Comparison of Rainfall Records Collected by Different Rain-gage Networks

By Timothy D. Straub and Paminder S. Parmar

Suggested Citation:

Straub, T.D., and Parmar, P.S., 1998, Comparison of rainfall records collected by different rain-gage networks: in Proceedings of the First Federal Interagency Hydrologic Modeling Conference, Las Vegas, Nevada. p. 7-25 - 7-32.

COMPARISON OF RAINFALL RECORDS COLLECTED BY DIFFERENT RAIN-GAGE NETWORKS

Timothy D. Straub, Civil Engineer, U.S. Geological Survey, Urbana, Illinois;
Paminder S. Parmar, Student Trainee, U.S. Geological Survey, Urbana, Illinois

Abstract
The implementation of surface-water quantity and quality models is only as sound as the available data. In a study done by the U.S. Geological Survey (USGS), in cooperation with the Du Page County Department of Environmental Concerns, simulated runoff tended to be higher when monthly rainfall totals recorded by National Oceanic and Atmospheric Administration (NOAA) precipitation gages were used as compared to using monthly rainfall totals recorded by USGS rain gages. The purpose of this paper is to describe whether a significant difference was detected between rainfall recorded by the USGS rain-gage network and the NOAA precipitation-gage (a precipitation gage is designed to record snow and rainfall, whereas a rain gage only records rainfall) network located in and near Du Page County, Illinois. Rainfall data recorded from 1986 to 1995 at 10 USGS rain gages and 5 NOAA precipitation gages in and near Du Page County, Illinois, were analyzed. Further insight into the physical basis for possible differences is provided by a dual-gage (weighing- and tipping-bucket) setup installed at one site. Three statistical tests were completed to check the hypothesis of no difference in the rainfall data recordings: the Wilcoxon rank-sum test, the Kruskal-Wallis test, and the paired t-test. Results from the statistical tests indicated that significantly different rainfall amounts were recorded at USGS and NOAA gages. Fitting a straight, least squares trendline to the data comparing monthly records from each NOAA gage with monthly records from each USGS gage showed that on average, USGS gages were recording 86 percent of the total rainfall recorded at the NOAA gages. Similar results have been found in the dual-gage (weighing- and tipping-bucket) setup comparison of rainfall data.

INTRODUCTION
Three commonly applied techniques of recording rainfall include the universal-type weighing-bucket recording gage, tipping-bucket rain gage, and standard 8-in. nonrecording precipitation gage (National Weather Service, 1989, p. 8-17). The purpose of this paper is to describe the methods applied and results obtained in the determination of whether a significant difference is present between rainfall recorded by the USGS rain-gage network and the NOAA precipitation-gage network located in and near Du Page County, Illinois. Further insight into the physical basis for possible differences in recorded rainfall amounts is provided by a dual-gage (weighing- and tipping-bucket) setup.

DESCRIPTION OF STUDY AREA
The study area is 17 mi west of the city of Chicago. The study area includes all of Du Page County and portions of the surrounding counties (Fig. 1). Rapid urbanization has lead to appreciable changes in the hydrologic environment. Higher peak flows and increased flooding have resulted because of urbanization.

Climate
Northeastern Illinois has a temperate, humid, continental climate that is slightly modified by Lake Michigan. Long-term climate data in and near the study area were obtained from five NOAA precipitation gages (Fig. 1). The long-term average annual precipitation and long-term mean annual temperature for the study area is approximately 33 in. and 49°F, respectively (U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1990).

