Environment Canada Imaging Cover Page

Report N.: *TEC-756*

SKP Box Number: 672672428

ATMOSPHERIC ENVIRONMENT SERVICE
DEPARTMENT OF THE ENVIRONMENT — CANADA

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Technical Memoranda

THE EFFICIENCY OF STERO-TOPPED GAUGES IN A MANITOBA BASIN

by

S.J. BUCKLER and J.F. QUINE

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U.D.C. 551·508·77

TEC 756
30 JUNE 1971

ENVIRONMENT CANADA - ATMOSPHERIC ENVIRONMENT SERVICE
4905 Dufferin Street
Downsview, Ontario

THE EFFICIENCY OF STEREO-TOPPED GAUGES IN A MANITOBA BASIN

by

S. J. Buckler

and

J. F. Quine

ABSTRACT

This study compares the relative catch efficiency of standard horizontal raingauges with stereo-topped (sloping orifice) rain gauges on three slopes in Western Manitoba. The gauge sites are in a heavily instrumented basin where observations have been obtained for seven years. Respective catches were examined by seven year totals and also by separate storm totals. For identifiable upslope wind flows, the stereo gauges were more efficient by 13%. For downslope or lee winds, the stereo gauges caught 15% less than the adjacent standard gauges. The undercatch on lee slopes appeared to be independent of wind speed, whereas the efficiency on windward slopes increased with wind speed.

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SERVICE DE L'ENVIRONNEMENT ATMOSPHERIQUE
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EFFICACITÉ D'UN TÉRÉOPLUVIOMÈTRE À ORIFICE BISEAUTÉ DANS UN BASSIN DU MANITOBA

par

S.J. Buckler

et

J.F. Quine

RÉSUMÉ

Cette étude compare l'efficacité des pluviomètres horizontaux standards et des stéréopluviomètres à orifice biseauté sur trois versants dans l'ouest du Manitoba. Les pluviomètres ont été placés dans un bassin muni de nombreux instruments et où des relevés ont été effectués pendant sept ans. Les quantités de pluie recueillies respectives ont été comparées par total des sept années et aussi par total de tempête isolée. Pour les courants de vent identifiables en versant amont, l'efficacité des stéréopluviomètres a été de 13 p. 100 supérieure. Sur les versants aval ou pour les vents aval, les stéréopluviomètres ont recueillis 15 p. 100 moins de pluie que les pluviomètres standards placés à proximité. La quantité de pluie moins élevée recueillie sur les versants sous le vent ne semble pas reliée à la vitesse du vent, tandis que sur les versants exposés aux vents, l'efficacité augmente avec la vitesse du vent.

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(Manuscript received April 6, 1971)

1. Introduction

In calculating the volume of precipitation in a basin for runoff calculations, the area of the basin is scaled from charts assuming that the basin is flat. Often the basin is not flat as it may contain hills and valleys resulting in a ground area greater than the map would indicate by a factor depending on the slope angle. In measuring the precipitation over this basin for runoff volume, the equivalent precipitation falling on a horizontal surface is required. Therefore, a gauge with a horizontal orifice should be used and the measured value should not be changed.

To know how many inches of rain a crop receives per unit area when a field is sloped is a different situation. In that case we should measure the depth of precipitation on the sloped (and hence larger) area, not on the projection of the sloped area on the horizontal plane. Because of the larger area, the depth of precipitation per unit area will be less than that recorded in a horizontal orifice gauge and the measurement should be reduced by the ratio of the horizontal orifice area to its projection on the sloping surface. An alternative method is to mount the standard gauge with the orifice parallel to the slope as in Figure 1(C). The catch is considered as falling on an area of slope equal to the area of the gauge orifice, not on the horizontal projection of the orifice. Geiger (2) discusses this problem and quotes experiments by J. Grunow showing the greater efficiency of the sloping orifice on windward slopes. Hayes and Kittredge (4) used tilted and non-tilted gauges in an extensive experiment on an exposed, windy, 40 percent slope. The horizontal gauges were markedly inferior to the tilted gauges in catching rainfall. In this experiment the rain-bearing winds were always upslope.

In sites on an extensive sloping surface the WMO Guide to Meteorological Instrument and Observing Practices (9) recommends the use of a gauge with aperture parellel to the slope. This is presumed necessary in regions where rain-producing winds are constant in direction, such as in the monsoon regime.

Storr has pointed out (7) that the Canada standard raingauge cannot be used in the above manner on slopes near or greater than 23°. As shown in Figure 1(C) the shallow slope of the funnel will cause ponding and will promote splashout. It is possible to use the standard gauge by placing a false or stereo top on the horizontal orifice such that the slope of the stereo top is parallel to the ground as in Figure 1 (b). This study considers the efficiency of such gauges when used on steep slopes of 28° to 36°. The final information desired is the depth of rain on a horizontal surface for the purpose of calculating runoff. Hence, a vertical standard gauge was located with each stereo and was used as the reference gauge.

