Computer Methods and Water Resources: Computational Hydrology

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PREFACE

The analysis and design of water resources systems are extremely complex. This complexity is due to the numerous simultaneous objectives and purposes of these systems, the changeable character of their components, their stochastic nature and the different scales under consideration. The importance of these systems cannot however be overemphasized, as water is a precious resource on which the well-being of future generations strongly depends. Developing countries in particular, have suffered and continue to suffer from repeated droughts. Better tools for water resources assessment are needed to provide for their optimum designs and their wise planning and management.

Advanced computational techniques are of permanent importance for the efficient utilization of water resources and are particularly useful to developing countries as they can provide a way of optimizing their resources. The 1st International Conference in Africa on Computer Methods and Water Resources was convened in order to discuss these problems. The Conference was organized by the Ecole Mohammadia D'Ingénieurs of Morocco at Rabat from March 14-18th, 1988 with the help of many international and national organizations and the collaboration of the Computational Mechanics Institute of Southampton, England.

The excellent response to the Call for Papers resulted in a large number of contributions being submitted to the meeting. The Conference Proceedings containing the edited papers were divided into six volumes, each of them grouping together contributions on the following topics:

Vol.1: Groundwater and Aquifer Modelling
Vol.2: Computational Hydraulics
Vol.3: Computational Hydrology
Vol.4: Computer Aided Engineering in Water Resources
Vol.5: Computational Transport Phenomena
Vol.6: Water Quality, Planning and Management

Vol. 3: Computational Hydrology

This volume contains edited papers related to Computational Hydrology submitted to the Conference. The first stage in the design of a water resources system is the correct description of the hydrology of the region and the study of the way in which this can be implemented in the design. The hydrological data to be analysed is of great complexity and requires special computational tools.

The book includes contributions on deterministic and stochastic modelling, risk analysis in normal, arid and semi-arid lands, subsurface hydrology and urban hydrology modelling. Some papers relate to the development of software codes and their applications.

The Editors would like to thank all the members of the Organizing and Scientific Committees, the Conference Sponsors, the contributors and participants and all the other people who have helped with the organization of the meeting and the preparation of the Proceedings.

The Editors

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SECTION 1 HYDROLOGY OF ARID AND SEMI-ARID AREAS

Effects of the Length of Record on Estimates of Annual and Seasonal Precipitation

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ABSTRACT

In arid and semi-arid regions, the available water resources must be carefully assessed and managed. In this paper, the effect of adding approximately six years of data to a precipitation data base consisting of eleven gages on the Nevada Test Site, Nevada, is examined. It is concluded that one effect of lengthening the period of record at typical desert precipitation gaging sites can be a significant change in the estimate of potential groundwater recharge. In addition, six of the eleven sites used in this study exhibit a trend to increasing annual and seasonal precipitation and increasing variability of summer season precipitation. Such a trend can have significant effects on both water resources management and erosion control.

INTRODUCTION

An understanding of the temporal and spatial distribution of precipitation is crucial in arid and semi-arid environments where the limited water resources must be carefully assessed and managed. The rapid and continuing population growth in the southwestern United States has both increased the demand on all sources of water supply and the need to control potentially destructive and dangerous storm runoff in urban areas and in the vicinity of hazardous waste management sites.

In Southern Nevada one of the primary sources of potable water is groundwater, and the intelligent management of this limited resource requires that the groundwater in storage and the rate at which natural recharge of the groundwater system is taking place be accurately estimated. Although there are many methods that can be used to estimate groundwater recharge, most of these methods assume a detailed and accurate knowledge of annual and seasonal precipitation. However, in most arid and semi-arid regions, the total number of precipitation gaging stations is limited, the period of record available for each station is often short, and there are few stations at high elevations. The eleven stations used in this paper represent the best precipitation coverage available in Southern Nevada and thus present an opportunity to examine both the effect of a changing period of record on regional groundwater recharge estimates.

In addition to a concern with water supply issues, the arid and semi-arid regions of the western United States have in the historical past experienced periods of significant and destructive erosion. A number of investigators, see for example, French[4], have suggested that these periods of erosion were caused by a combination of changes in the amount, duration, and frequency of precipitation and the actions of man. This precipitation data base has also been used to examine the possibility of periods of severe erosion occurring in Southern Nevada in the near future.

