfeld
Department of Botany
Arizona State University
Tempe, Arizona 85287-1601

ABSTRACT

A preliminary survey of several urban lakes in the Phoenix metropolitan area was undertaken to assess the degree of accumulation of priority pollutant metals and petroleum-based hydrocarbons in these impoundments. Three sediment samples were collected from each lake along a transect (from a probable point of stormwater addition to the opposite shore), and were composited on an equal weight basis prior to analysis. Total petroleum hydrocarbon concentrations ranged from 30 to 8000 mg/kg dry weight. The concentration ranges (mg/kg dry weight) of total metals were: arsenic 7-26, copper 25-2800, chromium 14-55, nickel 5-40, lead < 1-138, selenium < 0.5-1.1, and zinc 33-239. Silver and cadmium were undetectable (< 5.0 and < 0.5 mg/kg, respectively). Factors that may be associated with the magnitude of accumulation in urban lakes include lake age, primary source of influent, reception of stormwater runoff, mechanical aeration of the water, and direct chemical addition.

INTRODUCTION

The water quality of urban lakes in Arizona is not currently regulated by the State. However, because of the rampant development of master-planned communities incorporating lakes as recreational and stormwater retention structures, and pressure placed on the State Legislature by water conservation groups to restrict further development of urban lakes, the State has begun formulation of water quality standards and has adopted restrictions regarding water use for urban impoundments.

The Clean Water Act reauthorization bill dictates that states must develop plans for municipal stormwater discharges (Rhein 1987). Because many urban lakes are designed to retain stormwater runoff, State and local regulatory agencies will become increasingly interested in the accumulation and discharge of metallic and organic

pollutants associated with these urban reservoirs. Metals associated with automobile use have been found in unusually high concentrations in urban runoff (Galvin and Moore 1982, Athayde et al. 1983, Milligan et al. 1984, Pitt 1985) and receiving waters adjacent to urbanized areas (Pitt and Bozeman 1982, Cole et al. 1983, Calvin et al. 1984). Similarly, urban runoff has been found to contain measurable amounts of petroleum hydrocarbons (TPHCs) derived directly from crankcase oil deposits on streets and from associated agglomerations with street soil and dust particles (Hoffman et al. 1982, 1985).

Until recently, a limited number of urban impoundments have received sewage effluent and little attention was paid to unique environmental problems which might develop in the lakes as a result of contaminants remaining in the effluent. In 1987, the State of Arizona adopted Senate Bill 1200 as a water conservation measure, restricting the use of groundwater in new, non-public artificial lakes (Ferris 1986, State of Arizona 1987). In response, developers have begun incorporating sewage treatment facilities into their planned communities and have designed lake systems to receive the secondary effluent. The increasing number of these impoundments and the potential for aesthetic problems such as algal blooms and odors from the effluent has generated public concern.

Currently, over 40 urban lake systems have been identified in the Phoenix area. Due to the array of contaminants that are potentially present in the environment arising from urban and industrial pollution, it is necessary to chemically survey a wide variety of lakes systems to determine whether population densities, land use, geographic location, water source, lake age, design and operation, and stormwater addition affect the type of degree of contamination of the lake sediments and pose potential threats to surface water and groundwater resources.

Contamination of lakes can best be detected by analysis of sediments because pollutants usually have strong affinities for particulates which are deposited in the lake bottoms. Once deposited many pollutants tend to persist because degradative processes (photooxidation, chemical oxidation, and biological transformation) are inoperative or reduced in the anaerobic sediments (Neff 1979, Wallace 1986). Most metals which enter urban lake systems in central Arizona are in the particulate form and rapidly settle to the lake bottoms (Sommerfeld and Amalfi 1987). Precipitation at alkaline pH and in hardwater impoundments common to this area causes additional

accumulation of metals which originally enter the lake in the dissolved form.

THE STUDY

A survey of 22 urban lake systems in Central Arizona was conducted to provide a data base on the presence and accumulation of metallic priority pollutants and petroleum hydrocarbons in urban lake sediments. In addition, anaerobic EP Toxicity analyses were performed on the sediments to estimate the maximum potential for release of metals. Preliminary findings are presented below and include simple correlations of chemical and physical data collected to date. Multivariate statistical analysis necessary to confirm the implications of the regression analyses is in progress.

METHODS

Field Sampling

Twenty-two urban lake systems were sampled. With the exception of one system, all were located in the Phoenix metropolitan area.

Sediment samples were collected with an Ekmann dredge from three locations at each lake and were composited on an equal weight basis. The three subsamples were collected at equidistant points along a transect drawn from a major point of stormwater entry into the lake (if present) to the opposite shore.

All sample containers and preservation techniques conformed to the recommendations of the U.S. Environmental Protection Agency (USEPA 1983).

Laboratory Analyses

Metallic priority pollutants. Metallic elements that were quantitated included primary drinking water contaminants delineated under the Interim Primary Drinking Water Regulations Implementation (CFR 40, Ch. 1, Part 141, 1985) and elements named in the USEPA list of priority pollutants. Metallic analyses were performed by flame and furnace atomic absorption spectroscopy in accordance with the methods of the USEPA (1986). All sediment samples were acid digested according to EPA Method 3050 (USEPA 1986) prior to instrumental analysis.

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EP toxicity. To ascertain the degree of release of metals from the lake sediments, both the standard protocol and a modification of EPA Method 1310 (USEPA 1986) were evaluated to characterize the leachability of the lake deposits. Because most lake sediments become anoxic a few centimeters below the water-sediment interface and the standard EP Toxicity extraction is carried out under aerobic conditions, an additional extraction procedure was performed under anaerobic conditions. Deoxygenation was accomplished by treating extraction dilution water with sodium sulfite. Preliminary tests showed that the sodium sulfite effectively removes the oxygen from the dilution water, scavenges the oxygen remaining in the headspace of the extraction vessel during the tumbling period, and adds no measurable metals to the extract.

Total petroleum hydrocarbons. Petroleum-based hydrocarbons were quantitated by EPA Method 418.1 (extraction with trichlorotrifluoroethane and infrared detection, USEPA 1983). Sediment samples were dried with anhydrous magnesium carbonate and pulverized prior to extraction, and were quantitated on a dry weight basis.

Statistical Analysis. Chemical and physical data was analyzed using the nonparametric Spearman rank correlation program of SAS (SAS Institute Inc., Cary, NC) to identify significant associations between chemical constituent concentrations in the sediments and between constituent concentrations and physical characteristics of the lakes. Discriminant analysis using SAS was performed to obtain partial correlation coefficients for assessing the influence of other variables on highly correlated characteristics. SAS PRINCOMP was used to obtain simple linear correlations (Pearson product moment correlation) for development of regression equations of highly correlated variables. Variables analyzed included arsenic, cadmium, chromium, lead, selenium, silver, copper, nickel, zinc, TPHC, lake age, presence or absence of storm sewerage terminating at the lake, presence or absence of mechanical aeration systems in the lake, and primary water source of the lake (groundwater, surfacewater, or secondary domestic sewage effluent). Coded variables were placed into the data matrix for storm sewerage, aeration, and water source characteristics.

Results of the two EP Toxicity extraction procedures were evaluated nonparametrically by the Wilcoxson paired sample test (Zar 1984).

RESULTS

Metals

Table 1 presents the results for total metal concentrations in the lake sediments. Concentration ranges for arsenic, cadmium, chromium, nickel, selenium, and silver were relatively small, whereas rather large differences in concentrations of copper, lead, and zinc were apparent among the lakes.

Total Petroleum Hydrocarbons

Table 2 summarizes the total petroleum hydrocarbon concentrations in the sediments of the 22 lakes. The data illustrate substantial variability in distribution of hydrocarbons among the lakes. On a dry weight basis, lake 11 had the lowest concentration of TPHCs with 35 mg/kg in the sediment and lake 13 had the highest with 8070 mg/kg.

EP Toxicity

A statistical comparison of the standard protocol EP Toxicity extraction with the modified anaerobic extraction indicated that there were significant differences between the amounts of copper $(0.01 < p < 0.025)$ and zinc $(p = 0.005)$ released under each test condition. Concentrations of lead and cadmium in each extract type were also evaluated, but were so frequently at or below the detection limit that no statistical difference between the techniques could be identified. The modified procedure provided the best estimate of the maximum potential release of metals from the lake sediments. Results of the modified EP Toxicity extraction are presented in Table 3.

Associations of Variables

The nonparametric (Spearman) correlation matrix for the lake data indicated significant correlations $(p < 0.001)$ between lake age and TPHCs, lead, and zinc concentrations (r_S = 0.5702, 0.8151, 0.6359, respectively); and lake lead content and chromium, zinc, and TPHC concentrations (r_S = 0.7022, 0.8224, 0.6918, 0.8151, respectively). Analysis of partial correlation coefficients for these combinations still revealed high correlations $(p < 0.01)$ when the influences of the other variables in the data matrix were removed. As a graphic example, the linear relationship between lake age and lead content (following logarithmic transformation) of the lake sediments is presented in Figure 1. Poor correlation was found between coded variables of qualitative lake

characteristics and chemical constituent concentrations in the sediments.

DISCUSSION AND CONCLUSIONS

Preliminary results suggest that priority pollutant metals and petroleum hydrocarbons are accumulating in the urban lake sediments of metropolitan Phoenix. Lake age appears to be an important factor in determining the degree of accumulation of pollutants, with older lakes tending to have greater concentrations in the sediment. Lead, chromium, copper, nickel, zinc, and TPHCs were the chemical constituents found in highest concentrations. High concentrations of copper in at least three of the lake systems is attributable to the application of chelated copper or copper sulfate as algicides.

The highly significant correlations between lead, chromium, zinc, and TPHCs suggests that automobile-related contaminants deposited on streets are carried into the lakes by stormwater runoff. The absence of direct stormsewer discharges into a lake system does not preclude the capture and deposition of runoff-related contaminants by the lake. The lake feedwater source appears to have minimal influence on the quantity of metallic and petroleum-based contaminants accumulated in the lake sediments.

Although metals are found in high concentrations, the results of the modified EP Toxicity analysis suggest that they are tightly bond to the sediments and probably would not be released in concentrations that would impact the environmental quality of the surface water or underlying groundwater resources. A comparison of the range of metal concentrations determined for the lake sediment extracts and maximum contaminant levels for hazardous wastes and drinking water is presented in Table 4. None of the sediments can be considered hazardous wastes and only 6.6 percent (13 of 198) of the extract constituents analyzed had concentrations in excess of the drinking water standards.

The levels of petroleum hydrocarbons measured in the lake sediments exceeded, in 19 of 22 cases, the State recommended level for total petroleum hydrocarbons in soil (100 mg/kg). The extremely high value for lake 13 is attributed to accidental or intentional dumping of a decane-based solvent (tentatively identified by gas chromatography/mass spectroscopy) into the lake. Based on its association with zinc and lead, the origin of the

petroleum hydrocarbons in the other lakes appears to be engine oil wear metal deposits from roads and parking areas washed into the lake by precipitation runoff.

The simple statistical analyses applied to the data thus far infer some degree of association between lead, zinc, chromium, total petroleum hydrocarbons, and lake age. Before developing a model designed to predict the environmental status of urban lakes or to identify lake design and operational features which minimize contamination, additional data analysis and expended studies are required. Statistical analyses including evaluation of various coding techniques for qualitative information and multivariate analysis need to be performed on the current data set. Future studies should include chemical analysis of specific organic priority pollutants in the sediments as well as expanding the physical parameter evaluated to include demographic and watershed characteristics.

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TABLE 1

TOTAL METAL CONCENTRATIONS IN URBAN LAKE SEDIMENTS

Concentration mg/kg

Lake	AS	CD	CR	PB	SE	AG	CU	NI	ZN
1	7.8	<0.5	15	5.7	0.22	0.6	232	5.0	35.2
2	12.3	<0.5	20	24	0.07	1.1	62.6	11	57.7
3	15.3	0.5	48	138	0.60	2.1	173	25	239
4	15.8	<0.5	34	27	0.30	1.1	58.3	28	85.0
5	20.2	0.5	55	154	0.08	0.6	99.1	25	221
6	11.9	<0.5	36	44	0.01	0.2	30.4	16	82.7
7	25.6	<0.5	40	39	0.02	0.6	50.1	27	137
8	12.7	<0.5	21	8.8	1.05	0.2	573	16	73.6
9	11.6	<0.5	14	< 1.0	0.90	0.2	79.8	9.5	33.9
10	19.8	<0.5	34	15	0.16	1.1	218	28	92.5
11	17.3	<0.5	19	5.7	<0.01	1.1	56.9	16	54.5
12	11.5	<0.5	21	7.3	0.09	0.6	76.6	18	70.2
13	14.4	<0.5	24	12	0.13	0.6	75.8	11	61.4
14	10.9	<0.5	20	4.2	<0.01	0.2	76.6	20	34.3
15	11.1	<0.5	20	10	<0.01	0.2	38.3	10	54.3
16	26.6	<0.5	33	4.2	<0.01	0.6	834	40	49.4
17	8.6	<0.5	36	84	0.16	0.6	140	15	73.4
18	23.4	<0.5	39	7.2	0.02	0.6	72.6	34	62.9
19	11.2	<0.5	22	90	0.08	0.2	69.1	16	184
20	12.3	<0.5	24	12	0.05	0.2	86.3	15	61.4
21	10.7	<0.5	21	10	<0.01	0.2	25.1	11	48.0
22	15.4	<0.5	34	24	1.08	1.1	2756	9.5	55.6

TABLE 2

TOTAL PETROLEUM HYDROCARBONS IN URBAN LAKE SEDIMENTS

Lake I.D.	TPHC mg/kg dry wt	TPHC mg/kg wet wt
1	350	159
2	522	289
3	2360	554
4	353	101
5	4250	1590
6	1070	577
7	770	216
8	292	109
9	2160	1310
10	305	125
11	35	23
12	134	72
13	8070	4400
14	42	30
15	255	152
16	90	58
17	1440	544
18	425	220
19	4820	2020
20	1250	455
21	435	213
22	758	98

TABLE 3

RESULTS OF ANAEROBIC EP TOXICITY EXTRACTONS OF LAKE SEDIMENTS

Concentration mg/L

Lake	AS	CD	CR	PB	SE	AG	CU	NI	ZN
1	0.021	<0.005	<0.02	<0.05	0.011	<0.01	0.08	<0.02	0.07
2	0.021	<0.005	<0.02	<0.05	<0.001	<0.01	0.03	·<0.02	0.05
3	0.048	<0.005	<0.02	<0.05	0.005	<0.01	0.05	<0.02	0.26
4	0.050	<0.005	<0.02	<0.05	0.002	<0.01	0.02	<0.02	0.05
5	0.073	0.007	<0.02	<0.05	<0.001	<0.01	0.69	0.05	1.63
6	0.064	<0.005	<0.02	<0.05	<0.001	<0.01	0.13	0.05	0.66
7	0.068	<0.005	<0.02	<0.05	<0.001	<0.01	0.08	0.02	0.63
8	0.027	<0.005	<0.02	<0.05	0.013	<0.01	0.06	<0.02	0.09
9	0.026	<0.005	<0.02	<0.05	0.013	<0.01	0.22	0.04	0.03
10	0.075	<0.005	<0.02	<0.05	0.037	<0.01	0.05	0.05	0.06
11	0.026	0.007	<0.02	<0.05	<0.001	<0.01	0.13	0.04	0.02
12	0.043	<0.005	<0.02	<0.05	<0.001	<0.01	0.22	0.02	0.05
13	0.053	<0.005	<0.02	<0.05	<0.001	<0.01	0.07	<0.02	0.01
14	0.029	<0.005	<0.02	<0.05	<0.001	<0.01	0.45	0.09	0.01
15	0.041	<0.005	<0.02	<0.05	<0.001	<0.01	0.40	0.05	0.23
16	0.009	<0.005	<0.02	<0.05	<0.001	<0.01	6.20	0.09	0.09
17	0.054	<0.005	<0.02	0.17	<0.001	<0.01	1.05	<0.02	0.48
18	0.007	<0.005	<0.02	<0.05	<0.001	<0.01	0.30	0.07	0.11
19	0.084	0.007	<0.02	0.09	<0.001	<0'.01	0.22	<0.02	0.46
20	0.069	<0.005	<0.02	<0.05	<0.001	<0.01	0.80	<0.02	0.16
21	0.034	<0.005	<0.02	<0.05	<0.001	<0.01	0.21	0.04	0.13
22	0.124	<0.005	<0.02	<0.05	<0.005	<0.01	0.09	<0.02	0.05