The assumption is made in this study that most raindrops fall nearly vertically. The assumption is not justified in cases of precipitation with strong winds or in cases of light rain or drizzle. In such cases the trajectory of the drops will slant with the wind. If wind direction is variable, then overcatch and undercatch will tend to cancel out. If winds are not strong the difference will be less marked.

Bruce and Potter (1) have reviewed the sources of errors in measuring precipitation. All errors are negative except splash, so that the errors cumulate as a deficiency. As a result it is customary to assume when comparing different gauges that the gauge catching more rain is relatively more efficient. It is with this meaning that the term efficiency is used in the following report.

2. Wilson Creek Basin Experiment

(a) Topography and Climate

The Wilson Creek Basin is part of the eastern slope of the first prairie escarpment about 30 miles west of Lake Manitoba. The escarpment lies on a N-S line with an increase in general elevation from 1200 to 2200 feet above sea level in about 5 miles. Deep valleys (400-600') have been cut in the escarpment face by rapidly flowing streams draining to the east. There are many hillsides with local aspects facing north or south.

Most of the precipitation comes from low pressure systems moving from the north central states across Southern Manitoba.

Over the Wilson Creek Basin this gives an easterly wind shifting through north to northwest as the pressure system advances into Western Ontario. Summertime instability showers have variable wind direction.

(b) Instrumentation

This study at Wilson Creek was initiated in 1963. Pairs of standard and stereo gauges were installed on each slope with the gauges two to three feet apart and the rims at about 12 in. above ground. Each installation was made in the middle of a slope about 200 yards long. These gauges were part of a network of 34 gauges of various types spread over the 8 square miles of the Wilson Creek project. Figure 2 is a plan of the basin showing the standard guage network.

The tops of the stereo gauges were parallel to the slopes on which they were located. This was arranged by putting a special top on a vertical standard gauge. Diagrams of standard and stereo installations are shown in Figure 1, a and b.

Readings were made once a day but the reports used in this study are based on complete storms of one to three days duration. The pairs were installed as follows with readings from May to September each year up to and including 1969.

TABLE 1.

Gauge No.	Slope Angle	Observations Started	Aspect
27	36^o	May 31, 1963	Northeast
28	28^o	May 31, 1963	Southeast
29	30^o	June 29, 1963	Northwest

Other instruments used in the area at this time were: (a) an anemograph in the basin about one to three miles distant from the three pairs of gauges under study and about 30 feet above ground, (b) recording rain gauges located within 2000 feet of each pair of test gauges.

3. Results

(a) Totals for 1963 - 1969

The following table separates the seven-year totals according to individual storm amounts. No attempt is made here to make any adjustment for slope and the readings are all as shown by the standard rain-gauge glass graduate.

TABLE II.

Summary of All Data

Gauge No. 27 - Aspect Northeast, Slope 36°

Standard Gauge Reading	Number of Observations	Total Precipitation at Standard Gauge	Total Pcpn at Stereo Gauge	Ratio of Stereo to Standard (Percent)
.40" or less	141	25.90"	20.93"	80.8%
.41" to 1.00"	55	37.00"	31.49"	85.1%
1.01" and over	25	46.25"	44.17"	95.5%
Totals	221	109.15"	96.59"	88.5%

Gauge No. 28 - Aspect Southeast, Slope 28°

.40" or less	139	23.25"	19.26"	82.8%
.41" to 1.00"	54	35.74"	33.10"	92.6%
1.01" and over	22	41.64"	41.10"	98.7%
Totals	215	100.63"	93.46"	92.9%

Gauge No. 29 - Aspect Northwest, Slope 30°

.40" or less	143	22.64"	22.64"	100.0%
.41" to 1.00"	41	26.86"	25.95"	96.6%
1.01" and over	24	40.22"	39.64"	98.5%
Totals	208	89.72"	88.23"	98.3%

Table 2 shows that almost invariably the stereo gauge totals are less than the corresponding standard totals. The light rainfall amounts show the greatest discrepancies at sites 27 and 28 with decreasing differences for the heavier rains. Assuming that heavier rains have larger raindrops, then it would follow that the droplets should fall closer to a vertical trajectory and so both types of gauge would operate with equal efficiency.

Site No. 29 came closest to equal amounts with the light rains producing exactly equal totals. The overall total for 29 showed a difference of only 1.7%. Hiatt and Schloemmer (5) point out that differences in commonly used gauges run to the order of ± 5%. This puts the site 29 totals well within the limits of accuracy of the measurement system.

The precipitation amounts are separated into months for each gauge for detection of a seasonal bias. The results are shown in Table III.