DATA COLLECTION AND SELECTION METHODS
National Oceanic and Atmospheric Administration Network
5 NOAA precipitation gages located in and near Du Page County, Illinois were used for the study (Fig. 1). 4 of these were 8-in. nonrecording gages. These consist of a large diameter outer can, a smaller diameter measuring tube inside the outer can, a funnel that connects the outer can and measuring tube, a measuring stick, and a support. The funnel directs precipitation into the measuring tube, which holds exactly 2 inches of rainfall (additional rainfall will flow into the overflow can) (National Weather Service 1989, p. 8). The other NOAA precipitation gage type is the universal weighing-bucket recording gage. Precipitation falls

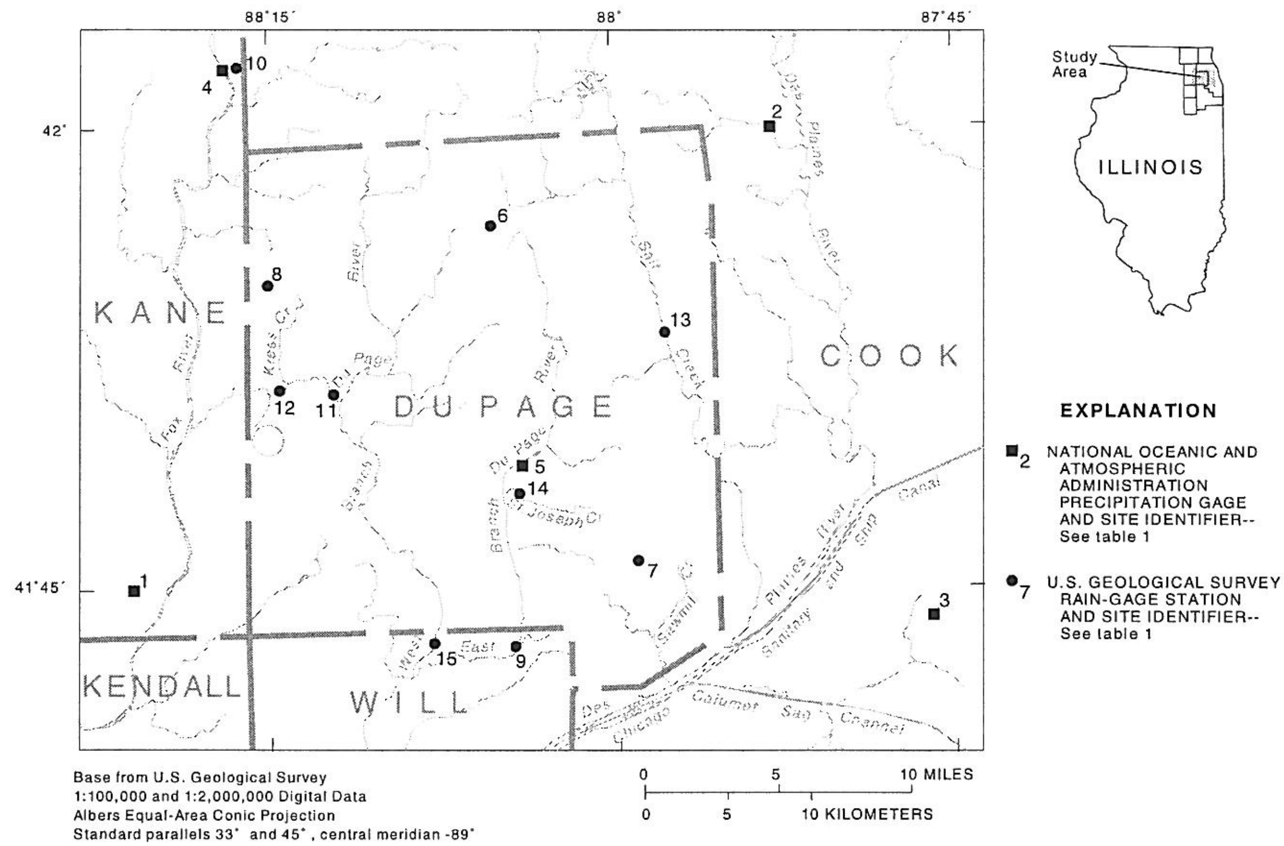

FIGURE 1: Locations of National Oceanic and Atmospheric Administration precipitation gages and U.S. Geological Survey rain gages in and near the study area.