TABLE 4

COMPARISON OF ANAEROBIC EP TOXICITY RESULTS WITH MAXIMUM
CONTAMINANT LEVELS FOR HAZARDOUS WASTES AND DRINKING WATER

Values in mg/L

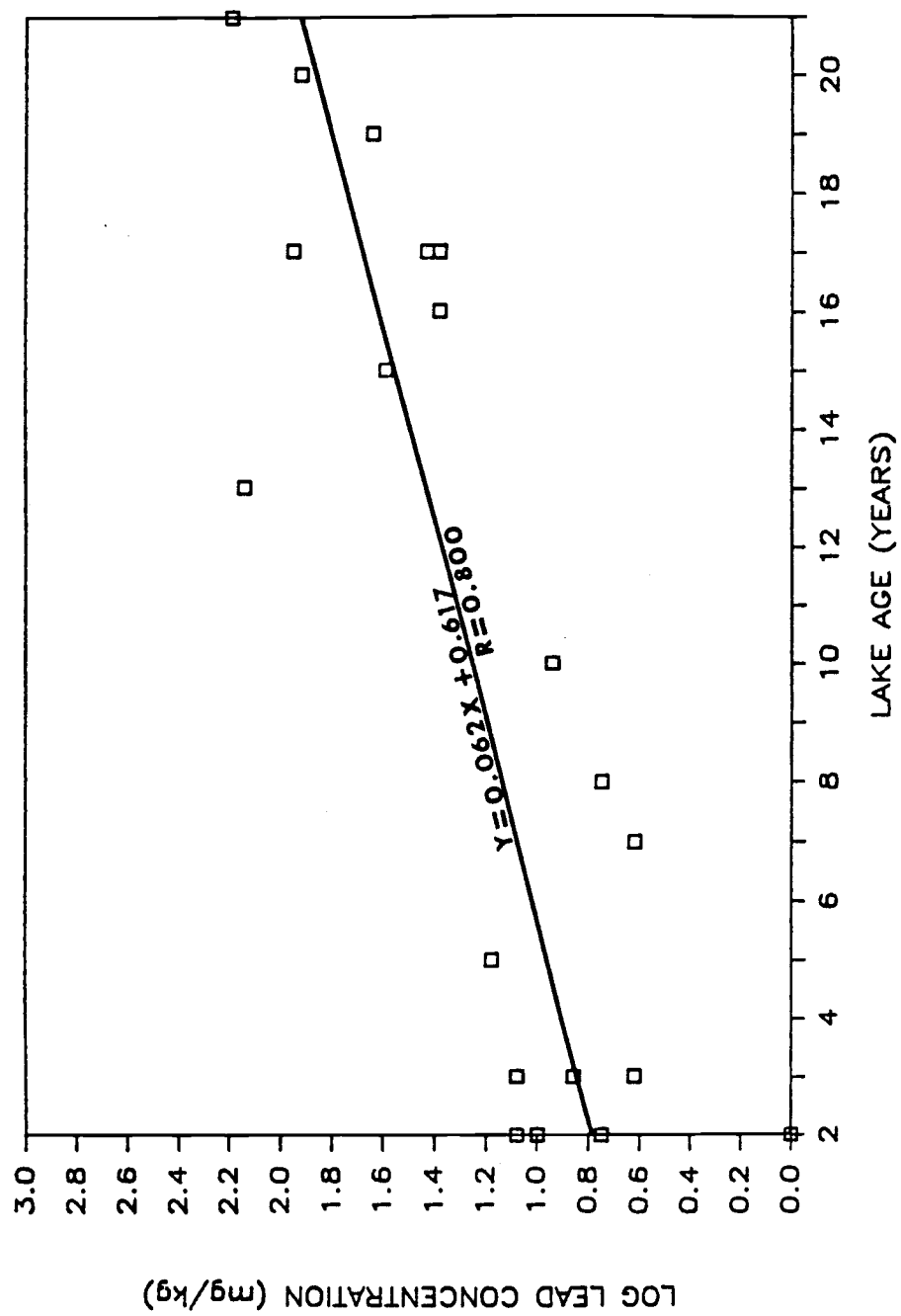| Metal	Range	EP Tox Max.	# Over EP MCL	DW MCL	# Over DW MCL
As	0.007-0.124	5.0	0	0.05	8
Cd	<0.005	1.0	0	0.01	0
Cr	<0.02	5.0	0	0.05	0
Pb	<0.05-0.17	5.0	0	0.05	2
Se	<0.001-0.037	1.0	0	0.01	1
Ag	<0.01	5.0	0	0.05	0
Cu	0.02-6.20	NS	-	1.0	2
Ni	0.02-0.09	NS	-	NS	-
Zn	0.01-1.63	NS	-	NS	-

(NS) No Standard

FIGURE 1. RELATIONSHIP BETWEEN LAKE AGE AND SEDIMENT LEAD CONTENT

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Occurrence of Enteric Viruses and Parasites in Reclaimed Wastewater
Used for Irrigation in Arizona

Ricardo De Leon, Jaime E. Naranjo, Joan B. Rose, and Charles P. Gerba
Department of Microbiology and Immunology
and of Nutrition and Food Science
University of Arizona
Tucson, Arizona 85721

ABSTRACT

The State of Arizona recently implemented virus and parasite standards for discharge and reuse of effluent. This study monitored for two years the enterovirus and Giardia content of reuse effluent from several Arizona wastewater treatment facilities. All treatment facilities met the restricted access irrigation virus standard of 125 enteric virus/40 L, but most plants would have to upgrade their treatment for open access year-round reuse which has a 1 enteric virus/40 L standard. Up to 43% of samples from facilities with primary treatment and oxidation ponds were positive and exceeded 1 enteric virus/40 L. Also, 27% of secondary (activated sludge) effluent samples, which were sand filtered and disinfected by ultraviolet light, were positive and exceeded the 1 enteric virus/40 L standard. Plants using sand filtration and/or chlorine disinfection of activated sludge effluent had the fewest positive samples (20% positive and only 12.5% exceeded 1 enteric virus/40 L). Parasites are monitored for presence or absence in recommended volumes. Giardia monitoring is required for effluent intended for food crop irrigation or full body contact recreation categories.

INTRODUCTION

The State of Arizona under its wastewater reuse permit system requires the monitoring of human pathogenic enteric viruses and certain parasites in addition to fecal coliform bacteria (Kramer, 1984). Reuse regulations affect some 180 facilities in Arizona which altogether reuse some 200 million gallons of wastewater a day. The level of enteric viruses acceptable for discharge as well as for restricted access irrigation and partial body contact recreation is 125 enteric viruses/40 L. The standard for irrigation of food crops for possible raw consumption or for full body contact recreation water is 1 enteric virus/40 L or less. Parasites, on the other hand, are monitored on a presence or absence basis. In our laboratory, one gallon samples are usually tested for Ascaris lumbricoides and Taeniarhynchus saginatus but larger volumes, 40 L, are examined for Giardia lamblia and Entamoeba histolytica. Sewage effluents reused for food crop irrigation or full body contact recreation are monitored for Giardia lamblia and Entamoeba histolytica. Effluents used for open access irrigation or for food crops for possible raw consumption, partial, and full body recreation are monitored for Ascaris lumbricoides. Taeniarhynchus saginatus is monitored in effluents used for pastures or livestock watering (Kramer, 1984).

Sewage has been found to contain over 120 possible enteric viruses (Bitton, 1980). The enteric viruses, with members in several animal virus families, may cause a diverse range of diseases in humans like diarrhea, aseptic meningitis, paralysis, conjunctivitis, myocarditis and hepatitis (Schmidt and Lennette, 1979). Well established cell culture methods are

available for the detection of most enteroviruses, such as polio, echo and coxsackieviruses. The detection methodology relies primarily on concentration by virus adsorption to and elution from filters followed by further reconcentration by organic flocculation to a 20-30 ml volume and assay on established mammalian cell lines (USEPA, 1984). The concentration of enteric viruses may vary greatly in domestic sewage depending on the time or perhaps season of the year, the prevalence of disease in the community, the socio-economic status of the community, etc. (Bitton, 1980). Disinfection by halogens is most effective against the free or non-solid associated viruses although resistance to chlorine differs among the enteric virus groups and even within a family of viruses like the enteroviruses (Liu et al, 1971). Parasites like Giardia lamblia, Entamoeba histolytica, Ascaris lumbricoides, Taeniarhynchus saginatus (Craun, 1986) and more recently Cryptosporidium (Musial, 1987; Madore et al, 1987) are present in wastewater and are potentially transmitted by water (Craun, 1986; D'Antonio, 1985). Chlorine resistance studies of Cryptosporidium by Campbell et al. (1982) suggest that Cryptosporidium, like Giardia, may be resistant to the levels of chlorine used in common wastewater disinfection practices. The concentration methods developed for Giardia used in conjunction with immunofluorescence have been used to detect cysts from environmental samples by Sauch (1985) and later by others (Rose et al., 1986).

MATERIALS AND METHODS

Enteric virus concentration. Enteric viruses were concentrated from water by adsorption-elution from microporous filters. The method is described in detail by Gerba et al. (1978a,b) and USEPA (1984). Viruses which were adsorbed to the filter were eluted by passage of 1 L of beef extract at pH 9.5 through the filter. Viruses in this eluate were reconcentrated to a final volume of 25-30 ml by the bioflocculation procedure of Katzenelson et al., (1976).

Enterovirus assays. Wastewater concentrates were assayed for human enteroviruses using the Buffalo Green Monkey Kidney (BGM) cell line which was grown, passaged, and maintained by previously described methods (Melnick et al., 1979). At least 2/3 of the reconcentrated sample was inoculated onto BGM monolayers in five replicate 75 cm^2 flasks (3 ml/flask), five 25 cm^2 flasks (0.3 ml/flask) and five 25 cm^2 flasks (0.03 ml/flask). The BGM monolayers were pretreated with trypsin for sensitivity enhancement by the method of De Leon and Gerba, (1987). The BGM monolayers were observed for 14 days for the presence of cytopathogenic effects (CPE). The concentration of viruses was determined by a most probable number (MPN) test (APHA), 1980).

Concentration of parasites. Parasites were concentrated from water in polypropylene filters, Micro Wynd II (AMF-CUNO Division, Meriden, CT) with 1.0 um nominal porosity at a flow rate no greater than 5 gallons/min. Adsorbed parasites were eluted by backflushing 2700 ml of deionized water with 0.1% Tween 80 (J.T. Baker Chemical Co., Phillipsburg, NJ). Filters were cut and fibers were washed with the original eluate to increase parasite recovery. The eluates were reconcentrated by centrifugation at 1200 x g for 10 min. Pellets were resuspended with 10-20 ml of phosphate buffer saline (PBS)-1% Tween 80, divided in two and centrifuged again. One volume was resuspended in 10-20 ml of 10% formalin and the other in 10-20 ml of 2.5% potassium dichromate.

Parasite enumeration. Pellet volumes equivalent to 40 L of original sample were cleaned by flotation in potassium citrate for Giardia. The final sample was filtered through a 1.2 um cellulose triacetate 13 mm 5 um filter for Giardia. Each filter was treated with 0.1 ml of primary monoclonal antibody against Giardia (obtained from John Riggs, California State Laboratory, Berkeley, CA) washed with PBS and tagged with fluorescein isothionate (FITC) labelled secondary antibody (AWWA, 1985). The Giardia filter was counterstained with 0.003% Evan's Blue. Samples were observed with 40x objective in an epifluorescent microscope.

RESULTS

Enteroviruses in effluent. Effluent from three separate oxidation pond facilities was positive for enteroviruses in 43% of samples examined. In all positive samples the 1 enteric virus/40 L standard for food crop irrigation or full contact recreation was exceeded but the 125 enteric viruses/40 L restricted access or partial body contact recreation standard was not (Table 1). Enteroviruses were isolated 27% of the time from samples of secondary effluent which was UV disinfected and sand filtered. The positive samples did not exceed 125 enteric viruses/40 L, but all samples positive with the exception of one were greater than 1 enteric virus/40 L. On one occasion the UV system from one plant malfunctioned and a 3 log higher enterovirus count was observed than the previous or following samples (Table 2). The enterovirus positive samples from secondary effluent which was sand filtered and/or chlorinated were 20%. Of the positive samples only 12.5% were greater than 1 enteric virus/40 L and none exceeded 125 enteric viruses/40 L (Table 3). The percent of enterovirus positive samples decreased as quality of treatment increased. The differences were more dramatic when the 1 enteric virus/40 L standard is considered. In this case, the number of positive samples for secondary treatment with chlorination greater than 1 enteric virus/40 L was only 12.5% and the values for the other treatments remain the same (Table 3). The percent enterovirus positive samples in plants where more than one sample has been analyzed follow a similar pattern as by treatment with the exception of plant G, which has been operating at greater than designed capacity.

Parasites in effluents. The percentage of positive samples in effluents examined was 37% for Giardia. The concentration of parasites ranged from 0-140/40 L for Giardia (Table 4). Geometric mean of Giardia in raw sewage was 3.7 cysts/L. In secondary effluent the geometric mean was 1.2 Giardia cysts/L. Sand filtration at two facilities gave geometric means of 0.008 cysts/L (Table 5). The occurrence of Giardia in effluent varied with the type of treatment. Overall, 43% of samples from oxidation ponds and 29% from chlorinated secondary effluent have been positive (Table 6). Sand filtration of secondary effluent does appear to reduce the number of cysts, however Giardia could still be detected (Tables 5 and 6).

DISCUSSION

Enterovirus removal efficiencies by the different processes in wastewater treatments has been reviewed by Bitton, (1980). More recent studies have dealt with the removal efficiency of sand filters in conjunction with coagulation and chlorination (Morris, 1984; De Leon et al., 1986). In these

studies, sand filtration was found to be efficient only when it was preceded by coagulation since virus removal by sand filters is essentially restricted to solid-associated virus. Sand filtration aids in the decrease of enteroviruses in effluent by decreasing the turbidity of the effluent and thus enhancing chlorine inactivation of free virus (Gerba, 1981). In this monitoring study oxidation ponds were found to be the least efficient in enterovirus removal; none-the-less, chlorination of oxidation pond effluent may decrease the enterovirus content. The virus standard of 125 enteric viruses/40 L for restricted access irrigation was met by all treatment plants, but most plants would need to upgrade their treatment to meet the open access irrigation and full body contact recreation standard of 1 enteric virus/40 L.

The parasite Giardia was more efficiently removed by secondary treatment followed by sand filtration, although it was still detected. Oxidation ponds were found to be less effective in the removal of this parasite. This preliminary data of the samples suggests that Giardia may be removed more efficiently by secondary treatment. Removal of Ascaris and Taenia has been reported to be efficient by oxidation ponds by Gunnerson et al. (1985). Both Ascaris and Taenia cysts are larger than Giardia cysts and Cryptosporidium oocysts. Ascaris was found to be removed effectively by sand filtration in a previous study (De Leon et al., 1986) but Giardia has been detected in sand filtered effluents in this study. It appears that the size of the cyst or oocyst is important in determining which treatment, pond, activated sludge or sand filtration conditions will be more effective in their removal, although other factors may be involved.

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TABLE 1

ENTEROVIRUSES IN EFFLUENT FROM OXIDATION PONDS

PLANT AND SAMPLE	MPN/40L[1]
A-1	4.5
B-1	2.0
B-2	0
B-3	0
C-1	0
C-2	10.8
C-3	0
TOTAL SAMPLES	7
1 MPN/40L	43%
125 MPN/40L	0%
POSITIVE	43%

[1]Most probable number in a 40 liter sample

TABLE 2

ENTEROVIRUSES IN SECONDARY EFFLUENT, SAND FILTERED AND UV DISINFECTED

PLANT AND SAMPLE	MPN/40L
D-1	2.6
E-1	3
E-2	1
E-3	2.4
E-4	1537 (MALFUNCTION)
E-5	8.4
E-6	0
E-7	0
E-8	0
E-9	0
E-10	0
E-11	0
E-12	0
E-13	0
E-14	0
E-15	0
E-16	1.5
E-17	0
E-18	0
E-19	0
E-20	0
E-21	0
E-22	0
TOTAL SAMPLES	23
1 MPN/40L	27%
125 MPN/40L	0%
POSITIVE	27%

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TABLE 3

ENTEROVIRUSES IN CHLORINATED SECONDARY EFFLUENT

PLANT AND SAMPLE	MPN/40L[1]
F-1-13*	0
F-14	0.3
F-15-16	0
F-17	0.2
F-18	0.4
F-19-28	0
G-1	0
G-2	2.9
G-3	4.0
H-1*	14.0
I-1	0
I-2	0
I-3	0
I-4	0
I-5	1.5
I-6	0
J-1*	0
K-1	5
TOTAL SAMPLES	40
1 MPN/40L	12.5%
125 MPN/40L	0
POSITIVE	20%

[1]Most probable number in a 40 liter sample.
*These plants also sand filter.

TABLE 4

VARIATIONS IN CONCENTRATIONS OF <u>GIARDIA</u> CYSTS IN TREATED SEWAGE*

	CYSTS
Percentage samples positive	37
Ranges in concentration per 40 L	0-140

*Partially adapted from Madore et al., 1987

TABLE 5

CONCENTRATIONS OF <u>GIARDIA</u> IN ARIZONA SEWAGE[1]

TREATMENT	NUMBER OF FACILITIES	NUMBER OF SAMPLES	CYSTS[2]/L
Raw	3	5	3.7
Secondary	5	14	1.2
Sand Filtered	2	6	0.008

[1]Partially adapted from Madore et al., 1987.