TABLE III

Monthly Totals 1963-9

No. 27.	Standard Total	Stereo Total	Ratio Stereo/ Standard Percent
May	14.23	14.11	99
June	24.83	23.41	94
July	24.24	19.35	80
August	25.40	21.26	84
September	29.36	18.46	90
Totals	109.15	96.59	88
No. 28.			
May	13.37	12.97	97
June	22.72	22.53	99
July	22.12	20.45	92
August	23.62	20.16	85
September	18.80	17.35	92
Totals	100.63	93.46	93

No. 29.	Standard Total	Stereo Total	Ratio Stereo Standard Percent
May	11.43	12.97	113
June	16.21	16.20	100
July	22.36	20.61	92
August	22.19	21.31	96
September	17.53	17.14	98
Totals	89.72	88.23	98

The lower percentages in July and August suggest a possible seasonal effect. July - August is the season of maximum convective activity and it may be that gusty surface winds account for the decrease in relative efficiency. However, the greater relative efficiency of the standard was apparent in this tabulation. Only in May for No. 29 was the standard total less than the stereo total by a significant amount.

(b) Individual Storm Totals

All the data for individual events for each pair of gauges were next plotted on separate graphs, Figures 3, 4 and 5. The distribution of the points showed the same bias as Table 2. However, many individual events showed the stereo total as the greater. Gauge sites 27 and 28, facing northeast and southeast respectively, were quite similar throughout the whole range of amounts, i.e., the stereo gauges (on the average) undercaught by 15 to 20% on amounts of .40" or less and the average discrepancy was down to a few percent when the amounts were over an inch. For some unexplained reason Gauge site 29 facing northwest had more nearly equal readings for standard and stereo totals.

(c) Effect of Wind Direction

Other investigators have found the efficiency of catch to depend on wind direction and velocity. Geiger (2) showed the results of experiments in which windward site stereos caught 20% more than standard gauges and leeward stereos caught 5% less than standard gauges. Hayes (3) in an extensive experiment with pairs of stereo and standard gauges similar to the USWB gauge, found (a) that stereo gauges caught more than standard gauges on both slopes and (b) the windward stereos caught as much or more than the leeward stereos. In contrast the standard gauges on the windward side caught only 80% to 90% of the standard catch on the leeward side. Hayes and Kittredge (4) on a windy, 40° slope, used tilted and horizontal USWB standard gauges. All precipitation occurred with an upslope wind. The tilted standard gauges caught within 2% to 3% of the catch from the reference gauges which were tilted, Niphershielded USWB standard gauges. The horizontal gauges were less efficient. The deficiency of the horizontal shielded gauges ranged from 5 to 10% and deficiency of the horizontal unshielded gauges was from 15 to 20%. Storr (7) worked on a prevailing lee slope and found that stereo gauges almost invariably caught less than the horizontal orifice MSC gauges.

These experiments suggest that on lee slopes a horizontal gauge orifice should be used. On slopes with a prevailing windward aspect, stereo topped or tilted orifice gauges should be used.

(d) Effect of Wind Direction at Wilson Creek in Individual Storms

Hourly wind data was available from the anemograph approximately one to three miles from the test sites. Recording rain gauges were situated within 2000 feet of each test site. Consequently, it was possible to determine the wind velocity during the rain periods. Definite upslope and downslope situations were separated and plotted against wind speed (at 30 feet), after Grunow's method as presented in Geiger (2). Only storm totals of 0.30" or greater were used.

When velocities of 5 mph or greater were considered, 27 storms of upslope and downslope effects at No. 28 and No. 29 were isolated. Precipitation totals showed the stereos caught 13% more than standard gauges in upslope winds, and 15% less than the standard in downslope winds. For the upslope case, 23 of 27 observations measured more in the stereo than in the standard. For the downslope direction only 1 of 27 observations measured more in the stereo than in the standard. The ratios of stereo catch to standard catch are plotted against wind velocity in Figure 6. Three storms provided similar identification of upslope and downslope effects when velocities were less than 5 mph. In this set of three, all observations recorded less in the stereo gauges than in the standards regardless of the aspect. These points were plotted also on Figure 6 which shows the definite bias towards undercatch by stereo gauges in downslope conditions.

Theoretically the point of inflection or the intersection of the two curves should be at zero wind and 100%. Grunow's curves (2) did meet at this point. The presence of both upslope and downslope points below the 100% line with light winds in Figure 6 suggests that some effect such as increased turbulence decreases the efficiency of the stereo top.

In 13 storms (not plotted), where the wind was greater than 5 mph and across the slope (no upslope or downslope effect), the results were inconclusive as might be expected. Difference between the 13-storm totals of standard and stereo was less than 2%.