TABLE 1: Precipitation Gages and Rain Gages Used in the Study

Site Identifier	Station Name and Abbreviation	Gage Type	Orifice Diameter, in inches	Accuracy, in inches	Months of Record Used
NOAA					
1	Aurora	Standard nonrecording	8	0.01	60
2	O'Hare	Universal weighing	8	.01	63
3	Midway	Standard nonrecording	8	.01	63
4	Elgin	Standard nonrecording	8	.01	60
5	Wheaton	Standard nonrecording	8	.01	63
USGS					
6	Bloomingdale Lift Station (BLOOM)	Tipping (Qualimetric[1])	8	.01	28
7	Clarendon Hills Cemetery (CLARE)	Tipping (Qualimetric)	8	.01	51
8	Du Page County Airport (DPCA)	Tipping (Qualimetric)	12	.01	45
		Universal weighing with alter windshield	8	.01	11
9	East Branch Du Page River (EBDP)	Tipping (Qualimetric)	8	.01	45
10	Elgin Wastewater Treatment (ELGIN)	Tipping (Qualimetric)	8	.01	34
11	Kress Creek (KRESS)	Tipping (Qualimetric)	8	.01	57
12	National Accelerator Lab (NAL)	Tipping (Qualimetric)	8	.01	33
13	Salt Creek at Elmhurst (ELM)	Tipping (Climatronic)	8	.01	38
14	St. Joseph Creek at Hwy 34 (HWY34)	Tipping (Climatronic)	8	.01	33
15	West Branch Du Page River (WBDP)	Tipping (Qualimetric)	8	.01	35

[1] The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U. S. Geological Survey, nor impute responsibility for any present or potential effects on the natural resources.

into the universal gage receiver, where it is funneled into a collector mounted on a weighing mechanism. The weight of the precipitation in the collector compresses a spring, which is connected to a pen (ink) arm. Ink from the pen leaves a trace on a paper chart, which is wrapped around a clock-driven cylinder. Ink tracings on the chart provide a "history of precipitation rates and amounts (National Weather Service 1989, p. 10). Gage information is listed in Table 1. Data used from the NOAA network were the monthly rain totals from March 1986 to September 1995 (U.S. Department of Commerce (1986-95)). Only the monthly totals for April through October were used for analysis so that snowfall-affected precipitation would not be a factor in the analysis.

U.S. Geological Survey Network

Between 1986 and 1990, the USGS installed a network of 14 tipping-bucket rain gages in and near Du Page County, Illinois. The 10 gages used in this study from this network are shown in Figure 1. Tipping-bucket rain gages work on the principle that rainfall collected by a funnel accumulates in a two-chambered bucket until the weight causes the bucket to tip on its pivot, dump the collected water, and move the other chamber under the funnel. The rain gages are connected to electronic data loggers that record the amount of rainfall in 0.01-in. increments at 5-minute intervals. Gage information for the 10 USGS gages used in the study is listed in Table 1. An insufficient amount of rainfall data for analysis were available at three gages and one gage did not operate properly. Monthly rainfall totals from the USGS network from March 1986 to September 1995 (Duncker and others 1993 and Straub and others 1997) were used in the study. Only the monthly totals for April through October were used for analysis so that snowfall-affected precipitation would not be a factor in the analysis.

U.S. Geological Survey Dual Gage Setup

Data have been collected by the USGS at Du Page County Airport, Illinois, where a tipping-bucket rain gage and a universal weighing-bucket recording gage have been installed within 5 ft of each other. Data used from this site were recorded from January 23, 1996, to December 11, 1997. Storms were selected for analysis when there were no equipment-related problems.

STATISTICAL TESTS

Statistical tests applied to the data were used to determine if there is a significant difference present between the amount of rainfall recorded for the same period of record between the USGS and NOAA gage networks. Three tests were selected to determine if the hypothesis of no difference in the measurements could be rejected. These were the Kruskal-Wallis test, the Wilcoxon rank-sum test, and the paired t-test. The Shapiro-Wilk test was randomly performed on the data to test for normality. A series of t-tests were performed and least squares trendlines were drawn for the dual-gage setup comparison in a manner similar to that used in the network comparison.