[2]Geometric Means.

TABLE 6

OCCURRENCE OF GIARDIA IN TREATED SEWAGE EFFLUENTS

TYPE OF TREATMENT	NUMBER SAMPLES POSITIVE/ NUMBER COLLECTED	PERCENT POSITIVE
Oxidation ponds	3/7	43
Biotowers	1/3	33
Secondary effluent Chlorinated	4/14	29
Secondary effluent sand filtration chlorinated	1/4	25
Secondary effluent sand filtration, UV	1/2	50

WATER CONTAMINATION SITES IN THE SOUTHWEST: COMPILING A DATA BASE

Donald T. Rivard, Martin M. Karpiscak, K. James DeCook, Glenn W. France, and Donald E. Osborn, University of Arizona, Tucson, Arizona 85719

ABSTRACT

The University of Arizona, under a contract from the Solar Energy Research Institute (SERI), investigated water contamination problems in six Southwestern States -- Arizona, California, Colorado, New Mexico, Oklahoma, and Texas. A variety of surface and groundwater problems were encountered, including 1) high total dissolved solids (TDS) concentrations, 2) contamination by organic compounds, 3) contamination due to high concentrations of inorganic compounds, 4) biological contamination, 5) radioactive contamination, and 6) toxic and hazardous waste disposal.

Literature and computer searches provided an overview of existing problems, but no central depository of information on water contamination problems was found to exist. Specific information was obtained from federal, state, and local government agencies concerned with water quality. Data were collected via telephone interviews, letters, and in-person office visits. Limitations inherent in these data collection methods included, 1) not knowing if all the correct contacts were made concerning a specific problem or site, 2) inability to ascertain whether all contacts were willing and/or able to supply complete, accurate, and updated information, 3) possible bypassing of important data sources, and 4) delays in receiving reports and materials by mail from telephone contacts.

Findings indicate that many localities in the Southwest have water contamination problems in some form; more than sixty sites have been described to date.

INTRODUCTION

Since September 1987, researchers from the Office of Arid Lands Studies, in cooperation with scientists from the Solar Energy Research Facility, University of Arizona, have been working on Task 1 of the Solar Thermal Water Reclamation Project to identify, investigate, describe, and prepare summaries on water contamination and/or hazardous waste disposal sites in six Southwestern States -- Arizona, California, Colorado, New Mexico, Oklahoma, and Texas. The Solar Energy Research Institute (SERI) will review these site summaries to determine if solar thermal technologies can be incorporated into remedial clean-up measures. Possible technologies include direct contamination clean-up processes such as solar-enhanced air stripping, UV-ozone decomposition, reactivation of the carbon used in carbon adsorption, and solar-fired incineration, as well as solar electric generation at remote sites to provide power for conventional treatment processes.

METHODOLOGY

To obtain information on water contamination and hazardous waste disposal sites, a number of approaches were employed. SERI provided a general outline of the types of information that they required. Literature and computer searches of the University of Arizona libraries provided a general overview of existing problems. Task 1 then developed a questionnaire based on SERI's outline. The questionnaire was employed to obtain specific site information from government agencies concerned with water quality (Table 1) via correspondence, telephone interviews, and in-person office visits.

Table 1. Sources of Information: Government Agencies

Federal:
   Bureau of Reclamation - Denver and Sacramento
   Environmental Protection Agency - Dallas, Denver, and
      San Francisco
   Geological Survey - Tucson
   Department of Defense - various military installations
   Department of Energy - Denver

Arizona:
   State Department of Health Services - Phoenix
   State Department of Environmental Quality - Phoenix and
      Tucson
   Regional Councils of Governments - Tucson, Flagstaff,
      and Douglas
   University of Arizona libraries - Tucson

California:
   State Water Resources Control Board - Sacramento
   Regional Water Quality Control Boards - Sacramento, Palm
      Desert, and Riverside
   State Department of Health - Los Angeles and Sacramento

Colorado:
   State Department of Health - Denver

New Mexico:
   State Department of Health, Environmental Improvement
      Division - Santa Fe

Oklahoma:
   State Department of Environmental Quality and Pollution
      Control - Oklahoma City

Texas:
   Texas Water Commission - Austin

Task 1 activities have led to 1) the establishment of a collection of technical reports obtained from the various government and/or responsible clean-up agencies and 2) a data base of sixty-two (62) site summaries stored on computer disks. Summaries were written using WordPerfect 4.2 software package to facilitate information exchange among the various project team members.

WATER PROBLEMS IN THE SOUTHWEST

A variety of surface and groundwater contamination/problem sites were encountered, many of them being either federal and/or State Superfund sites. In general, the sites can be classified into six (6) categories, depending on contaminant/problem. Five (5) of the categories are classified by contaminant: 1) salinity products, 2) organics, 3) inorganics, 4) biological pollutants, and 5) radioactive materials. The sixth category consists of a collection of both active and closed-down landfills, toxic and hazardous waste disposal facilities, and deep-well injection sites. At all of these, significant amounts of toxic and/or hazardous waste products are concentrated and there is potential for treatment and/or destruction of these wastes.

The six categories, the contaminants in each category, and representative sites for each category, are listed and described as follows:

1) Salinity/Total Dissolved Solids (15 Sites)

High concentrations of: Calcium, Chloride, Fluoride, Salts, Sodium, Total Dissolved Solids.

Representative Site

The Tularosa-Hueco Basin is located in south-central New Mexico, with Alamogordo as the major population center. The problem at this site is drinking water which contains a concentration range of 500 mg/l to 35,000 mg/l and an average of 1000 to 3000 mg/l TDS. Ninety-eight percent (98%) of the saturated deposits in the basin contain saline water at this concentration average.

Conventional treatment processes for high salinity/TDS include impoundment and evaporation, aeration, coagulation/flocculation, sedimentation, filtration, and demineralization. Possible solar applications include solar assisted desalination and solar electric generation used in conjunction with conventional treatment processes. None of these solar processes are currently in use at this site.

Information on this site was obtained from the U.S. Bureau of Reclamation, Engineering and Research Center, Denver, Colorado.

2) Organics (38 Sites)

Volatile Organic Compounds (VOCs): Dichloroethane (DCA), Dichloroethene (DCE), Tetrachloroethene (PCE), Trichloroethane (TCA), Trichloroethene (TCE)

Other: Acids, Aviation fuels, Benzene, Caustics, Chloroform, Halogenated organics, Hydrocarbons, Methyl ethyl ketones (MEKs), Polychlorinated biphenyls (PCBs), Pesticides, Phenols, Solvents

Representative Site

Tucson Airport Area, an Environmental Protection Agency (EPA) Superfund site, is comprised of two sections -- Tucson International Airport and Hughes/Air Force Plant #44. The problem at this site is groundwater contamination by VOCs, with TCE the most prevalent. Measured concentrations of TCE have been found as high as 3100 ug/l. Total volume of contaminated water is estimated at 33,700 acre-feet. The clean-up project involves pumping, treating, and recharging some 26 billion gallons of water. Treatment duration is estimated at 10 years.

Hughes/Air Force Plant #44, which is responsible for approximately half of the contamination - the portion located south of Los Reales Road - has built and is operating an air stripping water treatment plant with a capacity of 5000 gallons per minute (gpm). This facility will clean up only the Hughes portion of the contaminated plume. A second treatment plant will be constructed to clean up the portion of the plume located north of Los Reales Road.

One possible solar technology application is solar UV-catalyzed ozonation - the use of ozone in conjunction with UV light - to enhance and speed up the oxidation of VOCs.

Information on this site was obtained from the U.S. Air Force, the EPA, the U.S. Geological Survey, and the Arizona Department of Environmental Quality.

3) Inorganics (26 Sites)

Aluminum, Arsenic, Boron, Chromium, Cyanide, Fluoride, Freon, Iron, Lead, Manganese, Nickel, Nitrates, Selenium, Sodium, Zinc

Representative Sites

Odessa Chromium I and II, two EPA Superfund sites, are located just outside the northwestern city limits of Odessa, Texas. The main problems at these sites are groundwater and soil contamination by elevated concentrations of chromium. At Odessa I, hexavalent chromium concentrations of up to 72 parts per million (ppm) in groundwater and 4977 ppm in soil were found. At Odessa II, concentrations were 9.9 ppm in groundwater and 720 ppm in soil. Lead, zinc, nickel, and copper were also found in soils at elevated levels.

No conventional treatment processes have started at these sites. A possible solar application is solar electric generation used in conjunction with conventional treatment processes.

Information on these sites was obtained from the EPA, Region VI, Dallas and the Texas Water Commission, Austin.

4) Biological (2 Sites)

Fecal Coliform

Representative Site

The New River is located in the Imperial Irrigation District, south of the Salton Sea in Southern California. The New River is a grossly polluted water course that enters California after flowing through the heart of Mexicali, Mexico. It is polluted within Mexicali by a number of contaminants, including industrial wastes, untreated and partially treated sewage, and wastes from hog and cattle pens, a slaughterhouse, and a dairy located along the river.

Samples taken from the New River, along its 60-mile course from the international border to the Salton Sea, revealed median concentrations of fecal coliform of 550,000 colonies, with a maximum of 8 million colonies.

Possible solar thermal applications to clean up this type of contamination have not been identified by the project at present.

Information on this site was obtained from the California Regional Water Quality Control Board, Colorado River Basin - Region 7.

5) Radioactive (4 Sites)

Radioisotopes, Radionuclides, Gross alpha, and Gross beta

Representative Site

The Tuba City Uranium Mill Tailings Site is located six miles east of Tuba City, Arizona on the Navajo Indian Reservation, Coconino County. Leachate from the tailings pile has contaminated the underlying groundwater with a variety of radionuclides, heavy metals, and other constituents associated with the uranium mining process. Estimates are that 1.1 billion gallons of water are contaminated. Approximately five times this amount (5.5 billion gallons) must be removed from the aquifer to sweep the contaminated water out of the system.

Samples from within the contaminant plume have revealed concentrations of cadmium, gross alpha, selenium, and nitrate that exceed EPA Primary Drinking Water Standards. Gross alpha was found in concentrations ranging from 10 to 860 mg/l. The EPA primary standard is 3.0 mg/l. Concentrations of iron, manganese, TDS, and sulfate were found to exceed EPA Secondary Drinking Water Standards.

A possible solar thermal application at this site is the use of solar evaporation ponds to concentrate contaminated brine. The concentrated brine could be used to establish a solar salt-gradient pond to generate power for pumping and treating the groundwater.

Information on this site was obtained from a U.S. Department of Energy (DOE) report found during a literature search in the University of Arizona's main library, government documents section. This report led to calling the DOE to obtain reports on similar sites in the Southwest.

6) Toxic and Hazardous Waste Disposal (9 Sites)

Representative Site

Hardage-Criner Hazardous/Industrial Waste Disposal Facility, an EPA Superfund Site, is located 30 miles southwest of Oklahoma City in McClain County. The facility operated from 1972 to 1980 and received some 20 million gallons of industrial wastes from Oklahoma and Texas. The 60-acre site contains a 1.5-acre sludge mound which is 15-20 feet thick, and a drum mound 0.8 acres in area which is 30-40 feet thick. The drum mound may contain over 20,000 drums filled with waste materials.

Groundwater contamination has occurred at this site as a result of improper disposal practices. The principal groundwater pollutants and their corresponding maximum concentrations include: 1,2-DCA (350 ppm); 1,1,2-TCA (54 ppm); PCE (24 ppm); and TCE (36 ppm). Other contaminants include: toxaphene, arsenic, solvents, pesticides, PCB oils, paint sludge, ink, and heavy metals.

One possible solar thermal application at this site and other similar disposal facilities is solar powered/enhanced incineration.

Information on this site was obtained from the EPA, Region VI, Dallas.

DISCUSSION

Collection of data on water contamination is not an easy nor a straightforward process. Many limitations and obstacles were encountered during data collection, including (1) not knowing if all the correct and/or most appropriate contacts were made concerning a specific problem or site, (2) the inability to ascertain whether all contacts were willing and/or able to supply complete, accurate, and up-to-date information, (3) some important sources of information may have been completely bypassed, (4) waiting for reports and materials to arrive by mail from requests made by correspondence and telephone contacts was often time-consuming and nearly always required follow-up, while pre-arranged office visits often yielded immediate results, and (5) the requirement by some federal agencies that information on some sites can be released only through the Freedom of Information Act, which also can be quite time consuming.

Although many water contamination and waste disposal sites are known,

few to date have been fully investigated and/or documented, therefore no information is yet available on many of these sites. Different agencies may be dealing with the same problem, but may or may not have joint oversight responsibilities. The main problem in attempting to compile a data base on water contamination sites is that no one source or central depository of information on these sites exists. With so many water contamination sites in the United States - the U.S. Military Services alone have some 3,700 known sites - there is a definite need for such a central depository or clearinghouse.

THE QANATS OF YAZD

Jeffrey Zauderer
Office of Arid Land Studies
(University of Arizona)
845 N. Park,
Tucson, Az. 85719

Intoduction

Qanats are underground infiltration galleries excavated into water-bearing sediments of piedmont and alluvial fans. They can be considered as structures that drain a sloping aquifer (Bybordi, 1974; Schmid and Luthin, 1964). The gradient of qanats in a region is a function of tunnel length, water table elevation, and depth of mother well (highest well upslope). Gradients may vary from 4 to more than 10 o/oo (Mahdevi and Anderson, 1983). Once a slope is fixed, the yield is a function of the height of saturated alluvium above the tunnel, the slope of the water table, and the length of the tunnel into the saturated zone. In the Yazd region, qanat lengths can be from 40 to 0.35 km. The deepest well is about 120 m deep. Discharges vary from 400 to 1 cubic meter per hour. Water tables are phreatic, with gradients of 8 m/1000 in Taft, 10.8 m/1000 in Mehriz, and 2.7 m/1000 in the Yazd-Ardakan alluvial valley.

Achaemenid and Sassanians spread the use of qanats to the arid fringes of their extensive empires (English, 1968). The interior of Iran on the Central Plateau was settled by the Sassanians: Kirman in the early period, Yazd in the later period. Mehriz was established by Mehrnigar, daughter of Xosrau I (531-579) (Bonine, 1980).

The construction of qanats in the Yazd area was dependent upon a flourishing economy and stable politics. The area escaped Mongol devastation. In later times, qanats were built by provincial governors in the later half of the 18th century. During the Qajar period, several long-term officials were responsible for adding gardens and qanats to Yazd and Taft. Mushir al-Mamalik, head of the Qajar finance office for 4 decades in Yazd (Bonine, 1980) built a great branched qanat supplying Yazd from alluvial channels in the Shir Kuh 40 km distant.

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Studies in the trade and econimic networks of settlement in the Yazd-Shir Kuh area, the social and physical organizations of water use and distribution, and the impact of qanats on urban morphology (Bonine, 1979, 1980, 1982), as well as contempory Zproastrian agricultural practices (Boyce, 1969), link the various ways of Yazdi life to water supplied by qanats.

This paper aims to identify and inter-relate the physical characteristics of the geo-hydrologic system with settlement and agriculture location, water use, and supply. The major sources of information are Landsat images of the area (Dec. and Aug. 1973), (plate 1), and a report of the Ministry of Water and Power, 1974 for the Yazd region (Fahrzadi, 1974). Figure 1 shows the location of Yazd within the major features of Iran.

Results and Discusion

Regional Characteristics

The Shir Kuh, the region's highest mountains, lie in the north-western nose of the Central Iranian Plateau fold structure (Issar, 1969) containing thick Mio-Pliocene folded argillaceous lacustrine deposits of low transmissivity, and thick Pleistocene alluvial deposits; good aquifers, especially where they extend from Creatceous limestiones, prominently carved into scarp-breaching valleys, and dip-slope branching channels. Massive Jurassic sandstones are cliff formers near Taft. Near Mehriz is a fault scarp lineation of indurated Pliocene conglomerates. Tertiary-aged andesites occur in the Mehriz area, along the southwest, and west of the range.

The area has a yearly water deficit, but receives precipitation in winter as a result of easternmost extensions of Mediterranean lows. Only the Shir Kuh near Yazd and the mountains near Kirman in the southern nose of the fold structure are high enough to wring moisture from the winter atmospheric lows that move over the area. Figure 5 (data from Fahrzadi, 1974) shows the average monthly precipitation for 3 stations seen on figure 2. Montane vegetation is mostly limited to the upper wide openings of deeply cut valleys.

Figure 2 is a contour map of the area made by integrating topographic information with several Landsat images of differing solar azimuths and elevations. This map allows for the planimetric estimation of surface areas used for computation.

Figure 3 is a map of features seen on plate 1, including areas of active agriculture. This figure shows the myriad deeply cut valleys filled with coarse alluvium. A band of reflective fine-grained alluvium extends from Taft and curves behind the Shir Kuh. A coarse fan with wide and incised channels extends into the reflective inner alluvium of the Mehriz basin. Snow lies in the

figure's white areas above 9000 feet, filling high montane
valleys.   Arrows indicate the direction of surface runoff and
infiltrated water flow.   The Pliocene conglomerate outcroppings
cut across the basin west of Mehriz.