Results from gauge No. 27 were intractable when separated by wind direction. Right angle winds, downslope winds and light winds showed the stereo gauge catching 15% less than the standard. In 13 upslope situations the stereo did catch more, but only by 3%.

(e) Effect of Drop Trajectory

The assumption that raindrops fall more or less vertically was questioned. If the drops move with the airstream, then the trajectory of the drops would be the resultant of their terminal velocity in still air and the upslope (or downslope) component of the wind. Given such a trajectory it is possible to calculate the effective area of each gauge perpendicular to the path of the drops in a particular storm. The ratio of effective areas to actual catches should have a direct relation. Meinzer (6) has published tables of characteristic drop sizes and their terminal velocities. Rates of fall in individual storms were used to estimate a dominant drop size. Trajectories were plotted using the hourly winds for a number of storms and the respective terminal velocities.

The ratios of stereo to standard catch were plotted against the ratios of effective areas in Figure 7. If the assumption that the drops move with the air stream was correct, then the points would plot along a 45° line. It is apparent that the slope of the line is less than 45°, suggesting that the trajectory is intermediate between the two assumptions of vertical fall and motion with the ambient air.

(f) The data used in Figure 6 were then treated by differences rather than ratios - that is the standard catches were subtracted from the stereo catches and plotted against wind speed. Results appear in Figures 8 and 9. Surprisingly, on the leeward slope the windspeed has no identifiable effect on the undercatch by the stereo. The average deficiency is 0.14" and appears from Figure 8 to be independent of wind speed.

For the windward exposure there is a variation with the wind speed. The surplus of stereo over standard increases with wind speed after a threshold value of about 7 mph has been surpassed.

4. Conclusions

(a) On Wilson Creek, in rainstorms with identifiable upslope winds, the stereo gauges caught 13% more than the standard gauges. In rainstorms giving downslope winds, the stereo gauges caught 15% less than the adjacent standard gauges. This agrees well with other investigations of this type of gauge.

(b) The undercatch on lee slopes appears to be independent of the wind strength. On the other hand, the surplus in catch on windward slopes over the standard gauge, appears to increase with increasing windspeed.

(c) When rainfall totals were segregated by size of storm, the seven year totals (Table 2) showed that in every case the stereo gauges caught less than the adjacent standards. If it is assumed that the larger storm amounts represent greater rates of rainfall and the smaller amounts lesser rates of rainfall, then in general, the percentage of undercatch increases as the rate of rainfall decreases. Gauge No. 29 was an exception since the ratios were nearly equal at all intensities.

(d) It is apparent that no advantage is gained from the stereo gauge when totals by months or longer periods are considered. This is presumably due to the variability of wind direction during frontal precipitation. Only in considering individual rain events with pronounced upslope winds, does the stereo gauge offer any improvement over the standard gauge. Consequently it would appear prudent to discontinue the stereo gauge measurements.

APPROVED,

J.R.H. Noble,
Assistant Deputy Minister,
Atmospheric Environment Service.