The Kruskal-Wallis test (Conover, 1980, p. 229-237) is a nonparametric test for comparing more than two groups of data. This test was used to determine if there were significant differences among rainfall amounts recorded at rain gages within the same group (differences within the NOAA and USGS networks). The Wilcoxon rank-sum test (Conover, 1980, p. 215-227) is a nonparametric test for comparing two independent groups of data. This test was used to determine whether one group of rain gages tended to record different rainfall amounts than another group of rain gages (differences between the NOAA and USGS networks). The two-sample t-test (Schlotzhauer and Littell, 1987, p. 191) is a parametric test to compare two independent groups of data. Unlike the nonparametric tests, the data are assumed to be normally distributed in a parametric test, with the variances assumed to be equal.

The hypothesis of all tests performed is that no difference is present between the amount each rain gage records (null hypothesis). The null hypothesis is tested by the calculation of a test statistic. The value of the test statistic is compared to reference values that would be expected if the null hypothesis were true. The result of this comparison is a probability level, or p-level, that tells you if the null hypothesis should be believed (Scholotzhauer, 1987, p. 126). The null hypothesis is either rejected or not rejected. The null hypothesis is never "accepted", it can only be "not rejected". In testing the given hypothesis, the maximum probability of rejecting the null hypothesis when it is correct is called the significance level (Spiegel, 1988, p. 207). For example, if it was determined that a difference was present between two rain gages at the 0.10

or 10 percent significance level, then there is a 10-percent chance that the conclusion of a statistical difference is incorrect.

For this study, 10-percent is considered moderately significant, whereas 1 percent is considered highly significant. The 10-percent level was used for tests among rain gages located at different sites. This results in less stringent criteria in rejecting the null hypothesis. This criteria was applied because the spatial variability related to rainfall distribution results in variations in rainfall totals between nearby rain gages even at the monthly time scale. The 1-percent level (0.01) was applied for the dual-gage setup. The rain gages in the setup were 5 ft apart. A lower significance level was chosen to make it more difficult to reject the null hypothesis (more difficult to conclude that there is a significant difference) as compared to the 10-percent level. This was applied because it was expected for storm totals to be nearly identical due to the proximity of the rain gages. At the 10-percent significance level, a p-level of greater than 0.10 results in failing to reject the null hypothesis, and a p-level of 0.10 or less results in rejecting the null hypothesis. The procedure of failing to reject or rejecting the null hypothesis is the same at the 1-percent significance level, except that a p-level of 0.01 is used in the analysis.

Results of Comparison Between the National Oceanic and Atmospheric Administration and U.S. Geological Survey Networks

First, the data were analyzed to determine if there were significant differences among rainfall amounts at the gages in each network. The Kruskal-Wallis test was performed on monthly rainfall totals for the entire NOAA precipitation-gage and USGS rain-gage networks (Table 2). In both tests, a p-level of greater than 0.10 was determined and the null hypothesis was not rejected. The next test was to combine both networks, with each rain gage considered separately (15 groups). Again the null hypothesis was not rejected. Next, NOAA gages were placed into one group and USGS gages were placed into another group for analysis with the Wilcoxon rank-sum test. From this analysis, the null hypothesis was rejected at the 10-percent significance level.

TABLE 2: Kruskal-Wallis and Wilcoxon Rank-Sum Test Results

Bold values indicate p-levels below the 10-percent significance level

Test	Comparison	P-Level
Kruskal Wallis	NOAA Network	0.810
	USGS Network	.979
	NOAA and USGS Network	.914
Wilcoxon Rank Sum	NOAA vs. USGS Network	**.055**

A series of t-tests were done to perform paired comparisons between the NOAA gages and the USGS gages for monthly rainfall totals. The p-levels of these tests are shown in Table 3. Data used in the t-tests were randomly checked for normality and it was concluded that the hypothesis of normality could not be rejected at the 5 percent significance level. In the first series of tests the 10 USGS rain gages were tested with the 5 NOAA rain gages for a total of 50 paired t-tests. At the 10-percent level, rejection of the null hypothesis resulted from 28 tests. For three USGS gages (BLOOM, CLARE, and DPCA), the null hypothesis was rejected in the comparison with all five NOAA gages; whereas for two USGS gages (ELGIN and WBDP), the null hypothesis was rejected in comparison with only one NOAA gage. An unevenness also resulted in the rejection of the null hypothesis in the NOAA gages. In tests involving the O'Hare, Midway, and Elgin, NOAA gages, the null hypothesis was rejected in comparison with only 3-4 USGS rain gages; whereas in tests involving the Aurora and Wheaton gages, the null hypothesis was rejected in comparison with 8-9 of the 10 USGS gages.