BACKGROUND

As part of its continuing research program with the U.S. Department of Energy, the Water Resources Center of the Desert Research Institute developed and continues to maintain and analyze a precipitation data base for the 3500 km^2 Nevada Test Site (NTS). The NTS precipitation data base was first analyzed in 1983, French[6], when the data base was complete through the end of calendar year 1979 and was reanalyzed in 1986, French[5], with the data base complete through the end of calendar year 1985. French[5] noted that the addition of six years of data to the original data base resulted in significant changes in the calculated values of annual precipitation. In the case of precipitation gages with short periods of record (ten years or less) such changes in the calculated values of annual precipitation would not be unexpected; however, significant changes also occurred at stations where the period of record was reasonably long. Four potential reasons for the shifts in annual precipitation were hypothesized: 1) the available period of record is too short to expect stable values of annual and seasonal precipitation; 2) there is a trend in the data; 3) the shifts are artificial and caused by the fashion in which the data were initially analyzed and manipulated; and 4) during the period of record examined there were undocumented or unknown changes in gage location, exposure, instrumentation, or observational procedure. Of these four reasons, only the first two will be discussed since the last two can be shown to be invalid, French[4].

ANALYSIS

In Table 1 average annual and seasonal precipitation for the eleven precipitation stations on the NTS with relatively long and reliable periods of record are summarized, and the locations of these stations are shown in Figure 1. Note, the summer season is taken as May-September, inclusive, and the winter season as October-April, inclusive. In Col. (2) of Table 1 the elevations of the stations are specified. With regard to these data, it should be noted that 82% of the stations are below 1500m; 18% of the stations are above 1500m; and 9% of the stations above 2000m. In comparison, approximately 59% of the NTS area is below 1500m and 10% of the NTS area is above 2000m. Further, most of the natural groundwater recharge that takes place on the NTS is the result of snowmelt at high altitudes, Russell[9]. In Cols. (3), (4), and (5) of Table 1 annual and seasonal average precipitation using the record complete through the end of calendar year 1979 are summa-

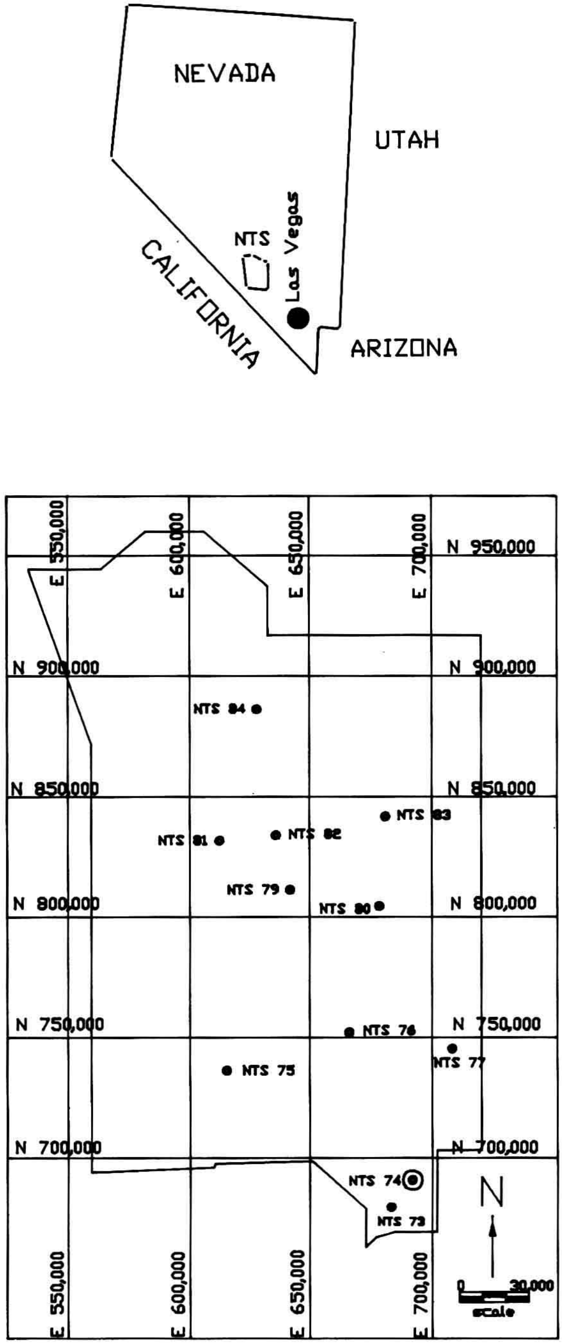

Figure 1. Location of the eleven precipitation stations used in this paper.