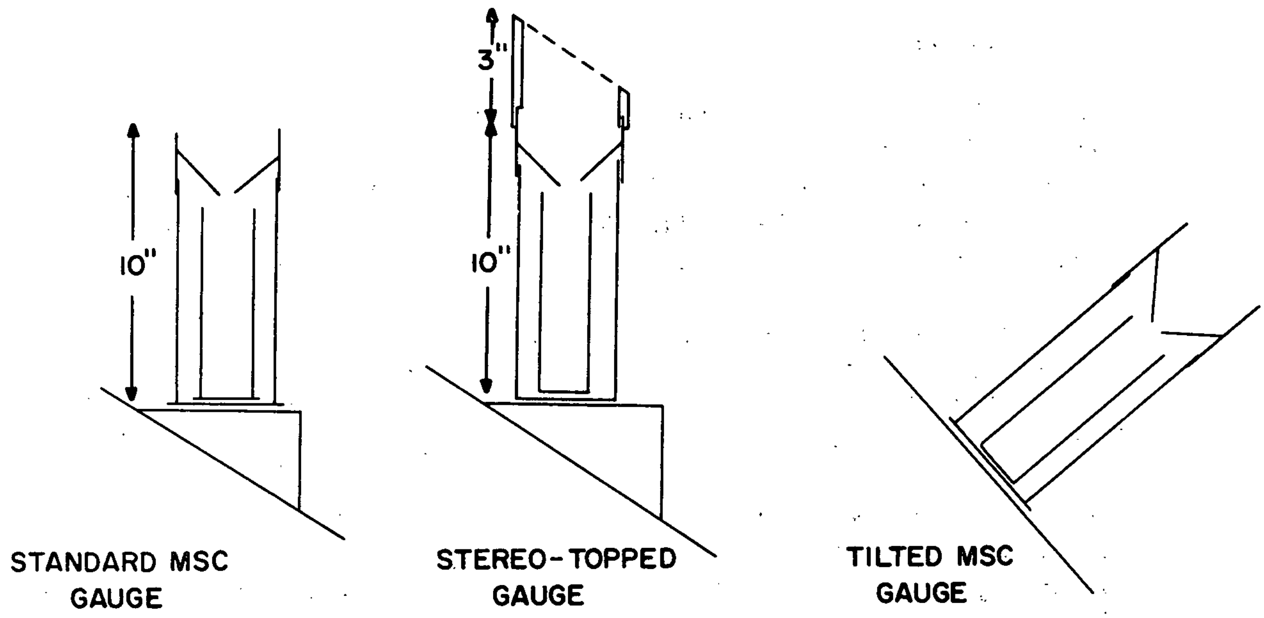
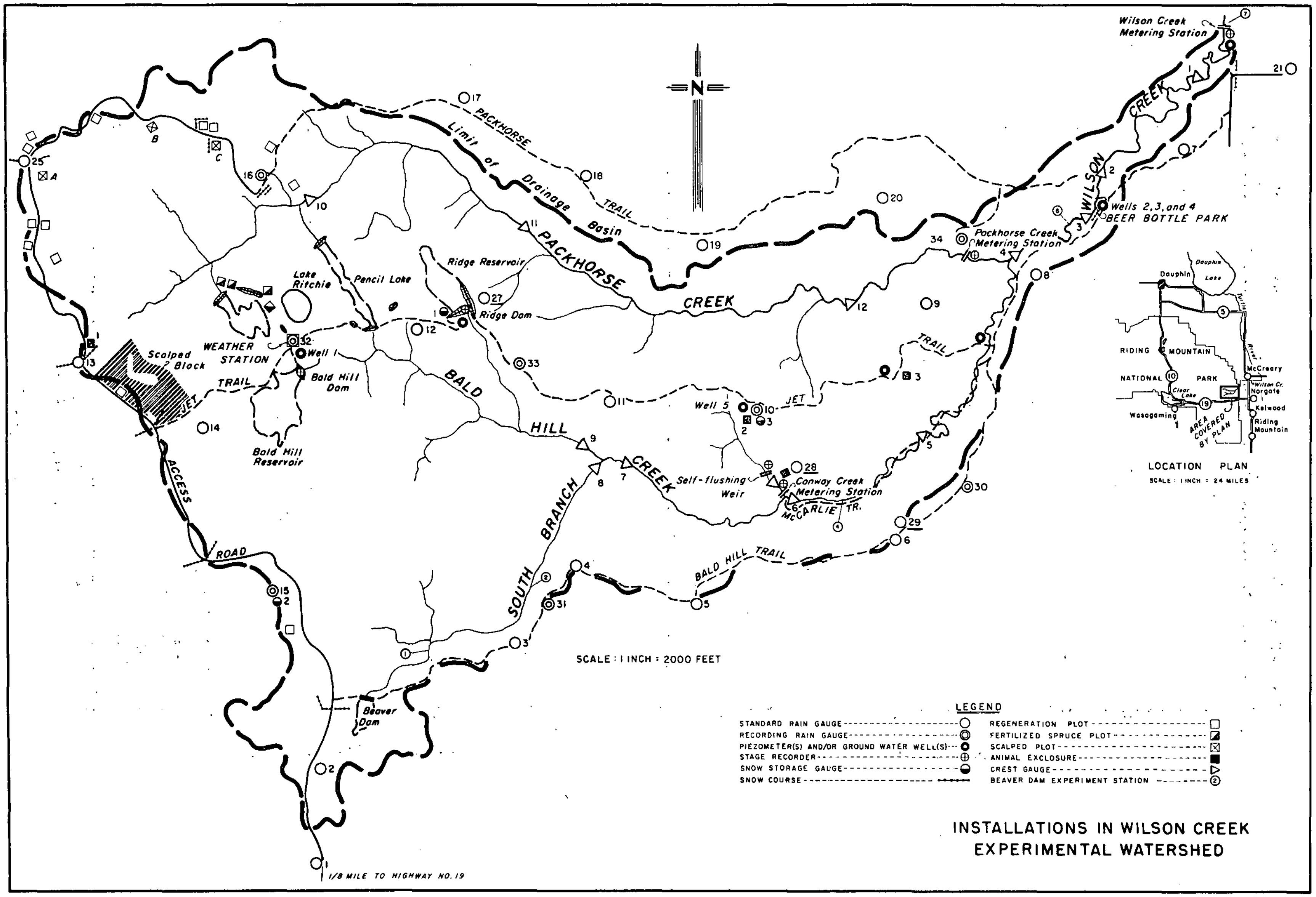

10"
STANDARD MSC GAUGE
3"
10"
STEREO-TOPPED GAUGE
TILTED MSC GAUGE

Figure 1.