Paired t-tests were then performed within each network to determine if the rain gages in the same network were recording similar rainfall amounts. The results for the USGS network are shown in Table 4. The null hypothesis was rejected in 22 of 50 paired t-tests. The null hypothesis was rejected six times in comparisons with the rain gage at KRESS. Lastly, paired t-tests were performed among the NOAA gages. Out of the 10 possible tests, the null hypothesis was rejected in 3 tests, all involving Aurora gages (Table 5).

TABLE 3: P-Levels of Paired t-Tests Between National Oceanic and Atmospheric Administration and U.S. Geological Survey Rain-Gage Networks

Bold values indicate p-levels below the 10 percent significance level

Site	Aurora	O'Hare	Midway	Elgin	Wheaton
BLOOM	**0.001**	**0.002**	**0.085**	**0.064**	**0.009**
CLARE	**.000**	**.096**	**.055**	**.031**	**.005**
DPCA	**.003**	**.032**	**.035**	**.041**	**.008**
EBDP	**.000**	.304	**.007**	.180	**.000**
ELGIN	.165	.591	.315	**.002**	.290
KRESS	**.045**	.783	.644	.747	**.074**
NAL	**.000**	.504	.425	.227	**.037**
ELM	**.008**	.761	.228	.717	**.031**
HWY34	**.016**	.401	.217	.270	**.021**
WBDP	**.034**	.583	.296	.517	.144

TABLE 4: P-Levels of Paired t-Tests Between U.S. Geological Survey Rain Gages

Bold values indicate p-levels below the 10 percent significance level

Site	BLOOM	CLARE	DPCA	EBDP	ELGIN	KRESS	NAL	ELM	HWY34	WBDP
BLOOM		0.349	0.801	0.805	0.387	**0.002**	0.545	**0.095**	0.450	0.506
CLARE	0.349		.331	**.072**	.539	.317	.190	**.023**	**.020**	**.038**
DPCA	.801	.331		.459	.743	**.080**	.927	.503	.928	.276
EBDP	.805	**.072**	.459		.664	**.005**	.381	.714	.381	.206
ELGIN	.387	.539	.743	.664		.519	.929	.403	.818	.970
KRESS	**.002**	.317	**.080**	**.005**	.519		**.000**	**.001**	**.002**	.277
NAL	.545	.190	.927	.381	.929	**.000**		.305	.610	.386
ELM	**.095**	**.023**	.503	.714	.403	**.001**	.305		.860	.347
HWY34	.450	**.020**	.928	.381	.818	**.002**	.610	.860		.915
WBDP	.506	**.038**	.276	.206	.970	.277	.386	.347	.915	

TABLE 5: P-Levels of Paired t-Tests Between National Oceanic and Atmospheric Administration Precipitation Gages

Bold values indicate p-levels below the 10 percent significance level

Site	Aurora	O'Hare	Midway	Elgin	Wheaton
Aurora		**0.076**	**0.040**	**0.096**	0.405
O'Hare	**0.076**		.971	.845	.150
Midway	**.040**	.971		.813	.137
Elgin	**.096**	.845	.813		.288
Wheaton	.405	.150	.137	.288	

Investigation of the Difference in Recorded Rainfall Between Networks

The statistical test results indicated that some gages were recording different monthly totals than others. The magnitude of the difference was estimated by fitting a straight, least-squares, linear regression between monthly data from one gage to the monthly data of another gage. The relation between the USGS BLOOM gage and the NOAA O'Hare gage is shown in Figure 2. In this study, a trendline slope multiplied by 100 represents the percentage of rain that a USGS gage recorded as compared to a NOAA gage. A number of scattergraphs were plotted and analyzed. For each of these plots, a trendline was drawn. The mean trendline slope of the USGS rain gages averaged 0.86 relative to the five NOAA gages. The standard deviation was 0.05, with a coefficient of variation of 0.06 (Table 6). Slopes from 8 of the 10 USGS rain gages fall within one standard deviation of 0.86.