Notice that most of the agricultural fields occur at the base
of extensive Pleistocene alluvial fans, and extend downslope
toward Ardakan.   The fields have a lineation indicating their
water supply: sources from Yazd or Taft.   The alluvial valley,
where not irrigated, has the high reflectance of dunes and salt.

Yazd and Ardakan grow wheat, most of the region's cotton and
pistacios. Yazd hyas half the region's almonds, and most of the
grapes.   Ardakan grows half of the region's pomegranates, figs,
and mulberry. Mehriz grows some wheat and barley, in addition of
orchard crops.

The cultivated fields in this figure are active in winter,
and watered by qanats.   Recent pumpwells are used to maintain
summer crops and orchards in June through August.

Figure 6 shows the hydrographs for Taft and Ibrahimabad,
which is inside the Mehriz basin.   The peaks occur at the April
decline of rainfall, about one month after the maximum average
rainfall when snow is melting and flooding the deep valleys into
the alluvial basins.   The Ibrahimabad station shows a longer
period of groundwater recession than Taft: this is probably due
to the effect of the Pliocene conglomerate, which acts as a
groundwater dam.   The general month's difference between
groundwater maximum height and maximum averagr rainfall represents
the infiltration time.

Figure 4 shows representative qanat paths.   The Mehriz area
supports more qanat systems and agruculture than the Taft area.
Qanats distribute water from the Yazd system downslope to Ardakan.

Results

Figure 7 shows two measures of yearly discharge into the
Mehriz   basin,   Q1   and   Q2,   in relation to surface area,
evapotranspiration (Et), precipitation (Ppt), and elevation.   The
curve Ppt-Et is an estimate of surface runoff plus infiltration.
ΔFl is obtained from the relation ΔFl/Ppt = exp $[-(Et/Ppt)]$
(Sellers, 1965).   The curve Q1 = Ppt-Et x area gives a lower
measure than Q2 = ΔFl x area: ΔFl gives more runoff at lower
elevations where Et exceeds Ppt, and so may be a more realistic
measure for desert winter flood conditions.

The boundary of the Mehriz watershed encloses about 720 sq
km.   Effective precipitation begins at about 7000 feet elevation.
The watershed area above 7000 feet is about 375 sq km.   Snow above
9000 feet covers 160 sq km.   The interior basin below 6000 feet
bounded by the Pliocene conglomerate encloses about 115 sq km.

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Based on the area above 7000 feet, Q1 total = 67.5 million cubic meters. Q2 total = 82 million cubic meters. Another measure of runoff, $\Delta F2/Ppt = 1-[Et/Ppt \; (\tanh \; Ppt/Et)]$ gives a total Q3 = 75 million cubic meters (not shown on figure 7). Fahrzadi (1974), for a total of 116 qanats in the Mehriz-Yazd system, gives a yearly total discharge of nearly 62 million cubic meters.

The recharge of the Mehriz basin is sufficient to supply the observed system discharges for the area's qanats. Ardakan is supplied by water that passes through the Yazd system and the Taft alluvial fan. (Fahrzadi estimates the Ardakan qanat yearly discharge at 67 million cubic meters, and the discharge of Taft qanats as nearly 57 million cubic meters per year.)

Conclusion

Life and irrigated agriculture in the Shir Kuh system is sustained by the happy confluence of of three factors:

1) Mountains of sufficient heitht and area to wring upper level moisture derived from the Mediterranean, and store it as snow until April. Rain at lower elevations maintains antecedent moisture conditions in alluvium and slope surfaces so that the melt water floods pass through the deep limestone valleys into the basin alluvium. Thus, snow melt-water with a short delay caused by groundwater flow time of the recharge wave feeds the qanats, whose discharges will follow the hydrograph trends.

2) Favorable geology. The interface of Cretaceous limestones, and their favorable structural attitude with the coarse Pliestocene alluvial fans, allows quick recharge from montane flow into the Mehriz basin. An active wet Pleistocene was responsible for the extensive dissection of the structure, and development of coarse piedmont and alluvial fans. Pleistocene groundwater poobably keeps the modern yearly fluctuation of ground water levels within reach of qanats. The occurrence of the fault and Pliocene conglomerate across the basin, acting as a dam, allows the qanats to drain the basin more efficiently.

3) Periods of political and economic stability, and the region's connection to a larger social network, allowed for the extensive capitalization needed to develop and maintain qanats.

The qanat systems of the Yazd-Shir Kuh presently are in equilibrium with the winter-spring recharge. On the whole, it supports about 60,000 souls and extensive agriculture. Extending the area drained by qanats would maximize recharge use, but the total discharge would still be limited by the system recharge.
The present qanat systems are close to the average recharge

volumes.   Pumpwell   development   in the Mehriz basin could cause most of the qanats to dry.

ACKNOWLEGEMENT

My appreciation to Dr. M.E.   Bonine   of   the   Middle Eastern Studies and Arid Land studies faculty, University of Arizona, for the generous use of his research materials.

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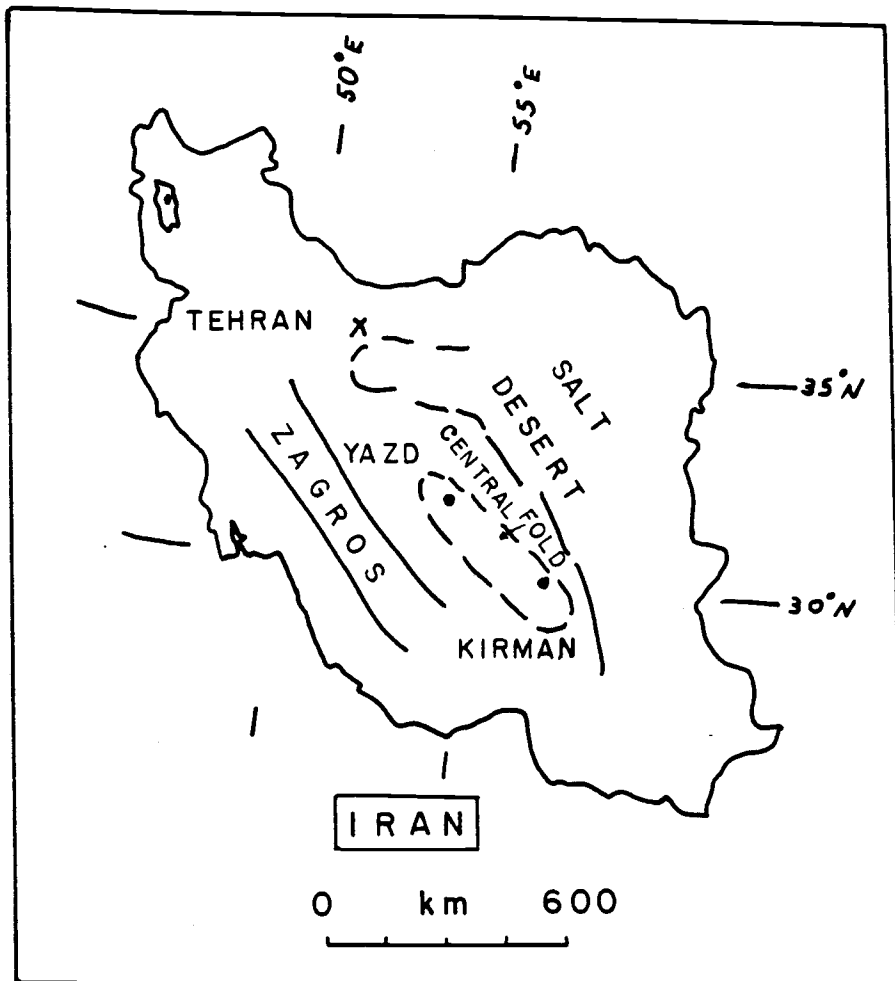   Chicago Press, Chicago. 272 pp.

FIGURE 1. GEOMORPHIC SETTING OF YAZD
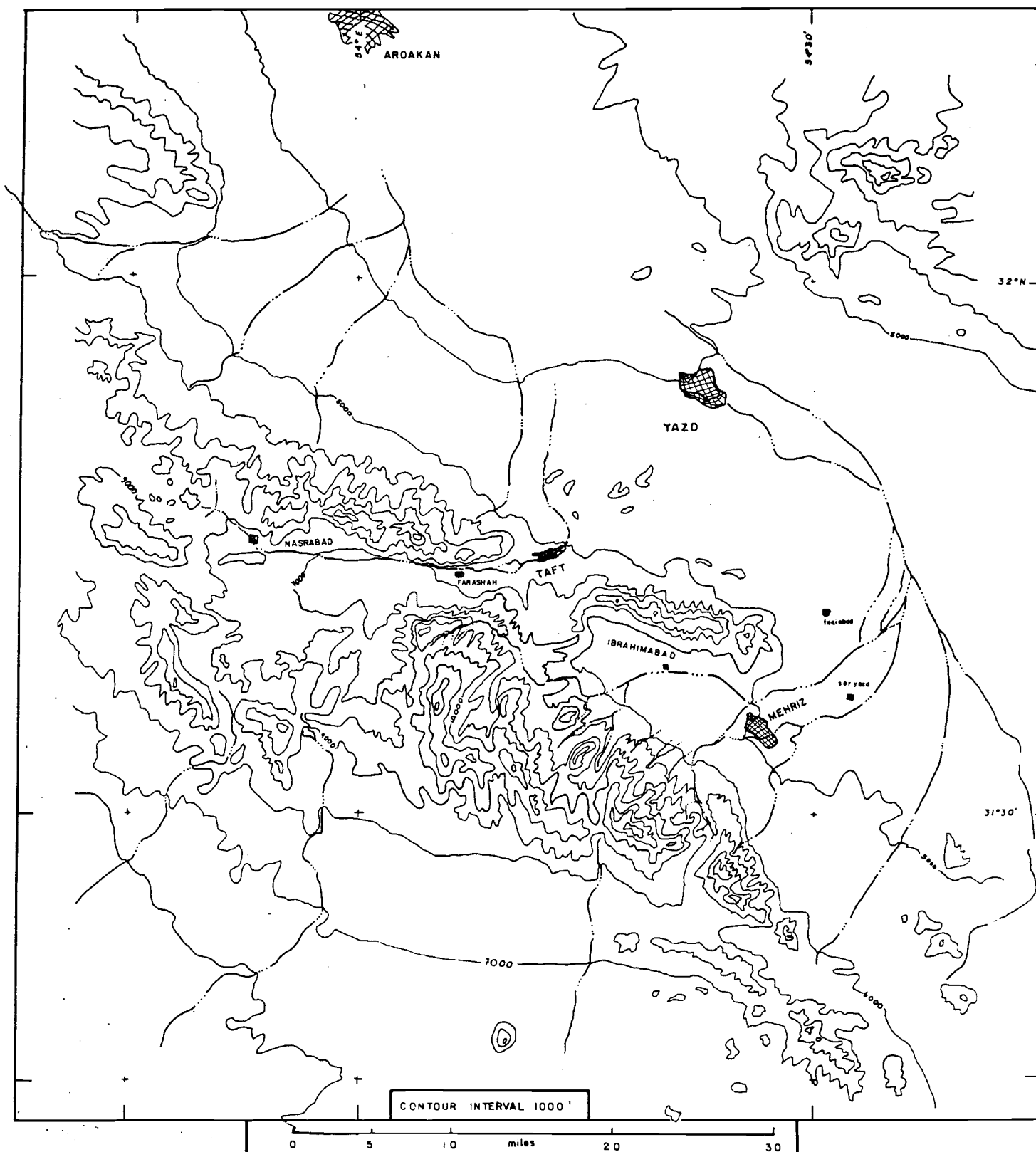
PLATE 1.   WINTER LANDSAT SCENE, BAND 5, OF SHIR KUH AREA

FIGURE 2. CONTOUR MAP OF SHIR KUH AREA DRAWN TO LANDSAT IMAGE
BASE

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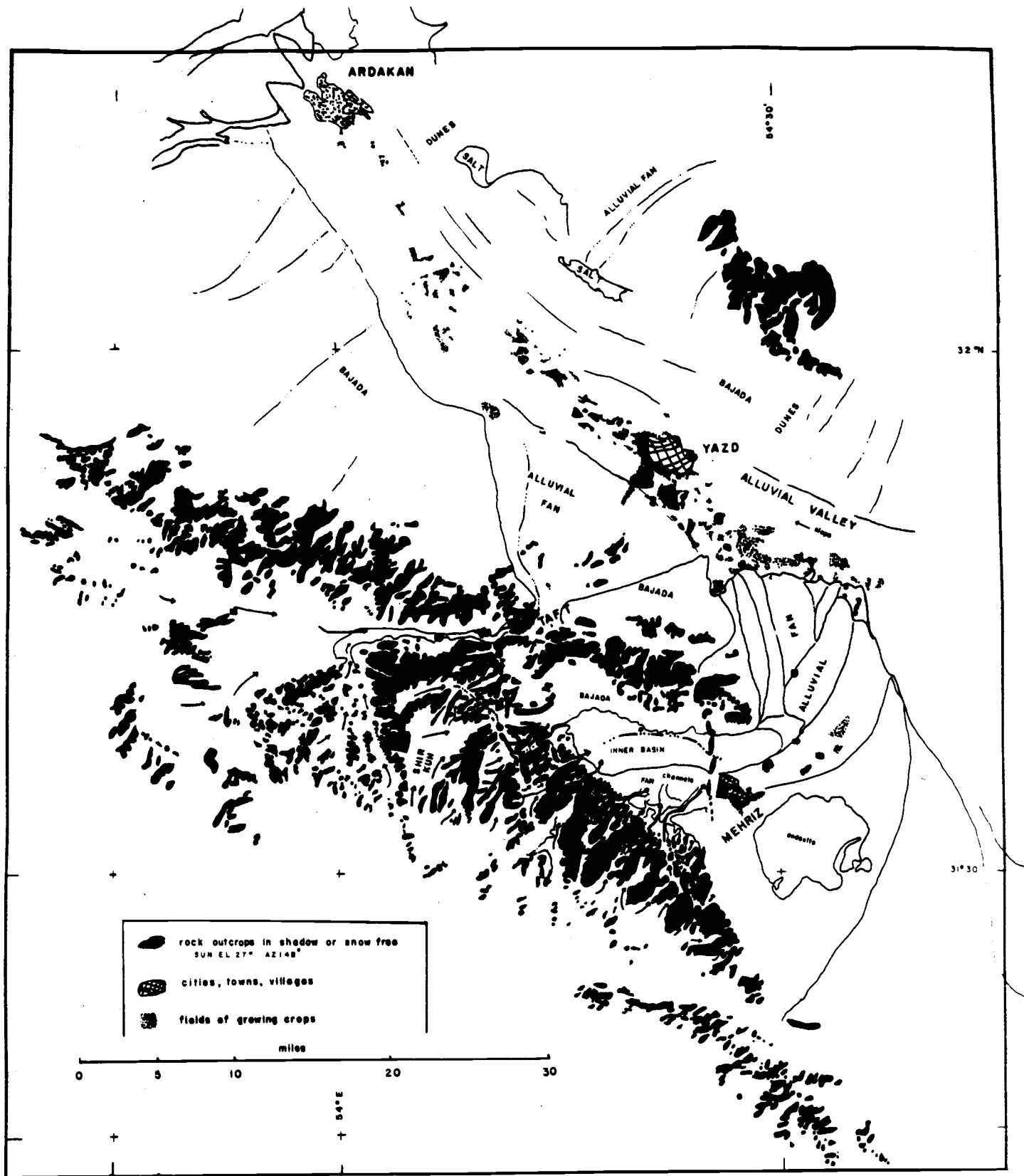
FIGURE 3. FEATURES SEEN ON LANDSAT WINTER SCENE OF SHIR KUH AREA

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Within the figure:

ARDAKAN

REPRESENTATIVE QANAT PATHS
IN THE YAZD-SHIRKUH
SYSTEM.

bajada

YAZD

alluvial valley

alluvial fan

TAF[T

bajada

alluvial fan

MEHRIZ

REPRESENTATIVE
QANAT PATHS

miles

0   5   15

54° 30'