Wilson Creek Metering Station
N
Limit of Drainage Basin
PACKHORSE TRAIL
PACKHORSE CREEK
WILSON CREEK
Wells 2, 3, and 4
BEER BOTTLE PARK
Packhorse Creek Metering Station
Ridge Reservoir
Ridge Dam
Lake Ritchie
Pencil Lake
WEATHER STATION
Well 1
Bald Hill Dam
Bald Hill Reservoir
Scalped Block
JET TRAIL
ACCESS ROAD
BALD HILL CREEK
SOUTH BRANCH
Well 5
Self-flushing Weir
Conway Creek Metering Station
McCARLIE TR.
BALD HILL TRAIL
Beaver Dam
1/8 MILE TO HIGHWAY NO. 19
SCALE: 1 INCH = 2000 FEET
LOCATION PLAN
SCALE: 1 INCH = 24 MILES
Dauphin
RIDING MOUNTAIN NATIONAL PARK
McCreary
Norgate
Kelwood
Riding Mountain
Wasagaming
Clear Lake
AREA COVERED BY PLAN
LEGEND
STANDARD RAIN GAUGE
RECORDING RAIN GAUGE
PIEZOMETER(S) AND/OR GROUND WATER WELL(S)
STAGE RECORDER
SNOW STORAGE GAUGE
SNOW COURSE
REGENERATION PLOT
FERTILIZED SPRUCE PLOT
SCALPED PLOT
ANIMAL EXCLOSURE
CREST GAUGE
BEAVER DAM EXPERIMENT STATION
INSTALLATIONS IN WILSON CREEK EXPERIMENTAL WATERSHED

Figure 2.