Table 1. Summary of Annual and Seasonal Precipitation Data for Eleven Stations at the Nevada Test Site
Note: The data in Cols. (4), (5), (7) and (8) are direct conversions from English units to three significant figures.

Station (1)		Elevation m (2)	Record thru 1979: Usable yrs of record (3)	Record thru 1979: $\bar{p}$ mm (4)	Record thru 1979: σ mm (5)	Record thru 1985: Usable yrs of record (6)	Record thru 1985: $\bar{p}$ mm (7)	Record thru 1985: σ mm (8)	% change in $\bar{p}$ (9)	% change in σ (10)	% change in length of record (11)
Desert Rock (73)	Annual	1005	16	136	57.9	22	154	67.1	+13.2	+15.8	37.5
	Summer			40.9	23.4		56.6	42.4	+38.3	+81.2	
	Winter			94.5	62.7		97.5	55.1	+3.2	-12.1	
Mercury (74)	Annual	1149	9	148	51.6	15	164	60.2	+10.8	+16.7	66.7
	Summer			41.9	31.2		62.7	49.3	+49.6	+58.0	
	Winter			106	57.2		101	46.7	-4.7	-18.4	
4JA (75)	Annual	1043	22	116	45.0	27	127	69.3	+9.5	+54.0	22.7
	Summer			33.0	20.6		40.1	34.0	+21.5	+65.0	
	Winter			82.8	59.2		87.1	57.4	+5.2	-3.0	
Cane Springs (76)	Annual	1219	15	197	99.8	21	208	94.2	+5.6	-5.6	40.0
	Summer			50.0	36.6		59.7	42.9	+19.4	+17.2	
	Winter			147	97.3		148	85.9	+0.7	-11.7	
Well 5B (77)	Annual	939	16	117	50.8	22	129	55.6	+10.3	+9.4	37.5
	Summer			36.6	19.5		48.0	33.0	+31.1	+69.2	
	Winter			80.3	54.1		80.8	48.0	+0.6	-11.3	
Mid Valley (79)	Annual	1420	13	231	106	19	246	103	+6.5	-2.8	46.2
	Summer			57.9	32.5		68.8	40.1	+18.8	+23.4	
	Winter			173	107		177	96.0	+2.3	-10.3	
Yucca (80)	Annual	1195	20	166	90.4	26	172	88.4	+3.6	-2.2	30.0
	Summer			51.3	33.3		57.2	41.1	+11.4	+23.4	
	Winter			114	80.3		115	73.2	+0.9	-8.8	
40 MN (81)	Annual	1469	17	180	74.2	23	201	88.1	+11.7	+18.7	35.2
	Summer			65.8	29.7		76.2	45.2	+15.8	+52.2	
	Winter			115	77.0		125	76.2	+8.7	-1.0	
Tippipah Springs 2	Annual	1518	15	241	111	21	246	52.3	+2.1	-52.9	33.3
	Summer			79.8	56.9		80.5	52.3	+0.9	-8.1	
	Winter			161	104		165	94.2	+2.5	-9.8	
BJY (83)	Annual	1241	19	153	74.7	25	166	80.8	+8.5	+8.2	31.5
	Summer			50.8	26.7		59.7	41.7	+17.5	+56.2	
	Winter			102	70.3		107	66.0	+4.9	-6.1	
Area 12 Mesa (84)	Annual	2283	20	316	152	26	329	151	+4.1	-0.7	30.0
	Summer			102	41.7		108	46.0	+5.9	+10.3	
	Winter			214	141		221	135	+3.3	-4.3	

rized; and in Cols. (6), (7), and (8) annual and seasonal average precipitation using the record complete through the end of calendar year 1985 are summarized. In Cols. (9), (10), and (11) the percent changes in annual and seasonal average precipitation, the associated standard deviations, and the lengths of the available period of record are summarized.

With regard to the data in Col. (9) of Table 1, the following observations can be made. First, the addition of approximately six years of record to the data base resulted in large percentage increases in the estimates of average annual and summer season precipitation, and much smaller percentage changes in the estimates of average winter season precipitation. Second, the largest percentage increases in estimated average precipitation were those associated with the summer season. Third, with one exception, the effect of lengthening the period of record was a one-way (positive) shift in both annual and seasonal average precipitation.