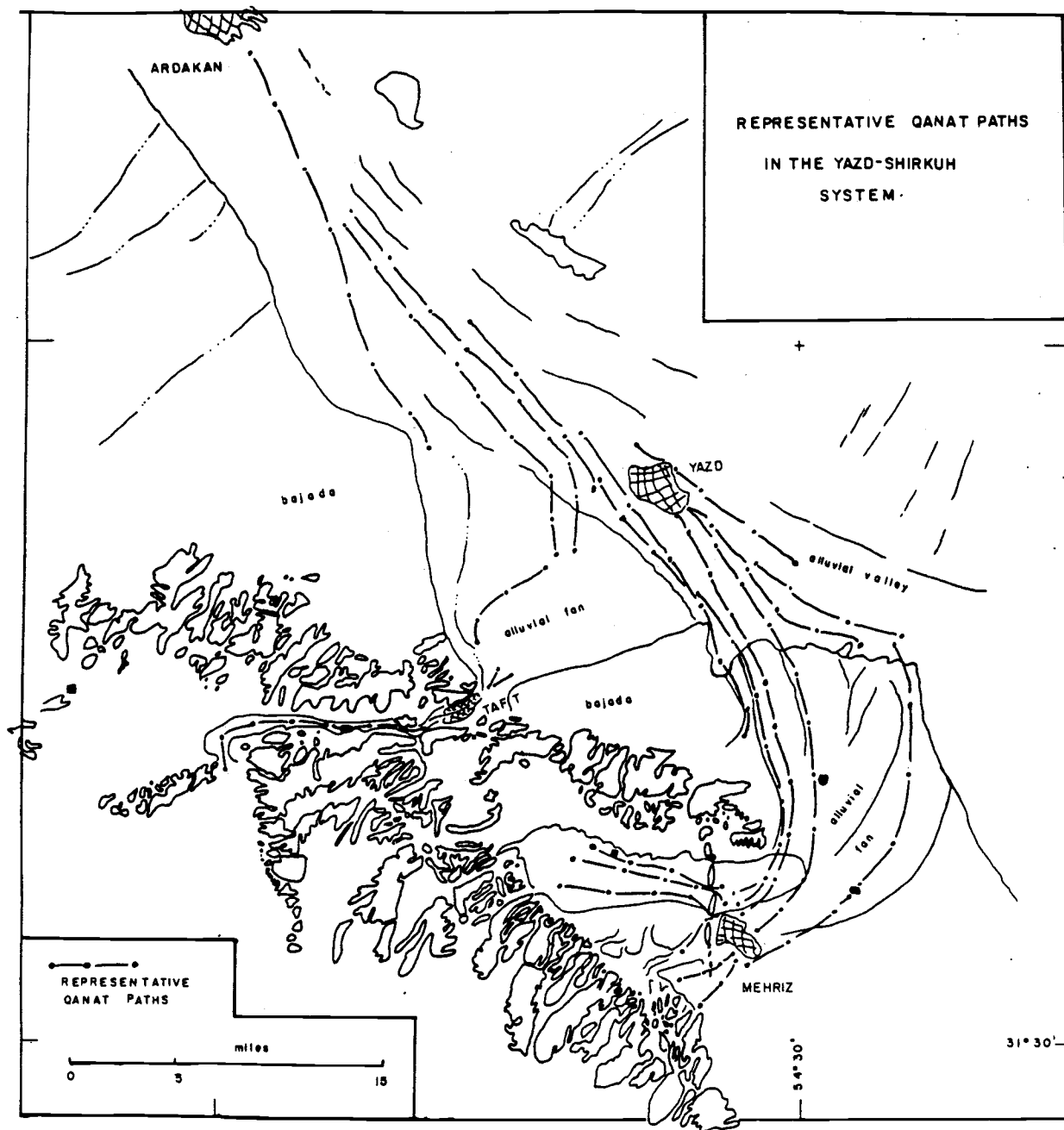31° 30'

FIGURE 4. REPRESENTATIVE QANAT SYSTEMS OF SHIR KUH AREA
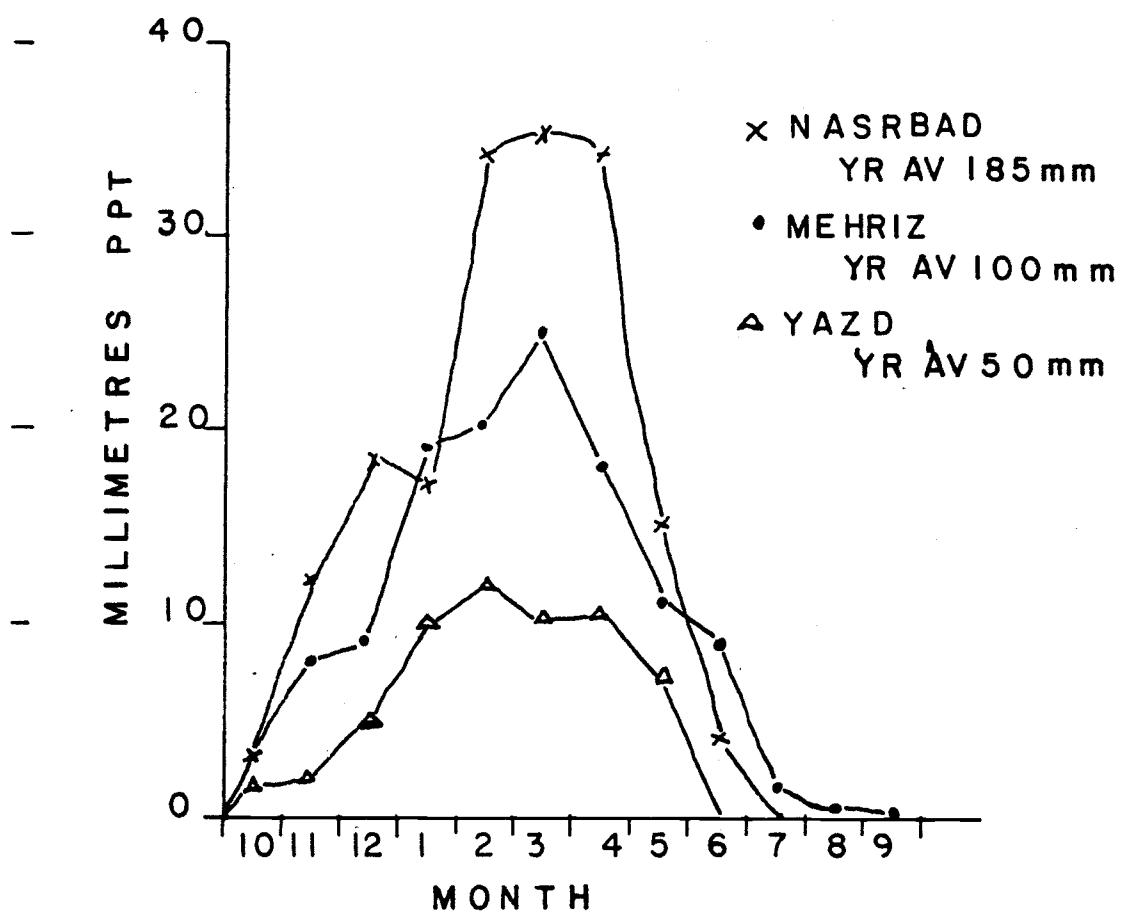
FIGURE 5. AVERAGE MONTHLY PRECIPITATION IN THE SHIR KUH AREA.
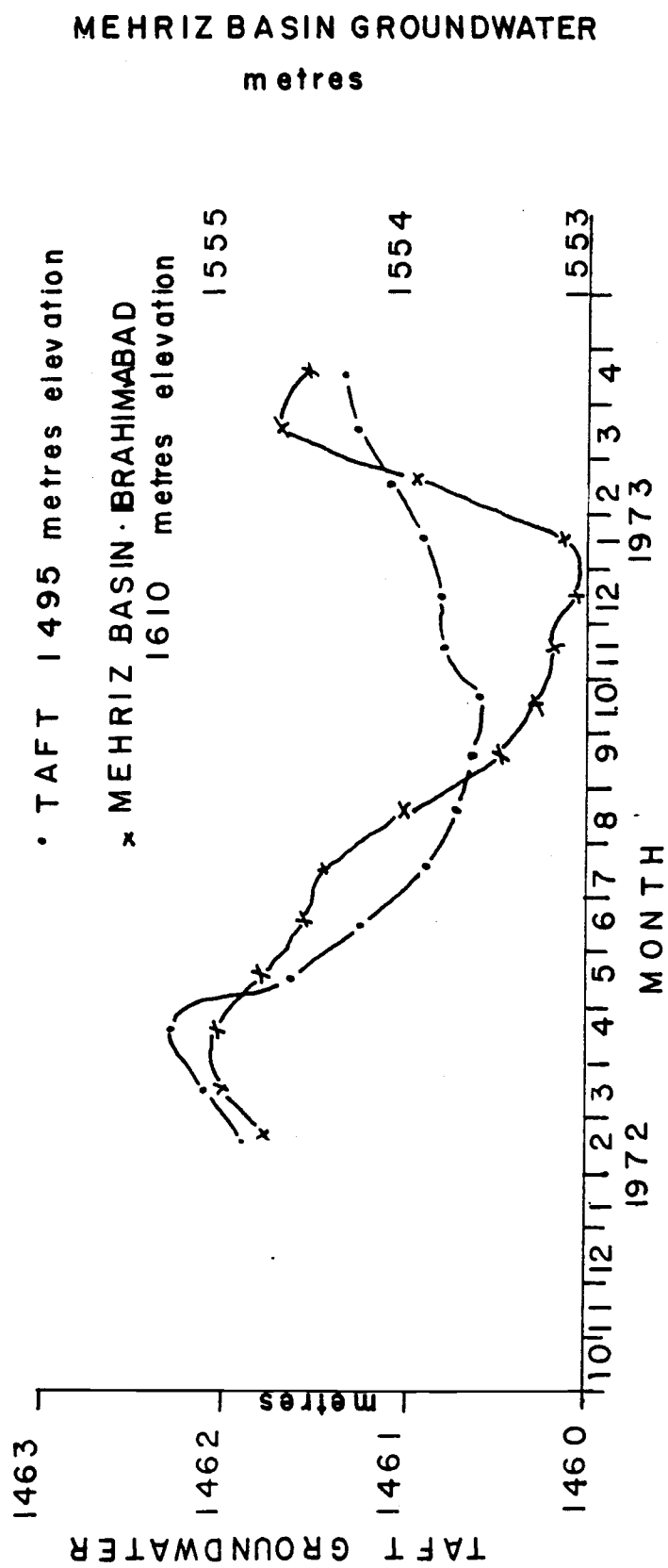(DATA FROM FAHRZADI, 1974)

MEHRIZ BASIN GROUNDWATER
metres

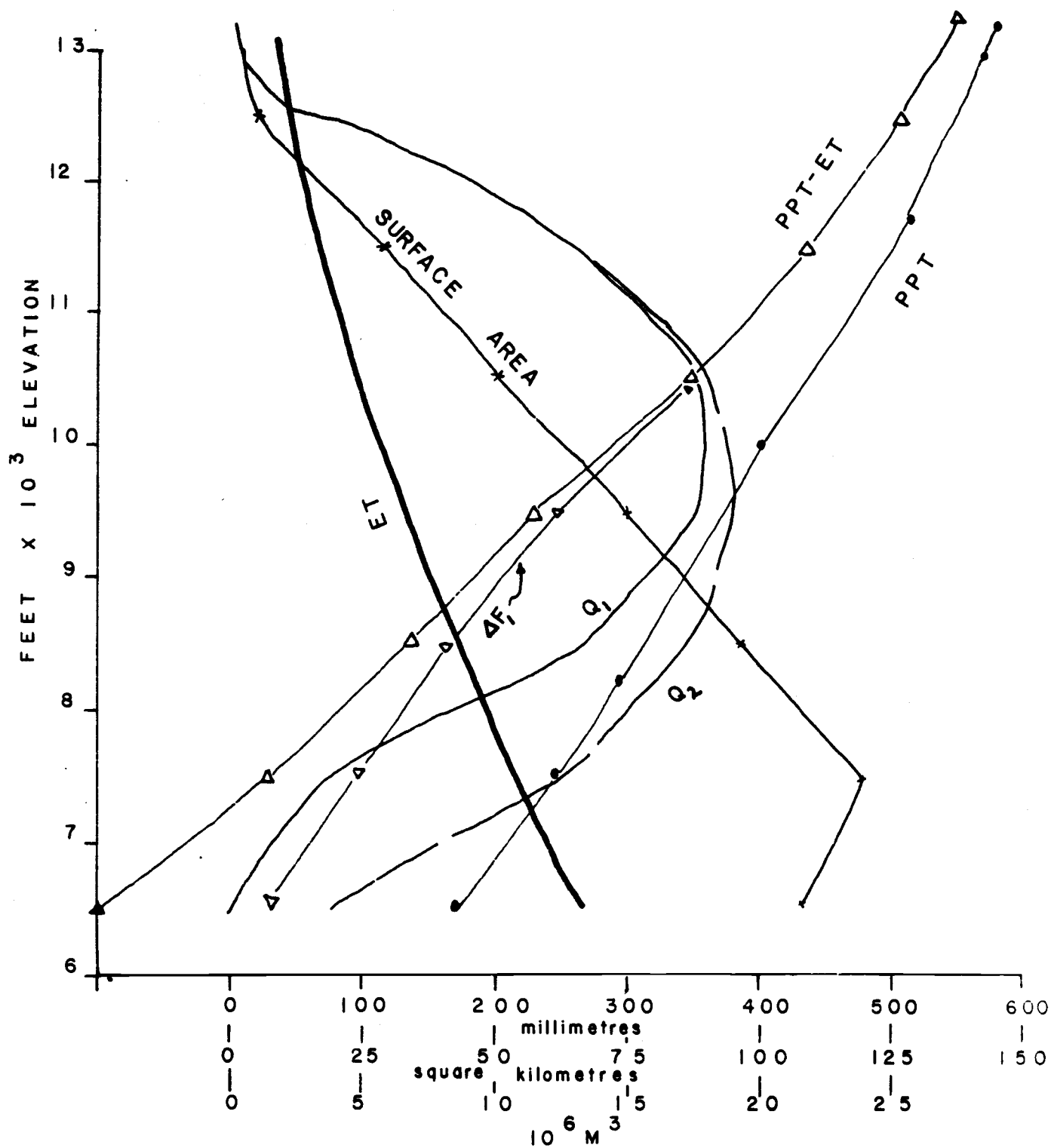FIGURE 6. HYDROGRAPHS OF TAFT AND IBRAHIMABAD.
(DATA FROM FAHRZADI, 1974)

FIGURE 7. SUMMARY CURVES SHOWING ELEVATION VARIATIONS FOR SURFACE AREA (IN SQ KM), ET (IN MM), PPT (IM MM), PPT-ET (IN MM), ΔF1 (IM MM), Q1 AND Q2 (IN MILLION CUBIC METERS).

THE SECOND MANAGEMENT PLAN:
A MANAGEMENT STRATEGY FOR THE 1990s

by

Katharine L. Jacobs, Director
Tucson Active Management Area
Arizona Department of Water Resources

The Arizona Department of Water Resources is now entering the
second phase of a five-phase process which is intended to
eliminate overdraft of the groundwater supplies by the year 2025
in selected parts of the state. The majority of Arizona's water
users are within regions of the state called "active management
areas" (AMAs). It is within these four geographic areas that the
conservation and augmentation efforts required by the 1980
Groundwater Management Act are focused.

The goal of the management efforts in the Prescott, Phoenix and
Tucson AMAs is to achieve safe-yield, resulting in a balance
between demand for groundwater and the average rate of
replenishment. The Pinal AMA's goal as stated in the Code is
less defined; it requires extending the agricultural economy for
as long as possible while preserving groundwater supplies for
non-irrigation uses. Groundwater depletions in the four areas
have been ongoing since the 1940s, when agricultural water use
expanded rapidly in central and southern Arizona. More recently,
rapid urbanization has placed increasing demands on the state's
groundwater supplies.

The primary tools that are available to the Department to control
demand for groundwater are the Management Plans, which contain
mandatory conservation requirements for most municipal,
industrial and agricultural water users within the AMAs. Other
tools include limitations on drilling new large wells, a
prohibition on bringing new irrigated land into production, and a
provision which precludes subdividing land in the absence of a
100 year assured water supply for the proposed development.

The First Management Plan (FMP) for the period 1980-1990 was
adopted in December of 1984; its requirements were not
enforceable until calendar year 1987. The FMP was an important
first step towards the goal of safe yield, but was viewed in part
as a vehicle to establish the management structure for subsequent
plans. The data base available when the first plan was written
was somewhat limited, since mandatory metering requirements went
into effect the same year it was drafted. Since then, DWR staff
have had significantly more opportunity to assemble water use
data and analyze alternative conservation approaches.

Maximum Reasonable Conservation

In contrast to the First Management Plan, the conservation goals
in the Second Management Plan have been deliberately designed to
achieve the maximum reasonable level of conservation in all
sectors. The Groundwater Code actually requires that
requirements for the agricultural sector "assume the maximum
conservation consistent with prudent long-term farm management
practices." Industrial users are required to use the "latest
commercially available conservation technology consistant with
reasonable economic return." The language in the Code is less
specific for municipal users than that for other sectors, but the
approach used in setting the municipal targets incorporated the
"maximum reasonable" concept.