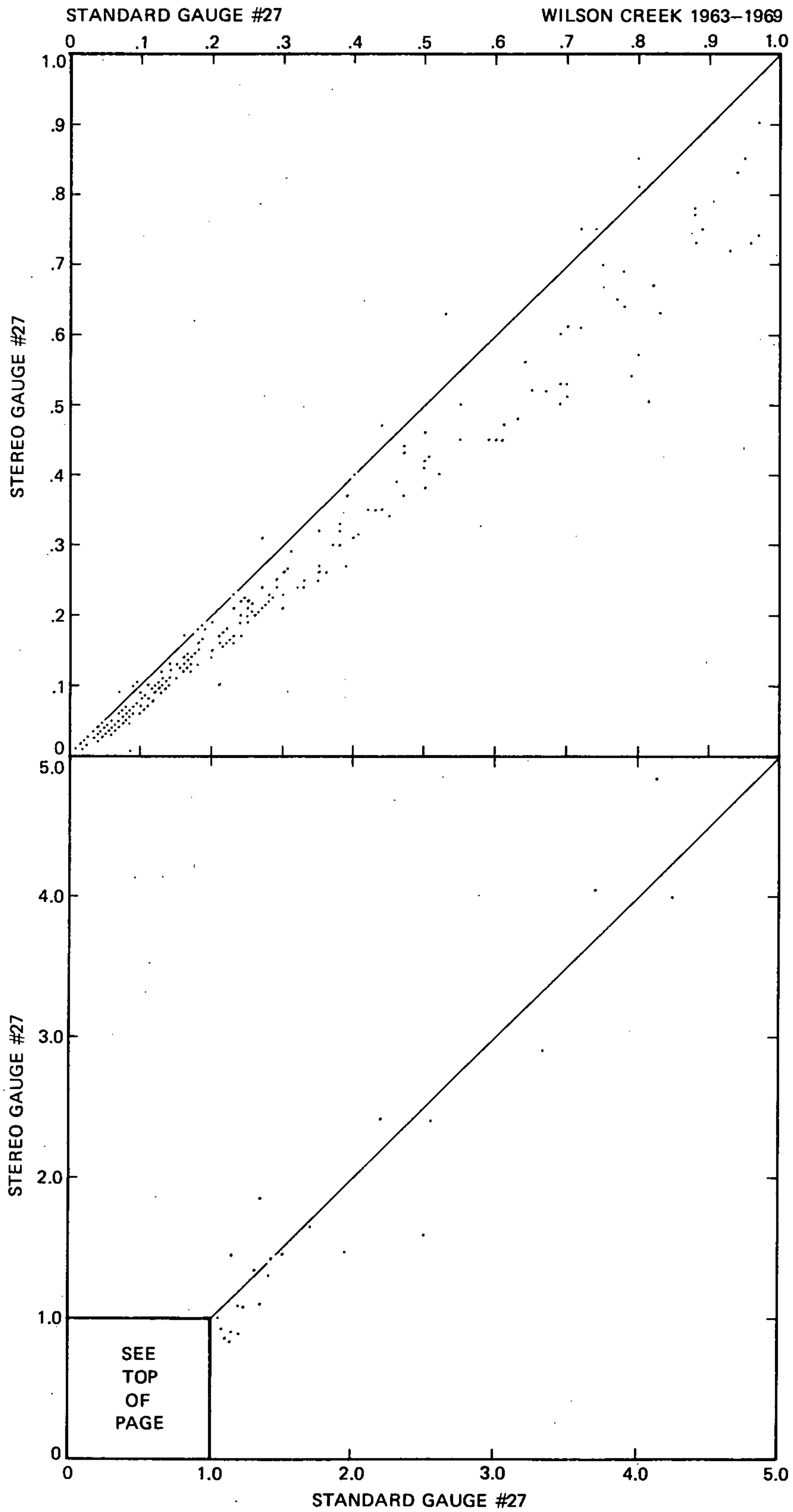

STANDARD GAUGE #27
WILSON CREEK 1963–1969
0
.1
.2
.3
.4
.5
.6
.7
.8
.9
1.0
STEREO GAUGE #27
5.0
4.0
3.0
2.0
1.0
SEE
TOP
OF
PAGE
0
1.0
2.0
3.0
4.0
5.0
STANDARD GAUGE #27

Figure 3.