The following observations can be made regarding the data in Col. (10). First, at six stations the standard deviations associated with annual average precipitation demonstrated an increase in variability, and the remaining stations demonstrated a decrease. Second, the standard deviations associated with average summer season precipitation increased at all stations; and in most cases, this increase was significant. Third, the standard deviations associated with average winter season precipitation decreased at all stations. Finally, the percent change in the period of record available for analysis, Col. (11), was rather uniform.

The calculation of annual and seasonal average precipitation tacitly assumes that the observations are independent and identically distributed. Given the large changes in annual and seasonal average precipitation that resulted from lengthening the period of record available for analysis, it is appropriate that the validity of these tacit assumptions be examined. Two statistical tests were used to examine the data. First, a non-parametric test, known as the runs above and below the median, was used to test the null hypothesis that the data are random and identically distributed, Brownlee[2]. This test yields a statistic that is normally distributed when the sample size is large. The results of this test at the 0.05 level of significance are as follows. First, for annual precipitation the null hypothesis should be rejected for Station 77. That is, the annual precipitation data for Station 77 are neither random nor identically distributed. Second, for summer season precipitation, the null hypothesis is accepted for all of the stations. Third, for winter season precipitation, the null hypothesis should be rejected for Station 73. The second statistical test used to examine the data was the mean square successive difference test of the null hypothesis that the data are a series of independent observations of a normally distributed population, Brownlee[2]. In applying this test to the NTS precipitation data, it was assumed that annual and seasonal precipitation are log-normally distributed data. The results of this test at the 0.05 level of significance are as follows. First, for annual precipitation, the null hypothesis is accepted for all stations. Second, for summer precipitation, the null hypothesis should be rejected for Station 75. Third, for winter season precipitation, the null hypothesis should be rejected for Station 77.

The foregoing results, especially those regarding the stations at which the null hypothesis was rejected, must be interpreted with care. Given the very few stations at which the null hypothesis was rejected, it must be concluded that there is not sufficient evidence at this time to reject the assumption that all observations are random and log-normally distributed.

If the series from which annual and seasonal average precipitation are calculated can be described by a log-normal probability distribution, then the number of years of record required such that the error of estimate is a fixed percentage of the average value can be estimated; i.e., the effect of a changing length of record on estimates of annual and seasonal average precipitation can be examined. In Table 2, the length of record required to be 95% confident that the error of estimate is less than a fixed percentage of the mean value are summarized. The data summarized in Table 2 explain, at least partially, the relatively large changes in annual and seasonal average precipitation that resulted when the period of record was lengthened. Annual and seasonal precip-

Table 2. Length of Record Required to be 95% Confident that the Error of Estimate is Less Than a Fixed Percentage of the Annual or Seasonal Average Precipitation

Station (1)		Elevation m (2)	Current Length of record yrs (3)	Length of record required for error of estimate to be ≤ 10% mean, yrs (4)	error of estimate to be ≤ 15% mean, yrs (5)	error of estimate to be ≤ 20% mean, yrs (6)
Desert Rock (73)	Annual			80	35	20
	Summer	1005	22	260	120	65
	Winter			140	60	34
Mercury (74)	Annual			54	24	13
	Summer	1149	15	300	140	76
	Winter			76	34	19
4JA (75)	Annual			100	45	25
	Summer	1043	27	200	90	50
	Winter			140	61	34
Cane Springs (76)	Annual			82	36	20
	Summer	1219	21	220	97	54
	Winter			120	52	29
Well 5B (77)	Annual			76	34	19
	Summer	939	22	280	130	70
	Winter			130	57	32
Mid Valley (79)	Annual			63	28	16
	Summer	1420	19	150	65	37
	Winter			95	42	24
Yucca (80)	Annual			100	46	26
	Summer	1195	26	190	84	47
	Winter			140	61	34
40 MN (81)	Annual			60	27	15
	Summer	1469	23	140	60	34
	Winter			120	53	30
Tippipah Springs 2	Annual			62	27	15
	Summer	1518	21	160	69	39
	Winter			130	58	33
BJY (83)	Annual			100	45	25
	Summer	1241	25	160	73	41
	Winter			170	76	43
Area 12 Mesa (84)	Annual			64	29	16
	Summer	2283	26	62	28	16
	Winter			110	49	27

itation on the NTS is highly variable as evidenced by the rather large standard deviations associated with the calculated average values. Thus, it is concluded that the estimation of a stable value of annual and seasonal average precipitation at a specified station requires a long period of record. Therefore, it must be expected that as the period of record available at the NTS stations lengthens there will be additional relatively large changes in the estimates of annual and seasonal average precipitation.