DWR's strong conservation approach in the SMP reflects the
Department's philosophy that establishing high expectations for
conservation in the early years will make the safe yield goal
more achievable. The majority of the water users who will be
served in 2025 have not yet moved to Arizona. With one of the
fastest growth rates in the country, it is important that DWR
require new users to start out with low water use landscaping,
low flow plumbing devices, and an understanding of the water
management strategies that are appropriate for this area. It is
far easier for social and economic reasons to build-in water
conservation "from the ground up" than to expect significant
retrofitting at a later date. Also, reductions in water demand
in the early years will result in higher groundwater levels when
the safe-yield goal is reached, since less water will have been
removed from the aquifer. Higher groundwater levels relate to
reduced pumping costs, better water quality, and reduced risk of
subsidence.

Greater Degree of Specificity

The Second Management Plan (SMP) is far more detailed than the
FMP for reasons in addition to the availability of a better data
base. In order to eliminate problems that have been identified
in the First Plan, the SMP is far more individually tailored,
especially in the municipal program. For example, the FMP used
an across-the-board percent reduction for all municipal providers
whose 1980 water use rate exceeded 140 gallons per capita per
day. The SMP contains target rates that are based on an
individual analysis of the conservation potential of the
approximately 100 large providers in the four AMAs. The
conservation potential analysis required the development of a
detailed data base for each provider, enabling disaggregation of
residential-vs-non-residential, single-vs-multifamily, and
interior-vs-exterior water use patterns in each service area.
Water use projections for each sector enabled identification of
new-vs-existing users. In each service area, conservation
measures were selected which would be appropriate for
implementation in the water use categories which were determined
to have conservation potential.

There are several other examples of areas in which the SMP
requirements have greater specificity than the FMP version. The
requirements for turf and "other industries" are more tailored to
the water use patterns of the affected facilities. In the
agricultural sector, the program is laid out in a manner quite
similar to that in the FMP, but the water allocations are based
on an analysis that is far more detailed than the original
version.

Effluent Use Incentives/Requirements

The FMP baseline assumed 100% of the effluent generated within
the AMA would be reused by 1990. This assumption proved to be
overly optimistic. In the SMP, it is assumed that 60% of the
total effluent generated in the AMA will be used by 2000 (50,000
acre feet). This number has also generated questions about how
realistic the effluent use projections are. In 1985, 11% of the
effluent generated was being used.

In light of these concerns, stronger effluent use incentives have
been built into the SMP, and for the first time, there are also
effluent use requirements included. The draft plan is expected
to undergo further revisions to expand the incentives for
effluent use, but at present they include the following:*

Municipal

o Effluent does not count against a municipal provider's
   gallons per capita per day target. This target is
   calculated by taking the total water withdrawn, diverted
   or received except effluent, and dividing this number by
   the population served.

Industrial

o Turf facilities that use effluent are given an additional
   $\frac{1}{2}$ acre-foot per acre per year in their maximum annual
   water allotment

o Effluent lakes on new golf courses are not limited in
   size, while potable water lakes are indirectly limited
   through the allotment

o Turf facilities that experience technical difficulties
   associated with effluent use may apply for a modification
   of their allotment. In addition, a leaching allowance
   can be obtained as needed.

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* Since this paper was presented, a 10% discount rate for
  effluent use has been added for agricultural users, and the
  turf application incentive in the Phoenix AMA has been
  increased to one acre-foot per acre per year.

o Cooling towers (in excess of 250 tons of cooling
capacity) are exempt from recycling requirements if they
use effluent.

o New large landscape users (in excess of 10,000 square
feet of water-intensive vegetation) are exempt from
acreage limitations if they use effluent.

o Augmentation grant funds may be available to fund certain
effluent-related projects.

In addition to the incentives listed above, new turf facilities
built after 1990 must use effluent to serve at least 50% of their
total annual water requirements after 1995. The incentive rate
is set to encourage users to exceed the 50% requirement. Thus,
those who exceed the 50% figure get 0.3 acre-feet per acre of
effluent incentive, and those in excess of 90% effluent use get
0.5 acre-feet.

Sand and gravel and metal mining facilities are both required to
evaluate the potential for effluent use.

Expanded Augmentation Program

The Augmentation Program that was contained in the FMP for Tucson
related to a specific project, the Alamo Wash/Rillito Recharge
Project. An amendment to the FMP document contained the
rationale for development of this project, which is a multi-
agency cooperative effort that is currently in the feasibility
assessment phase. The Alamo/Rillito project was intended to
demonstrate how urban floodflows could be safely charged into the
aquifer. Effluent and CAP water may also be considered for
recharge at that site.

The SMP Augmentation Program contains a complete assessment of
five new sources of supply for the Tucson Basin, and evaluates
the role of effluent use and artificial recharge as a storage
mechanism. The evaluation is done on both a statewide and a
local level for the following augmentation options:

o Expanded utilization of CAP/Plan 6
o Storm water runoff
o Water transfers
o Watershed management
o Weather modification

In addition to this assessment of potential augmentation
measures, the SMP develops goals and objectives for the TAMA, and
defines the role the Department is likely to take in regional
supply enhancement schemes. The chapter also establishes
criteria for determining consistency with management plan goals
to be used in evaluating underground storage and recovery
projects. Finally, the SMP prescribes the development of an
augmentation grants program to be allocated to entities that

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intend to build augmentation projects and do planning and feasibility studies. The grants will be supported by the augmentation fees collected within TAMA.

Water Quality

The Code requires that DWR include, for the first time, a water quality assessment in the SMP. A program for water quality management is optional under the Code, but DWR is specifically directed to seek legislation that authorizes any new water quality management programs that are deemed to be necessary. The SMP water quality program includes an assessment of six major constituents found in groundwater. It was determined that the water quality management program could be achieved within existing authority given that primary responsibility for water quality protection rests with the Department of Environmental Quality.

The importance of water quality issues in the overall water management picture should not be underestimated. Use limitations associated with poor quality water may have a significant impact on the AMA's ability to achieve safe-yield and to demonstrate 100 year assured supplies.

The constituents that were evaluated as part of the assessment included the following:

    o Total dissolved solids
    o Sulfates
    o Nitrates
    o Metals
    o. Pesticides
    o Volatile organic compounds

In general, it was found that groundwater quality in the Tucson AMA is excellent. Maps of the occurence of these constituents have been included in the Plan. The groundwater management strategy proposed by the Department incorporates water quality considerations into rule packages that are presently being developed on the following subjects:

    o Assured water supply
    o Well construction and drillers licensing
    o Well spacing/impacts analysis
    o Groundwater withdrawal permits
    o Recharge and underground storage and recovery projects

In addition to this effort, the DWR has committed to an ongoing water quality assessment program and evaluation of incentives for the use of poor quality water.

Conservation Assistance

The Second Management Plan alludes to the Department's commitment to assist water users in meeting conservation requirements. It is anticipated that the Department will be very active in development of education materials and providing technical assistance to various water users. The program is presently being developed, but will definitely include several strategies. Sample conservation programs, demonstration projects and cooperative programs will be developed. Consultants may be engaged to provide detailed technical assistance to user groups. DWR staff will facilitiate ongoing conservation activities through public presentations, interagency coordination, development of educational materials, and flexible compliance programs.

Conclusion

The Second Management Plan provides a comprehensive water management strategy for the 1990's. From the perspective of the Tucson AMA, a number of the limitations of the First Management Plan approach have been addressed through the use of a more comprehensive data base and a more tailored regulatory approach. Greater emphasis on "maximum reasonable" levels of conservation is complemented by a greatly expanded augmentation effort. The water quality considerations that are crucial to integrated, effective water policy have been identified. Finally, DWR has committed to an ongoing partnership with water users in achieving regional conservation goals.

THE PHOENIX WATER RESOURCE PLAN--1987

PHIL REGLI[1]

ABSTRACT: The Phoenix Water Resource Plan--1987 is the official water resource plan for the City of Phoenix, Arizona. It covers the areas of supply, demand management and supply augmentation. The plan also addresses the issue of drought management.
KEY TERMS: Water resource plan; demand management; supply augmentation; drought.

INTRODUCTION

The Phoenix Water Resource Plan--1987 is part of an ongoing planning process to meet the water needs of the City of Phoenix in both normal and drought periods. The city will meet water demands during normal or drought period through supply augmentation and by reducing water demand through conservation. To address potential water problems, the plan was broken up into three areas: the current supply and demand situation, water conservation through demand management, and supply augmentation through obtaining new supplies or exploring new avenues of water reuse.

The City of Phoenix is divided into two water service areas (Map 1). The Salt River Project water service area, referred to as "on-project," and consists of lands with a right to water stored behind Salt River and Verde river dams. Lands not located on-project are referred to as "off-project". Some land located within the project boundaries, but without water rights, are referred to as "non-member lands" and are part of the second service area, the off-project area.

SUPPLY AND DEMAND

Demand

Fifty year water demand projections for both the on- and off-project service areas were developed by incorporating the following factors: Population, weather, and current water conservation programs. The base demand was developed using population and historical water use. Then high and low water use levels were developed by incorporating weather related impacts. The base demand then was adjusted for the following conservation programs: Public Awareness Program, Water Rates changes, Building Code Revisions, and the Retrofit Program. The Public Awareness Program is an on-going public information program. It is estimated that this program will result in a 2.5 percent reduction in demand during the 50-year planning period (P&M 1986). Increasing block water rate schedules saved an estimated 10,700 acre feet in 1985 and are planned to maintain the same proportional savings throughout the planning period. The 1980 building code revision resulted in a 2,300 acre-ft/yr savings for 1985 based on a 40 percent compliance rate. The actual savings of this building code program are estimated to increase over the planning period. The home emergency plumbing retrofit program saved the city 2,700 acre-ft/yr by retrofiting 41,000 homes in 1985. This

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[1] Water Resource Specialist, City of Phoenix Water and Wastewater Department
455 N. 5th Street, Phoenix, AZ 85004

Future Water Service Area

N

Legend:
- ⊞ On-project
- ▦ Nonmember
- ▨ Off-project North of CAP
- ▧ Off-project South of CAP
- ◪ Area sold to Scottsdale

0 2 4 6
SCALE OF MILES

LAKE PLEASANT REGIONAL PARK

WADDELL DAM

FOREST

TONTO

32ND ST.

56TH ST.

JOMAX RD.

SCOTTSDALE RD.

AGUA FRIA RIVER

NEW RIVER

67TH AVE.

51ST AVE.

43RD AVE.

EL MIRAGE RD.

99TH AVE.

CAMELBACK RD.

BUCKEYE RD.

SALT RIVER

HIGHLINE CANAL

PECOS RD.
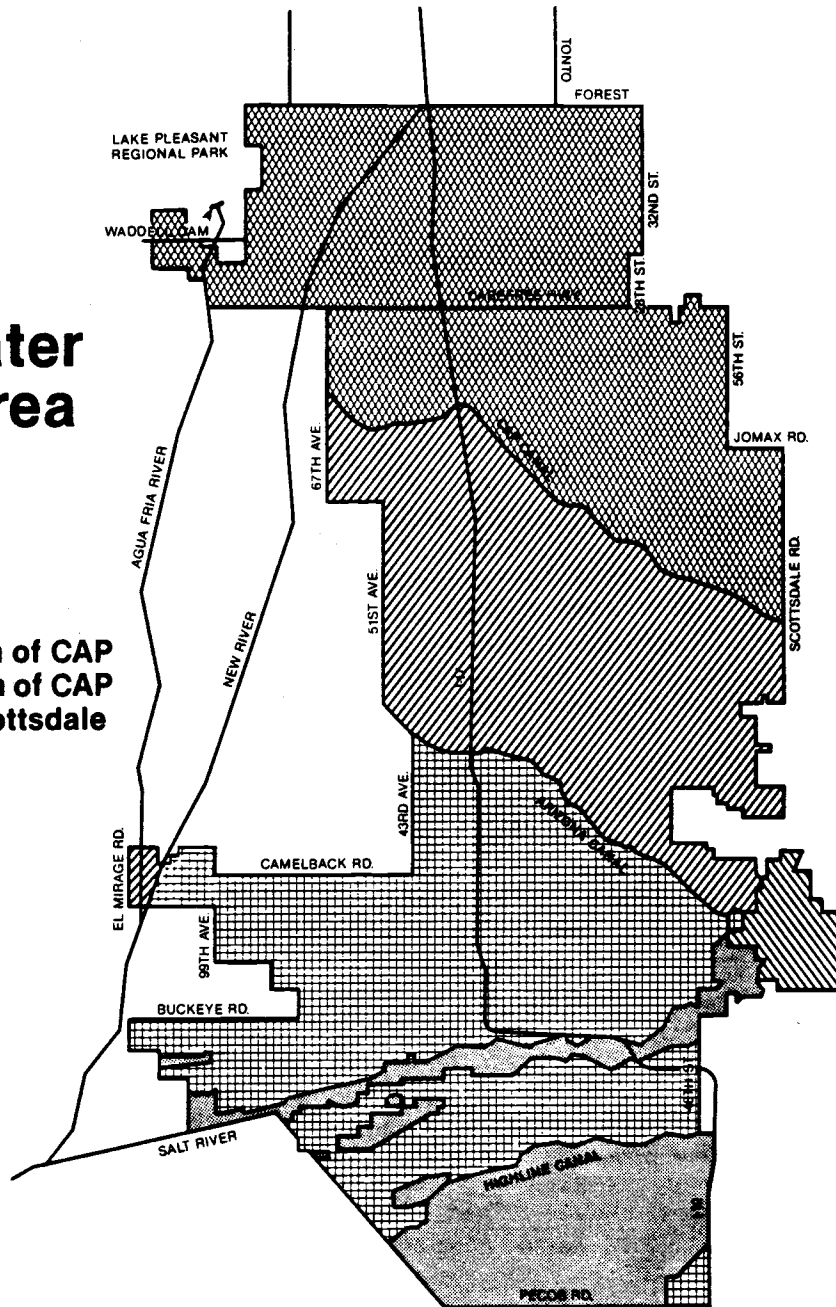
program's impact will diminish over the planning period. The combined savings of these four programs along with the base demand are presented in Table 1.

TABLE 1
ON-PROJECT AND OFF-PROJECT
SUPPLY & DEMAND
(Thousands of Acre Feet)

On-Project

Year	1985	2000	2015	2025	2035
Demand					
Unadjusted Demand	185	224	252	263	268
Conser. Programs Savings	12	17	21	23	25
Adjusted Demand	173	207	231	240	243
Supply					
a) SRP Surface	127	155	195	220	241
b) SRP Groundwater	63	48	24	0	0
c) Groundwater	28	18	7	0	0
Total Supply	218	221	226	220	241
Surplus (Deficit)	45	14	(5)	(20)	(2)

Off-Project

Year	1985	2000	2015	2025	2035
Demand					
Unadjusted Demand	107	198	259	284	294
Conser. Programs Savings	11	16	24	27	29
Adjusted Demand	96	182	235	257	265
Supply					
a) Groundwater	63	39	16	0	0
b) Gatewater	37	21	19	19	19
c) CAP	0	114	114	114	114
d) Effluent	0	2	2	2	2
e) Roosevelt Space	0	25	25	25	25
f) Mc Mullen Valley	0	30	30	30	30
Total Supply	100	231	206	190	190
Surplus (Deficit)	4	49	(29)	(67)	(75)

Supply

Salt River Project (SRP) provides water for the on-project area. In 1986 more than 193,000 acre-ft/yr of surface water was delivered by SRP and that will increase to 240,000 acre-ft/yr as agricultural land is converted to urban use (Table 1). Mined groundwater use will be reduced to zero by 2025, in compliance with the 1980 Arizona Groundwater Management Act. The off-project water supply consists of four sources: Groundwater, gatewater, freewater, and Central Arizona Project (CAP) water. Groundwater is the most dependable water supply in the off-project area and it needs to be preserved. The City of Phoenix used more than 63,000 acre-ft/yr of groundwater in 1985 and must reduce its mined groundwater use to 0 by 2025. Gatewater is captured water stored behind gates built on top of SRP's Horseshoe Dam spillway. SRP has projected gatewater use to 2000 will be 21,000 acre-feet/yr and then 19,600 acre-ft/yr thereafter. Gatewater is unpredictable and has the potential of dropping to zero in any given year. Free water is that released by SRP from the dams for lack of storage capacity. This water is free to all water users for use both on and off project. Since freewater is unpredictable it is not considered in long term supply projections.

Central Arizona Project has been delivering water to the City of Phoenix since May of 1986. Eventually it will deliver 113,882 acre-ft/yr of Colorado River water.

The city has made a financial commitment to the expansion of groundwater rights, conservation space at Roosevelt Dam, and the development of treated wastewater for turf irrigation (Table 1). In 1986 the City of Phoenix purchased approximately 14,000 acres of land in McMullen Valley west of the City for its groundwater rights. The city plans to withdraw 30,000 acre-ft/yr over the next 100 years and transport that water to Phoenix through the Central Arizona Project canal. New conservation space is being constructed on top of Roosevelt Dam to capture water traditionally lost during wetter than normal years. The amount of storage space has been estimated to be 11,250 acre-ft/yr. Reclaimed wastewater for turf irrigation soon will begin to have an impact on construction of golf courses. Two water treatment developments, the South Pointe and the Foothills, may use advanced wastewater treatment to support golf courses and lakes. Treated wastewater from these plants for appropriate uses is projected to save 1,800 acre-ft/yr of potable water supplies.