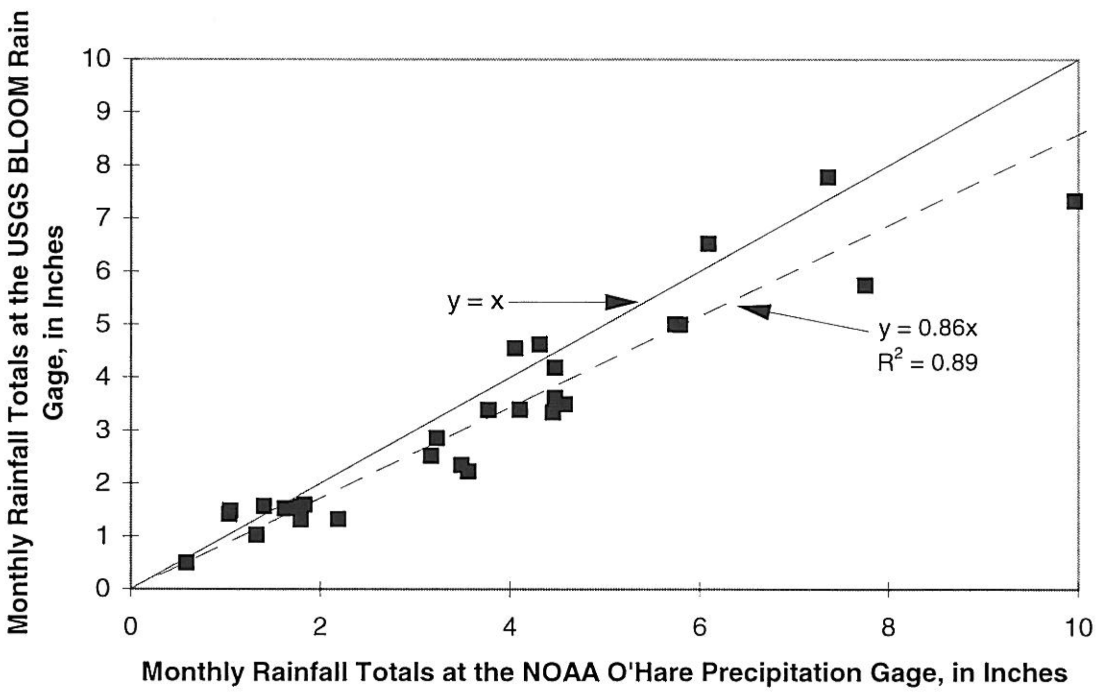

FIGURE 2. Comparison of monthly rainfall totals between the USGS BLOOM gage and the NOAA O'Hare gage.

TABLE 6: Trendline Slopes of U.S. Geological Survey versus National Oceanic and Atmospheric Administration Monthly Rainfall Totals

Site	Aurora	O'Hare	Midway	Elgin	Wheaton	Averages
BLOOM	0.792	0.858	0.782	0.807	0.802	0.808
CLARE	.811	.859	.828	.832	.836	.833
DPCA	.727	.687	.805	.804	.719	.748
EBDP	.848	.896	.882	.869	.875	.874
ELGIN	.823	.939	.807	.930	.874	.875
KRESS	.896	.916	.961	.964	.896	.927
NAL	.866	.892	.901	.868	.859	.877
ELM	.859	.948	.847	.917	.873	.889
HWY34	.878	.897	.867	.880	.897	.884
WBDP	.882	.904	.907	.898	.931	.904
Averages	.838	.880	.859	.877	.856	**.862**
Mean =	**0.862**					
St. Dev =	.052					
C. O. V. =	.060					

Dual-Gage Setup Comparison

A dual-gage setup comparison was performed between the USGS tipping- and weighing-bucket rain gages located at DPCA. The period for this comparison was from January to December 1996, this is a different time period than that used in the network analysis (April 1986-September 1995). In this study, it was discovered that there were scattered periods of time when the tipping bucket was not recording rainfall from storms or recording only during parts of a storm. For the dual-gage setup comparison, the data were analyzed for specific storms where the tipping-bucket rain gage was working properly. Storm totals were analyzed in the dual-gage setup instead of monthly totals which were used in the network analysis. Rainfall data from 26 storms were used in the dual-gage setup analysis.