Although the foregoing analysis tacitly addressed the possibility of data trend, it did not specifically examine this issue. It is hypothesized that the reason lengthening the period of precipitation record results in positive shifts in annual and seasonal average precipitation is that there is a trend in the data. Given this hypothesis, a strategy must be designed to test its validity. The strategy developed is as follows: 1) it is assumed that the logarithms of annual precipitation series demonstrate a linear relationship with time and 2) a log-linear regression of the data series with time being the independent variable will yield a line with a slope that is different from zero and normally distributed residuals.

In Figure 2a, annual precipitation data at Station 73 is plotted as a function of time and in Figure 2b the logarithms of annual precipitation are plotted as a function of time. Similar plots of annual precipitation at the other ten stations would exhibit similar characteristics. The hypothesized relationship between precipitation and time is

$$\log(p) = c + d(i)$$

where p = annual precipitation, i= year of record index with the first year of record being 1 and the n-th year of record being n, and c and d are regression coefficients. Once d is estimated, a t-test can be used to determine whether the value of d is significantly different from zero. The results are as follows. At the 0.05 level of significance, the null hypothesis (d is not significantly different from zero) is rejected for Stations 73, 75, 77, 81, 83, and 84; i.e., at these stations the log-transformed annual precipitation is increasing with time since for these stations d is positive. The null hypothesis is accepted for Stations 74, 76, 79, 80, and 82; i.e., at these stations the log-transformed annual precipitation is not increasing with time.

The foregoing analysis suggests that six of the eleven stations examined demonstrate trend in their annual precipitation record. The cause or reason for these trends are not obvious nor is it entirely clear that the trend is linear. It must also be noted that three of the stations whose observations exhibit trend (73, 75, and 77) also failed one or more of the statistical tests for randomness discussed previously. Possible explanations of the trend are short-term aberrations of the climate, long-term climatic change, or simply a random fluctuation. It must also be noted that the identification of trend in short-term precipitation records is difficult and the result may often be misleading; see for example, Osborn and Frykman[8].

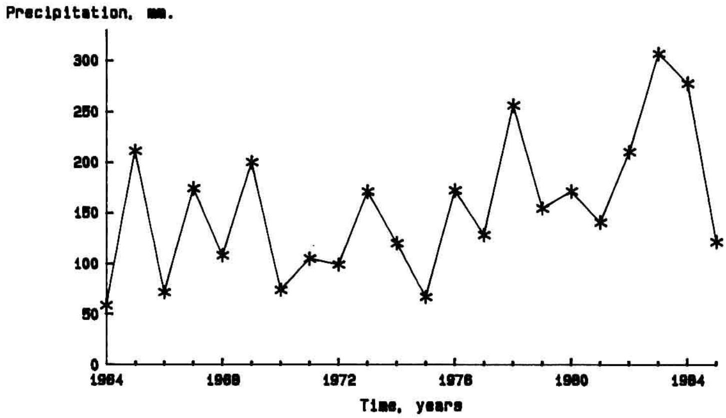

Figure 2a. Annual precipitation at Station 73 as a function of time.

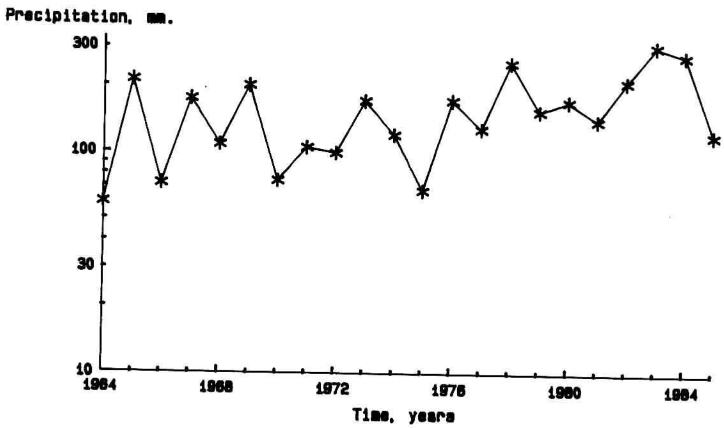

Figure 2b. Annual precipitation at Station 73 as a function of time. Note, the ordinate in this figure is a log scale.