Current supply and demand figures are presented in Table 1. The demand for water exceeds projected supply by 2015 in both the on-and-off-project areas.

DROUGHT SUPPLY AND DEMAND

The Phoenix metropolitan area has experienced droughts during the last 100 years and can expect them to recur within the next 50 years. To plan for a drought, historical water flows had to be examined for both the Colorado River system and the Salt River and Verde River systems. In a drought, demand for water rises because an increase of sunny days. Supply of water would decline due to the lack of rainfall. It was then determined that Central Arizona Project, gatewater, freewater, and new conservation space would be reduced to zero in a severe drought. Surface flows from the Salt River and Verde River would be reduced to 60 percent of normal. These combined impacts are presented in Table 2. The end results show that supply to both the on-project and off-project areas will not be able to keep up with the demand throughout the planning period.

TABLE 2
ON-PROJECT AND OFF-PROJECT
SUPPLY AND DEMAND IN A SEVERE DROUGHT
(Thousands of Acre Feet)

On Project

YEAR	1985	2000	2015	2025	2035
High Demand with Conservation Saving	175	221	250	261	264
100 yr Drought Supply					
SRP Surface Water	76	93	117	132	145
SRP Groundwater	63	48	24	0	0
Groundwater Wells	28	18	7	0	0
Total Supply	167	159	148	132	145
Water Deficient	-8	-62	-102	-129	-119

Off-Project

YEAR	1985	2000	2015	2025	2035
High Demand with Conservation Sav.	118	232	208	324	334
100 yr. Drought Supply					
CAP	0	114	114	45	45
Gatewater/Roosevelt	37	0	0	0	0
Groundwater	63	40	16	0	0
McMullen Valley	0	30	30	30	30
Reclaimed Wastewater	0	2	2	2	2
Total Supply	100	186	172	77	77
Water Deficient	-18	-46	-126	-257	-267

FUTURE DEMAND MANAGEMENT

Water conservation alternatives were evaluated to determine how to reduce the forecasted water demands under both normal and drought conditions. A wide range of water conservation alternatives were evaluated based on applicability, technical feasibility, and social acceptability (P&M 86). If a water conservation alternative met those criteria it was then re-examined: How would the measure be implemented? What would be the duration of the measure? How effective is the measure? What are the direct and indirect costs.

Nine measures met the above criteria and were conceptually approved by the City Council. These measures in 2035 would save 52,400 acre-ft/yr on-project and 54,600 acre-ft/yr off-project (Table 3). That Demand Management Program will allow the City of Phoenix to meet the future water needs for the entire service area up to 2020.

That programs is described below.

Stricter Enforcement of Existing Plumbing Code:
The 1980 plumbing code requires 4 gallon-per-flush toilet and 3 gallon-per-minute showerheads. Compliance is currently at 40 percent. This code has not been strictly enforced. Full enforcement of this code would save approximately 1,000 acre-ft/yr by 1990 and 15,000 acre-ft/yr by 2035.

Retrofit:
A major retrofit program would be implemented to retrofit all homes constructed prior to 1980. The result of this program would be a savings of 8,400 acre-ft/yr by 1990, dropping to 3,300 acre-ft/yr by 2035 because of the demolition of older homes.

New Plumbing Code:
A plumbing code revision will reduce the flow for toilets to 1.5 gallons per flush and shower heads to 2.0 gal/min. This measure would save 1,200 acre-ft/yr in 1990 and the savings would grow to 22,000 acre-ft/yr by 2035.

Limiting Turf Size:
This measure limits the amount of turf in new developments to not more than 50 percent of the landscapable area. Estimated water savings would be 1,000 acre-ft/yr by 1990 and 20,000 acre-ft/yr by 2035.

Turf Management:
The turf management program is designed to provide good weather data which will assist turf managers in reducing water application by about 10 percent. Anticipated annual water savings from these actions will be approximately 1,000 acre-ft/yr by 1990 and 20,000 acre-ft/yr by 2035.

New Water Rate Structure:
Uniform water rates based upon marginal cost instead of average cost would have a tremendous impact on water demand. It is estimated that water savings on this measure alone would be approximately 19,000 acre-ft/yr by 1990 and 31,000 acre-ft/yr by 2035. A modified increasing block rate structure would achieve a strong conservation benefit in a less disruptive way than the marginal structure. Meeting revenue requirements alone would reduce demand by 6,000 acre-ft/yr in 1990.

Watering Alert:
This program is intended to reduce peak summer usage by advocating that customers water their lawns every third day for a two-week period. This program will increase public awareness of efficient water use and is expected to save approximately 3,000 acre-ft/yr by 1990 and 7,700 acre-ft/yr by 2035.

Best Available Commercial/Industrial Technology:
The Best Available Commercial/Industrial Technology Program (BAT) is designed to encourage commercial and industrial high water-use customers to reduce water consumption by adopting the most advanced technologies. Estimated water savings from this measure will reach approximately 6,400 acre-ft/yr by 1990 and 10,500 acre-ft/yr by 2035.

Secondary Education:
It is proposed that the current primary school program be expanded to teach students in intermediate and secondary schools about water conservation and water resources management.

TABLE 3
ON-PROJECT AND OFF PROJECT
SUPPLY AND DEMAND WITH NEW DEMAND MANAGEMENT PROGRAMS
(thousands of acre feet)

On-Project

YEAR	1990	2000	2015	2025	2035
Average Demand	188	207	231	240	243
Conservation Plan Savings	31	37	42	48	52
Adj. Demand	167	170	189	192	191
Supply	220	221	226	220	241
Surplus (Deficit)	53	51	37	28	50

Off Project

	1990	2000	2015	2025	2035
Average Demand	122	182	235	257	265
Conservation Plan Savings	14	23	42	49	55
Adj. Demand	108	159	193	208	210
Supply	222	224	206	190	190
Surplus (Deficit)	114	65	13	(18)	(20)

The implementation of these nine new measures is still not adequate to meet the demand for water in the off-project area, nor adequate during a severe drought. Strict conservation measures are still needed to help reduce the demand for water during a severe drought. Three major conservation programs that the City of Phoenix would implement during a severe drought are: Drought Emergency Education, Restrictions on Sprinker Use, and Voluntary Commercial/Industrial Conservation. To finance these programs, a drought surcharge of up to 25 percent of current rates would be implemented to cover the cost of the emergency drought program. These programs are described below.

Drought Emergency Education would be implemented in the beginning of a mild drought and would be maintained until the drought is over. This education campaign is essential to communicate to the public what needs to be done. Public response could reduce demand by 21,200 acre-ft/yr in 1990 and 23,500 acre-ft/yr in 2035.

Restrictions on Sprinkling Use would be voluntary in a mild drought but would become mandatory in a severe drought. In a mandatory situation the overall savings of this program would be 18,000 acre-ft/yr in 2035.

Voluntary Commercial/Industrial Conservation: A survey of 68 manufacturing firms and commercial establishments in Phoenix which showed that substantial reductions in water use can be achieved during droughts without significant impact on operations. The average reduction in manufacturing plants was 25.3 percent, and in commercial use, was 33.5 percent. Based on these figures, a savings of 34,000 acre-ft/yr could be achieved during a severe drought.

Drought Surcharge: Designed to recover costs during periods of normal demand and supply, the drought surcharge could be as much as a 25 percent increase in rates. In the first year of implementation,in 2035, savings through reduced demand would be 7,500 acre-ft/yr and by the third year the savings would be 23,000 acre-ft/yr. The total savings from the emergency conservation program in 2035 would be 60,000 acre-ft/yr on-project and 34,000 acre-ft/yr off-project. Even with the implementation of emergency conservation programs, there would be a 7,000 acre-ft/yr deficit in the on-project area and a 168,000 acre-ft/yr deficit in the off-project area in 2035. Emergency groundwater will cancel the deficit in the on-project area but will not reduce the deficit on the off-project and non-member lands.

WATER RESOURCE AUGMENTATION

The need for additional supplies to meet demand during normal and drought conditions is apparent. To meet future needs these options are under evaluation: Central Arizona Project (CAP) reallocation; state trust land allocation; reuse options for treated wastewater; purchase of water rights; and groundwater recharge. The impact of these water resources projects is described below.

Central Arizona Project Reallocation:
Additional allocation CAP water may be allocated to Phoenix because some of the original CAP allocatees may not contract for the water. The amount of water from reallocation has not been determined.

State Trust Land Allocation:
The Arizona State Land Department is finalizing the contracting of CAP municipal and industrial water that will permit the use of up to 12,000 acre-ft/yr of CAP water on state trust land within the City of Phoenix service area.

Reuse Options for Treated Wastewater:
The Phoenix water supply may be augmented by treating wastewater to make it acceptable for turf irrigation, agricultural transfers, industrial use and potable water use.

1. The turf irrigation option is already being developed through two projects within the City of Phoenix. 0.5 to 2 Mgal/day satellite facilities will be constructed at various locations to treat wastewater for use in turf irrigation or other similar uses. Treatment cost estimates range from $350 to $150 per acre foot, respectively. Capital costs will depend on the amount of pumping and lengths of pipe that must be installed. This option will be able to produce 3,300 acre-ft/yr by 2015.

2. Approval has been given for Agricultural transfers among the City of Phoenix, SRP and the Roosevelt Irrigation District. The City of Phoenix will deliver to RID as much as 30,000 acre-ft/yr of SRP water which will be diverted to the Salt River/Pima/Maricopa Indian communities. After the Roosevelt Irrigation District is converted into urban form, the water then can be treated and made suitable for industrial use or agricultural use in the Estrella industrial district.

3. Using wastewater for potable use is undergoing a feasibility analysis by the City of Phoenix. This option is controversial because of public perception that wastewater is not a potable water resource, and the perceived expense. This option is expected to generate 20,000 acre-ft/yr by 2000 and a total of 40,000 acre-ft/yr by 2035.

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Purchase of Water Rights:

The City of Phoenix evaluated numerous parcels of land to determine if purchasing the water rights would be beneficial to the city. Of all the lands evaluated, the City of Phoenix purchased McMullen Valley in 1986 and is planning to purchase additional land that will generate 20,000 acre-ft/yr for use by 2020.

Groundwater Recharge:

The City of Phoenix plans to recharge 80,000 acre-ft/yr of surface water. The recharge program is essential will be a joint effort of local water agencies and municipalities. This program will allow the City to withdraw groundwater to maintain pressure within the city system and to develop a groundwater reserve during times of water shortages.

SUPPLY AND DEMAND WITH BOTH NEW SUPPLIES AND DEMAND MANAGEMENT

The development of water resources in addition to the Demand Management program will allow the City of Phoenix to meet the forecasted water demand throughout the planning period and to meet the requirements of the State of Arizona. The supply and demand situation for the off-project area is presented in Table 4.

TABLE 4
OFF-PROJECT
SUPPLY AND DEMAND WITH DEMAND MANAGEMENT AND SUPPLY AUGMENTATION
(Thousands of Acre Feet)

Year	1985	2000	2015	2025	2035
Demand with Conserv. Savings	96	182	235	257	265
Current Supply	100	231	206	190	190
New Supplies	0	36	78	111	111
Total Supply	100	267	284	301	301
Surplus	4	85	49	44	36

SUPPLY AND DEMAND WITH NEW SUPPLIES IN A DROUGHT

In a severe drought, the implementation of the water conservation plan, along with the development of additional resources, is essential to meet forecasted demand for water. Unfortunately, these two measures will not be enough. Emergency conservation program will be needed in both the on- and off-project areas along with the use of all groundwater facilities. By implementing these programs the City will be able to meet the water demand in a severe drought throughout the planning period. In Table 5 the supply and demand situation in a severe drought is presented. This table shows a combination of emergency conservation programs and emergency supplies necessary for the off-project area. It also shows that a surplus may exist. In the case of a surplus, the most expensive supply or conservation program would be reduced.

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TABLE 5
ON-PROJECT AND OFF-PROJECT
SUPPLY AND DEMAND IN A SEVERE DROUGHT
WITH DEMAND MANAGEMENT & SUPPLY AUGMENTATION
(Thousands of Acre Feet)

On-Project

Year	1985	2000	2015	2025	2035
High Demand with					
Cur. Conservation	175	221	250	261	264
Conservation Plan	- 0	-37	-42	-48	-52
Emer. Conservation	-49	-53	-58	-60	-60
Adjusted High Demand	126	131	150	153	152
Supply in Drought	167	159	148	132	145
Emergency Wells	34	51	62	62	62
Total Supplies	201	210	210	194	207
Surplus (Deficit)	75	79	60	41	55

Off-Project

Year	1985	2000	2015	2025	2035
High Demand with					
Cur. Conservation	118	232	298	324	334
Conservation Plan	-14	-23	-42	-49	-55
Emer. Conservation	-19	-23	-29	-32	-34
Adjusted High Demand	85	186	227	243	245
Supply in a Drought	100	186	172	77	77
Emergency Groundwater	0	50	97	112	112
New Supplies	0	40	75	99	98
Total Supplies	100	276	344	288	287
Surplus (Deficit)	15	90	117	45	42

CONCLUSION

Without a combination of new supplies and demand management, the City of Phoenix cannot meet the demand for water and will be unable to deal with a severe drought during the next century. It is crucial to examine both water conservation and demand augmentation to determine which strategies best benefit a municipality. In the case of the City of Phoenix, planning and implementing the Phoenix Water Resource Plan--1987 is prudent. Our Water is Our Future.

Literature Cited:
Planning & Managment Consultants, 1986. Water Conservation Evaluation for the Phoenix Water Service Area. City of Phoenix.

(This paper was also presented at the American Water Resources Association symposium, "Water-Use Data for Water Resources Management," held in Tucson, August 28-31, 1988. The paper is included in the proceedings of that symposium.)

WATER RESOURCES RESEARCH CENTER
SERVES
THE ARIZONA WATER COMMUNITY

Joe Gelt
University of Arizona
Office of Arid Lands Studies/Water Resources Research Center
Tucson, Arizona 85721

Marvin Waterstone
University of Arizona, Water Resources Research Center
Tucson, Arizona 85721

Introduction

The Water Resources Research Center has a broad focus. The center, which is funded by federal and state monies, is located within the University of Arizona's College of Engineering and Mines. The Center's scope of interest, however, includes all academic disciplines that are involved in water-related studies. Further, the center, although located on the UA campus, is involved with other Arizona universities--Arizona State University and Northern Arizona University.

Also, the center promotes communications between the universities and the wider water community, including federal, state and local government agencies and the private sector. The center is one of 54 water centers funded nationally by the U.S. Geological Survey. Centers exist in each of the 50 states and in Guam, Puerto Rico, the Virgin Islands, and the District of Columbia.

This paper discusses the center's main activities--research support and information transfer--and will describe the specific services the center provides to the people, agencies and institutions that make up the state and regional water community.

As the center plans its research support and information transfer activities, it confers with representatives of water users groups, public water agencies, and other water decision makers to identify critical state water issues. Information is exchanged through the center's formal advisory committee, water conferences and meetings, and informal discussions. The identified state issues provide the basis for research and information transfer activities.

Research Support

The center's research support program is best understood as a process involving state-of-knowledge assessments, specific projects or reports from Scientific Advisory Committees organized

by the water center. For example, a research topic might be addressed by a state-of-knowledge assessment which is later reviewed by a Scientific Advisory Committee. From the review the committee might then develop further research topics for future state-of-knowledge assessments and also suggest topics for specific research projects. The assessments are published as issue papers and are distributed as part of the center's information transfer program.

Each of the components of the research support program will be discussed.

State-of-Knowledge Assessments

The important first step in any research enterprise is an assessment of current knowledge. By investigating what is known, a sense of what further work needs to be done is developed; therefore, the center funds state-of-knowledge assessments. The assessments are usually supported for about three to six months. Currently, state-of-knowledge assessments are being developed for institutional aspects of integrated and conjunctive water management and for a unified hydrologic flow model. As mentioned the results of the assessments will be presented as issue papers to be distributed as part of the center's information transfer program.

Scientific Advisory Committee

A Scientific Advisory Committee responds to state-of-knowledge assessments and is made up of members of the Water Resources Research Center's advisory committee, university researchers and others who are knowlegeable in particular subject areas. An assessment helps set the agenda of the Scientific Advisory Committee which proposes additional research in the area and sets research priorities.

Specific Projects

Specific projects respond to research priorities set by the Scientific Advisory Committees. These projects are major research efforts and can be supported for periods up to three years.

Information Transfer

Information transfer and research are closely related activities. Research gathers and interprets information and information transfer disseminates the results in a timely fashion. Along with disseminating research results, the center's information transfer program also provides interpretation of research results and identifies areas of needed research.

The center's information transfer program consists of publications, conferences and workshops, and database services.

Publications

The Water Resources Research Center's publications include issue papers, newsletters and other periodic publications.