A series of t-tests were performed and least-squares trendlines were drawn for the dual-gage setup comparison in a manner similar to that used in the network comparison. A significance level of 0.01 was used in the dual-gage setup. The null hypothesis was rejected at the 1-percent significance level when all 26 storms were considered (Table 7). The fitted trendline for all storms was 0.91. It should be noted that the tipping-bucket rain gage at this location contains a 12-in. diameter cylinder instead of an 8-in. diameter cylinder used in all other USGS gages. Past research has shown that the 8-in. diameter rain gage averages 2.6 percent less rainfall than the 12-in. diameter rain gage (Jones, 1969).

A number of factors including temperature, wind speed, rainfall amount, and rainfall intensity for each storm was studied to examine why there was a difference in amount of rainfall recorded. No correlation was found between temperature or wind speed and the amount of rain recorded, but a relation was found between storm totals and the difference between amounts recorded at each gage. For storm totals with rainfall amounts greater than 1 in., the null hypothesis was not rejected. Upon further examination, it was determined that the storms producing greater than 1 in. of rain tended to have periods of more intense rain. Rainfall intensity was studied more closely. Four classes of rainfall intensity were considered: light, moderate, intense, and very intense. These were assigned based on the amount of rain recorded per 5-minutes. A criteria of greater than 0.27 in. per 5 minutes was selected for very intense rainfall. This was based on recommended corrections for tipping-bucket rain gages for periods when rainfall exceeded 0.27 in. per 5 minutes (Qualimetrics, Inc., 1986, p. 8) The criteria for other levels are listed in Table 7. Storms were classified according to the majority of the amount of rainfall. For example, a 2-hour storm with a total rainfall of 0.5 in. would be classified as intense if three 5-minute periods of intense rainfall resulted during the storm. The majority of the amount of rain in this storm would have been classified as intense, while only 15 minutes of the 2 total hours would have been an intense period of the storm. At the 1-percent significance level, light rain was the only category in which the null hypothesis could be rejected. Trendline slopes were established, and a relation was found between intensity and amount of rainfall difference among categories. Slopes of 0.88 and 0.97 were calculated for light rain and very intense rain, respectively. The 5-minute values for very intense rain were already corrected for the tipping-bucket rain gage as per manufacturer specifications, but the amount of the correction was small enough that these adjustments alone could not account for the result that an almost perfect trendline slope was determined for the very intense rainfall classification. Data from light storms are more sensitive to wetting losses (amount of rain required to moisten the funnel and inside surfaces). In the dual-gage setup, the tipping-bucket gage had a funnel, whereas no funnel was present for the weighing-bucket gage. It is estimated that 2-15 percent of each rain event measured at an initially dry gage is not recorded because of wetting losses in the summer (Sevruk, 1982). A shielded gage, such as the weighing-bucket in the dual-gage setup, records 3-5-percent greater amount of rain depending on the wind speed compared to unshielded gages, like the tipping bucket in the dual-gage setup (Linsley and others, 1975).

TABLE 7: Paired t-Tests Between Tipping- and Weighing-Bucket Gages at DPCA for Various Storm Classifications

Storm Classification	Trendline Slope	P-Level	Number of Storms
All Storms	0.91	0.002	26
Less Than 1 Inch Storm Total	.92	.005	21
Greater Than 1 Inch Storm Total	.91	.050	5
Light (0.01 - 0.04 inches per 5 minutes)	.88	.009	9
Moderate (0.05 - 0.09 inches per 5 minutes)	.92	.060	7
Intense (0.10 - 0.26 inches per 5 minutes)	.94	.200	4
Very Intense (Greater than 0.26 inches per 5 minutes)	.97	.400	5