Issue Papers The center sponsors a series of issue papers on water topics of critical importance. The purpose of the issue papers is to disseminate information about research findings and to identify research gaps that exist; thereby, setting the agenda for the next round of research. Depending upon the subject matter and its treatment, the papers are directed to various audiences, from water professionals to the general public. For example, the issue paper, "Central Arizona Project Water Quality: An Examination of Management Options," discussed diverse water-quality management options. It described possible choices and evaluated the relative advantages and disadvantages, strengths and weaknesses, and costs and benefits of various water-quality management methods. The issue paper was intended as a resource to assist water managers in choosing a suitable water-quality strategy for various CAP water uses.

The center's most recent issue paper, "Water Farming: The Promise and Problems of Water Transfers in Arizona," has a different focus. This issue paper provides a general review of the issues and concerns relating to water transfers. The publication is intended for professionals as well as a general, nonspecialized audience, with material presented in a question-and-answer format.

The previously mentioned state-of-knowledge assessments that are in progress will be published as issue papers.

Newsletters The center also publishes a quarterly newsletter "Arroyo." The newsletter is sent to almost 2,000 people, most from Arizona but some from other parts of the Southwest and a few from other areas of the country. Readers come from a wide range of backgrounds and interests.

Each issue of "Arroyo" focuses on a different water topic. Two recent topics were water quality and water transfers. The next issue will discuss the Arizona Groundwater Code and the Second Management Plan.

The center also publishes the "Arizona Water Research News." This newsletter, which is published during the academic year, is distributed to water researchers at the state universities in Arizona. The newsletter contains information about research, funding sources and general information of interest to water researchers.

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Other periodic publication The center publishes an annual report that describes its activities, including sponsored research, publications, conferences, staff activities, and other aspects of the center's operations. The annual report is published each July. The center also makes available project completion reports from research efforts, and plans to provide access to theses and dissertations resulting from these projects. Other publications are developed as specific needs are identified.

Conferences and Workshops

The center sponsors an annual research conference to promote communications between water researchers and research users. The first conference, which was held two years ago, was called appropriately, "Getting Acquainted: Arizona's Water Researchers and Research Users." It provided a unique opportunity for research users to tell of their concerns, needs and priorities; and researchers from the three Arizona universities to present the results of their work.

This year's conference was titled, "University Water Research in Arizona: What Have We Learned? Where Are We Going?" The morning session was made up of three panels each featuring a main speaker who presented an overview of research in a specific area. Each main speaker was followed by two research users who commented on the conducted research and provided ideas for future research needs. A poster session was also organized to provide researchers the opportunity to display the results of their work.

The third annual research/researcher users conference is planned for this fall.

The Water Resources Research Center also organizes specialized workshops on water topics of current interest. Last fall the people of Tucson were asked to vote on a proposition that would decide whether the city's allotment of Central Arizona Project water should be entirely recharged into the aquifer or whether a portion should be treated and distributed. To help Tucsonans decide the issue, the water center organized a series of public meetings to discuss the issue from various perspectives. Other workshops or forums will be conducted as needed.

Data Base Services

The center's objective is to provide several types of database services, primarily to the academic community. Several numerical water databases (e.g. WATSTOR, STORET, Hydrodata, etc.) will be available, as will a variety of bibliographic databases (through PROSEARCH). Also a computerized expertise directory/referral service is being devploped that will list water and water-related researchers at Arizona's state universities and

their specialized interests. The center is also in the process of cataloguing and computerizing its library, a 40,000-document collection. The library has an extensive collection of the so-called "gray literature" (e.g., conference proceedings, project completion reports, etc.) and will represent a significant resource for researchers once ongoing automation procedures are completed in about a year and a half.

CURRENT RESIDENTIAL WATER CONSERVATION PRACTICES AND BEHAVIORS: COMPARING TWO POPULATIONS

By

Glenn France
University of Arizona
Department of Geography and Regional Development
Tucson, Arizona 85721

ABSTRACT

The availability of quality water is an important issue facing the residents of Tucson, Arizona and several communities in the Southwestern United States. As cities continue to grow, more emphasis is being placed on the importance of adopting efficient water use practices and behaviors. A water conservation demonstration, education, and research single family residence named Casa del Agua (Spanish for House of Water) has been established in Tucson, Arizona. Water conservation information is presented to the public via oral and video presentations and a guided tour of the perimeter of the residence. A questionnaire is given to the visitors as they arrive for the tour. The responses to this questionnaire make it possible to determine the types of water conservation behavior being practiced by the visitors to Casa del Agua. Water conservation attitude questions were also included in the questionnaires as were questions about several water issues. From this preliminary study, it has been determined that the levels of adoption of water conservation behaviors have been low to modest.

It appears that many of the visitors to Casa del Agua have about the same level of knowledge concerning water conservation as the general public, although the random survey data for the Tucson area has yet to be analyzed. A comparison was made of similar questions asked in a random survey conducted in the Phoenix metropolitan area March 17-20, 1988. Some of the findings include: 1) The amounts of self-reported water conservation behavior adoption are similar, although the residents of the Phoenix area seem to report a slightly higher percentage of water conservation practices being implemented. 2) Few respondents from either survey indicated they have attended a water conservation demonstration or workshop. 3) Negative public perceptions of water utilities need to be addressed. 4) Water conservation programs that include economic incentives are favored by both survey populations.

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INTRODUCTION

A water conservation research and education project is located in Tucson, Arizona named <u>Casa del Agua</u>. The house is a single family residence equipped with various water conservation technologies. Tours are offered to the public on weekends and through special arrangement. These tours explain and demonstrate the water conservation techniques and technologies that are appropriate in this semi-arid region of the country.

Research conducted by the University of Arizona Office of Arid Lands Studies has been continuous at the house since it was opened in November, 1985. This research has focused on quantifying all water inputs and outputs in order to assess the overall impact of the various systems on water conservation. On November 1, 1986, my family and myself became the residents of Casa del Agua. My contribution to the research being conducted has focused on the visitors who come to take the tours offered and their knowledge of water conservation and water issues. My thesis involves the evaluation of the tour offered at Casa del Agua and its effectiveness producing water conservation behavior changes. This paper deals with the self-reported water conservation perceptions and behaviors of these individuals and a random sample survey of Phoenix area residents (Arizona Field Research, 1988).

BACKGROUND

Approximately 33 percent of the earth's land surface can be classified as arid or semi-arid. The Tucson Active Management Area (Tucson AMA) is included within this classification. Because of the rapid increase in population, coupled with the sparseness of rainfall, concern has been expressed whether an adequate supply of quality drinking water will be available in the future. In the Tucson AMA groundwater withdrawals exceed replenishment by a factor of 2 to 1 (Foster and DeCook, 1986). Tucson currently relies totally on pumped groundwater for its water supply. Also in the Tucson AMA, 40% of the total water use is for municipal purposes. Residential consumption accounts for about 65% of this use (Tucson Water Co, 1987).

The population of the Tucson AMA is expected to increase by more than 50% by the year 2000. Even with the transfer of Colorado River water via the Central Arizona Project (CAP) to the Tucson AMA (proposed for completion in 1991), the reuse of sewage effluent for large turf areas such as golf courses and parks, and changes in per capita use as a result of conservation, there will still be 84,000 acre feet more water withdrawn from the ground than is replenished (Foster and DeCook, 1986). To help insure an adequate supply of water for the future and to better manage current supplies, Arizona enacted the Arizona Groundwater Management Act of 1980. The cornerstone of that act is conservation.

To increase the amount of change in per capita use of water through conservation, a water conservation education and experimental research single family residence named <u>Casa del Agua</u> (Spanish for <u>House of Water</u>) has been built in Tucson. The residential sector represents one area of

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potential water savings in which individuals can participate directly (DeCook, Foster, and Karpiscak, 1987). Casa del Agua exists to educate the public and thus help realize some of this water savings.

Support for the residence is supplied by Tucson Water Company, which under state law, The Arizona Groundwater Management Act of 1980-Second Management Plan, must show a continued reduction in residential water use through the year 2000 (A.R.S. @ 45-565.A.2), Pima County Wastewater Management Department, the Arizona Department of Water Resources, the Southern Arizona Water Resources Association (SAWARA), and many community business contributors.

Since November 1985, the University of Arizona's Office of Arid Lands Studies and Department of Microbiology have been conducting research which has focused on six interrelated tasks:

> *1) continuing a water quality sampling program which characterizes the graywater and rainwater produced and determines the potential for impact on our environment; 2) conducting a water balance analysis which quantifies fresh water use, graywater production and use, rooftop runoff and use; 3) continuing evaluation of system components which could enhance graywater reuse; 4) determining the impacts of water reuse and conservation on quantity and quality sewer flows; 5) refining the "W-Index", a residential water efficiency rating system, for retrofit and new home construction which provides a measure of water conservation potential; and 6) maintaining and modifying existing systems* (Karpiscak, Foster, DeCook, Gerba, and Brittain, 1987).

Some significant findings of the ongoing research include:

> *1) The operation of the graywater reuse system and the rainwater harvesting system, with storage, can significantly reduce the summer demand peak for municipal water; 2) Use of municipal groundwater at Casa del Agua is about 50 percent of that used in "average" homes; 3) Interior use of municipal water for toilet flushing can be reduced by 75 percent by installation of 1 gallon per flush units; 4) Total fecal coliform concentration in graywater appears to be reduced by as much as 99 percent in passing through the water hyacinth aquacells and sand filter* (Karpiscak, 1988) .

Until recently the educational aspects of Casa del Agua had not been included in the research conducted. They are considered to be important aspects by many of Casa's support organizations. The focus of my research at Casa concerns how effective the water conservation education is in producing water conservation behavior changes. Were the tours of Casa presenting water conservation information to the public in a manner that would encourage the visitors to adopt some of the techniques presented? This question turned into a master's thesis topic and this paper presents some of my early findings.

The primary duty of the residents is to conduct the water conservation education tours on weekends. The presentation includes a lecture, a video tape presentation and a guided tour of the perimeter of the home. The tour acquaints the visitors with the various low-flow plumbing fixtures available, ways of capturing and utilizing rainwater, and graywater recycling systems. Landscape irrigation techniques are demonstrated and xeriscape techniques are described and presented. A list of low-water-use plants and brochures containing water conservation information for interior and exterior use are available.

METHODOLOGY

A questionnaire is given to the visitors of Casa del Agua before they take the tour or are exposed to any water conservation educational materials. No correlation analysis has been performed on the data collected for this paper. Some descriptive analysis was possible and the results are presented below.

The questionnaire given as people arrive for the educational tour includes questions that are designed to elicit socio-economic information so a determination can be made concerning the average education, age, and income of the respondents and if the respondents own or rent their home. Respondents are asked to rate the importance or usefulness of several water related issues using a five response Lichert Scale ranging from 1-"not at all important" or "not at all useful" to 5- "very important" or "very useful". They are also asked to rate the usefulness, as they perceive it, of several possible ways water conservation could be mandated by water suppliers or government entities. Finally the visitors are asked how they rate the importance or usefulness of several water conservation techniques and devices and which of these have been adopted by the respondents themselves.

The responses to the questions were analyzed descriptively using straight percentages. Since I was most interested in the responses that were answered as 4-"important" or "useful" or 5-"very important" or "very useful" I did not use the other responses in my analysis.

The data from the Phoenix study conducted by Arizona Field Research was based on 624 interviews with full-time residents 18 years of age or older living in Maricopa County. The method of selection was Random Digit Dialing, which insures non-listed telephone numbers are included in the sample. A margin of error of + or - 5% was placed on the 350 responses to the questions answered by those who had voluntarily made an effort to conserve water.

189 visitors filled out questionnaires prior to taking the tour of Casa del Agua. 164 (87%) of the respondents are residents of Pima County, 71 (36%) have lived in the county for less than five years and 93 (64%) have lived there for more than five years. 105 (55%) of the respondents have a college degree; 78 (41%) are over 44 years old; 147 (77%) own their own home; 124 (74%) own a single family home. Only 68 visitors were asked income levels; of those 35 (51%) have an income of $25,000 a year or more. 76% of the respondents indicated that they practiced at least one water conservation technique.

The Phoenix survey had 624 respondents. 76% have lived in Maricopa County more than 5 years and 24% have lived there for less than 5 years. 21% have a college degree and 44% are over 44 years old. 72% own their own home and 69% own a single family home. 61% have incomes in excess of $25,000 per year. 56% of the 624 respondents stated that they practice some sort of water conservation.

WATER ISSUES

The 189 Casa del Agua responses to the water issues questions using the five part Lichert Scale gave the following responses:

172 (91%) rated water conservation within their community as important or very important.

132 (70%) rated the cost of quality drinking water as an important or very important water issue.

178 (94%) rated an assured supply of quality drinking water as an important or very important water issue.

182 (96%) rated the quality of the water as an important or very important water issue.

144 (76%) rated the source of the quality drinking water as an important or very important water issue.

When asked which entity should be responsible for the cost, quality, quantity and the source of the drinking water the 189 respondents replied as follows (some chose more than one answer):

105 (55%) stated government agencies.

73 (39%) stated water companies.

129 (68%) stated experts in water resource management.

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WATER CONSERVATION PROGRAMS

The 189 respondents to the water conservation program questions using the five part Lichert Scale gave the following responses:

56 (30%) rated raising the price of water as useful or very useful in promoting water conservation.

106 (56%) stated that some form of water use limitation guidelines would be useful or very useful in promoting water conservation practices.

116 (61%) stated that local water conservation publicity campaigns would be useful or very useful in promoting water conservation.

142 (75%) stated that monetary incentives paid after water conservation practices had been adopted would be useful or very useful in promoting water conservation practices.

47 (25%) stated that water rationing would be useful or very useful in promoting water conservation practices.

134 (71%) stated that economic incentives for switching to an arid adapted landscaping would be useful or very useful in promoting water conservation.

The Phoenix area respondents rated water rationing at a 26% favorable rate and water use limitation guidelines at a 67% favorable level. The remainder of the responses could not be compared because of non-compatible questions being asked.

INDIVIDUAL WATER CONSERVATION ATTITUDES AND BEHAVIORS

The 189 respondents to the individual water conservation attitude and behavior questions, using the five part Lichert Scale, gave the following responses:

90 (47%) of the respondents rated a low-flow shower head as an "important" or "very important" water conservation device. Of those 90, 47 (52%) have installed a low flow shower head.

110 (58%) of the respondents rated low-flow toilets as an "important" or "very important" water conservation device. Of those 110, 46 (41%) have installed a low-flow toilet.

92 (49%) of the respondents rated storing and using stored rainwater as an "important" or "very important" water conservation technique. Of those 92, 8 (9%) have stored and used stored rainwater.

131 (69%) of the respondents rated using low-water-use vegetation or the removal of high water use vegetation as an "important" or "very important" water conservation technique. Of those 131, 89 (68%) have planted low-water-use or removed high water use vegetation.

The 350 (or 56% of the total) Phoenix area respondents who said that they practiced some form of water conservation gave the following responses:

47% have installed a low-flow toilet; 57% have installed a low-flow showerhead; 46% have planted low water use vegetation or removed some high water use vegetation. The low-flow toilet figure may seem high, but with the 5% margin of error it comes out about the same as the Casa sample. So far, Phoenix is the only city meeting the water reduction goals set by The Arizona Department of Water Resources First Management Plan. These were the only questions from this section that were the same on both surveys.

CONCLUSIONS

There are some conclusions and/or implications that can be drawn from the comparison of these two studies. Both populations agree on the importance of water conservation. Neither population indicated that (less than 10%) they have attended any water conservation demonstrations or workshops/seminars. This would indicate that more information and publicity about the need to conserve water and the availability of demonstration projects similar to Casa del Agua needs to be made available to the public.

When 91% of a population think that water conservation is important; 94% think that an assured supply is important; and 96% believe quality water is important, then those issues should be examined and addressed by the policy makers. So far the water conservation issue has not been addressed in any meaningful manner. Policy makers should also take note of the types of water conservation programs that are preferred. Programs that include economic incentives appear popular in both populations. People would agree to saving money on their water bills as an incentive for conserving in some instances; however, the public is more likely to agree to incentives that are oriented toward the installation costs of the water devices. Pilot programs could be implemented that test some of the these incentive programs. If reductions in water use are noted then permanent programs could be put in place.

Another area that could be examined by policy makers concerns which entities should be responsible for our water. The respondents to the Casa questionnaire don't seem to want water companies to have control of their water supplies. They think experts in water resource management should be the responsible parties. Negative public perceptions concerning the role of the water utilities should be addressed.

The most important finding or conclusion that can be drawn from this comparative investigation, in my opinion, is that more water conservation information needs to reach the public. Since both surveys indicate that less than 10% of the respective populations have received some kind of water conservation information from a demonstration or workshop/seminar. More of these types of programs should be implemented. Water conservation demonstration programs, that show the

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pubic water conservation practices and techniques, should be implemented in all cities that have water shortage problems or are expected to have problems in the future (That would include most of the Southwest U.S.). The more that is known about the techniques of water conservation, the more likely the techniques will be adopted. The practice of conserving water must take place in desert regions if man is survive in those regions.

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