CONCLUSIONS

Conclusions for the Network Comparison

From the results of the Wilcoxon rank-sum tests a statistically significant difference between monthly rainfall totals recorded by the two networks was determined, whereas there appeared to be no difference within a particular network, based on the results of the Kruskal-Wallis tests. Results from the paired t-tests indicated that within each network there were a few inconsistent rain gages, but for the most part, it can be concluded that some inherent difference in monthly rainfall amounts is present between the two networks and that the difference is not caused by variations within one particular network. Results of the least-squares regression showed that, on average, USGS rain gages recorded 86 percent of the total rainfall recorded at NOAA precipitation gages.

Conclusions for Dual-Gage Setup Comparison

The paired t-tests indicated that a statistically significant difference at the 1-percent significance level was present in the amount of rain recorded at the tipping-bucket gage as compared to the weighing-bucket gage when all storms were analyzed. On average, the tipping-bucket gage recorded 91-percent of that recorded by the weighing-bucket gage. The difference in the trendline slope (0.91) found in this analysis compared to the trendline slope found in the network comparison (0.86) can partly be explained in that only storms were selected when it was known that the tipping-bucket gage in the dual-gage setup was working under optimum conditions. In addition, the difference in the diameter of the rain gage at DPCA compared to other gages in the USGS network can result in a 2.6-percent increase for the rain recorded (Jones, 1969).

A difference was found between the two gages when different classifications of rainfall intensities were tested. As rainfall intensity increased, the difference in the amount of rainfall recorded between the tipping- and weighing-bucket gages decreased. These results should be considered with caution because only between four and nine storms were included for each rainfall classification. Two other factors in the setup of the gages can also affect the results when classifying by intensity. The weighing-bucket gage in the dual-gage setup did not contain a funnel which can decrease the losses due to wetting by 2-15 percent (Sevruk, 1982). Lastly, a shielded gage, such as the weighing bucket in the dual-gage setup, records 3-5-percent greater amount of rain depending on the wind speed compared to unshielded gages, like the tipping bucket in the dual-gage setup (Linsley and others, 1975).

REFERENCES

Conover, W.J., 1980, Practical nonparametric statistics: New York, New York, John Wiley and Sons, Inc.

Duncker, James J., Vail, Tracy J., and Earle, John D., 1993, Rainfall in and near Du Page County, Illinois, February 1986-September 1991: U.S. Geological Survey Open-File Report 92-485

Jones, D.M.A., 1969, Effect of housing shape on the catch of recording gages: Urbana, IL, Monthly Weather Review, v. 97, no. 8, p. 604-606.

Leighton, M.M., Ekblaw. G.E., and Horberg, Leland, 1948, Physiographic divisions of Illinois: Illinois State Geological Survey, Report of Investigations 129, 33p.

Linsley, R.K. Jr., Kohler, M.A., Paulhus, J.L., 1975, Hydrology for engineers (2d ed.): New York, New York, McGraw-Hill, Inc., p. 69-70.

National Weather Service, 1989, Cooperative station observations: Silver Spring, Maryland, National Weather Service Observing Handbook No. 2, Silver Spring, MD.

Qualimetrics, Inc., 1986, Manual for precipitation gage calibrator model 60103: Sacramento, California, Manual No. 60103-001, October 1986, p. 8.

Schlotzhauer, S.D., and Littell, R.C., 1987, SAS system for elementary statistical analysis: Cary, North Carolina, SAS Institute, Inc., 416 p.

Sevruk, B, 1982, Methods of correction for systematic error in point precipitation measurement for operational use: Geneva, Switzerland, World Meteorological Organization, Operational Hydrology Report No. 21, WMO - No. 589, 91 p.

Spiegel, M.R., 1988, Theory and Problems of Statistics (2d ed.): New York, NY, McGraw Hill Inc., 504 p.

U.S. Department of Commerce, National Oceanic and Atmospheric Administration, 1986-95, Climatological data, Illinois: Asheville, N.C., Environmental Data and Information Service. (published monthly).