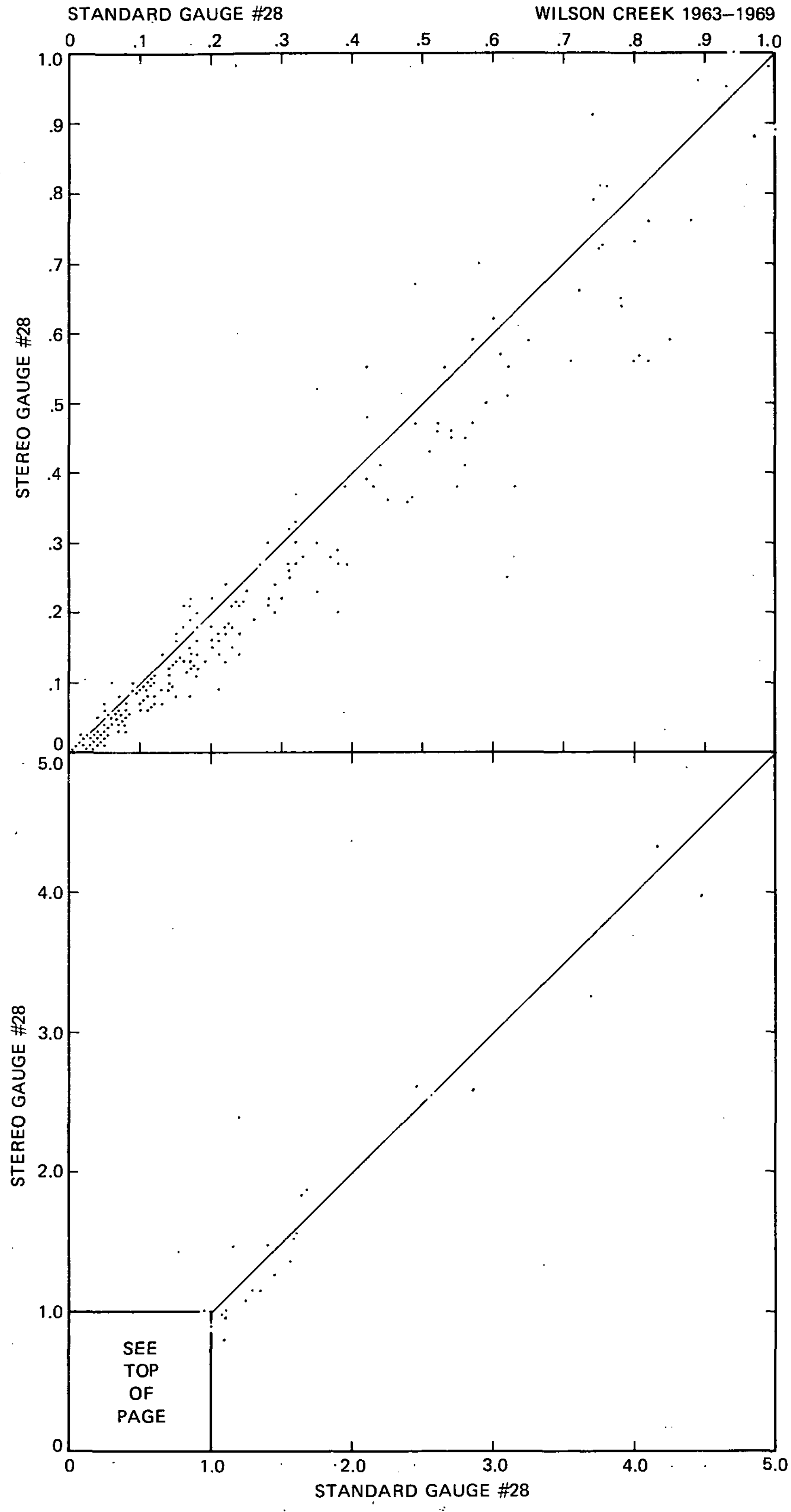

STANDARD GAUGE #28
WILSON CREEK 1963–1969
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
1.0 .9 .8 .7 .6 .5 .4 .3 .2 .1 0
STEREO GAUGE #28
5.0 4.0 3.0 2.0 1.0 0
STEREO GAUGE #28
SEE TOP OF PAGE
0 1.0 2.0 3.0 4.0 5.0
STANDARD GAUGE #28

Figure 4.

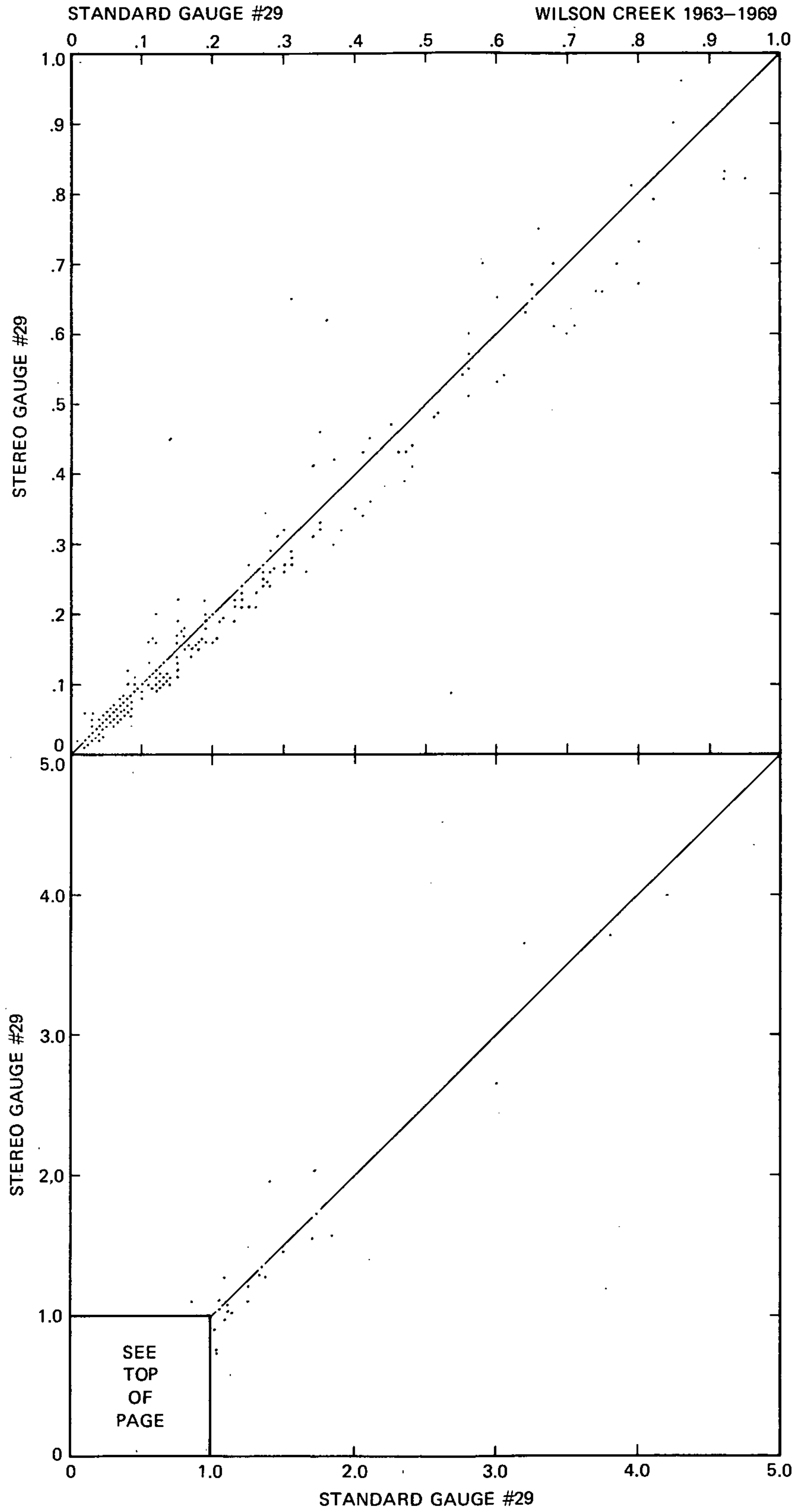
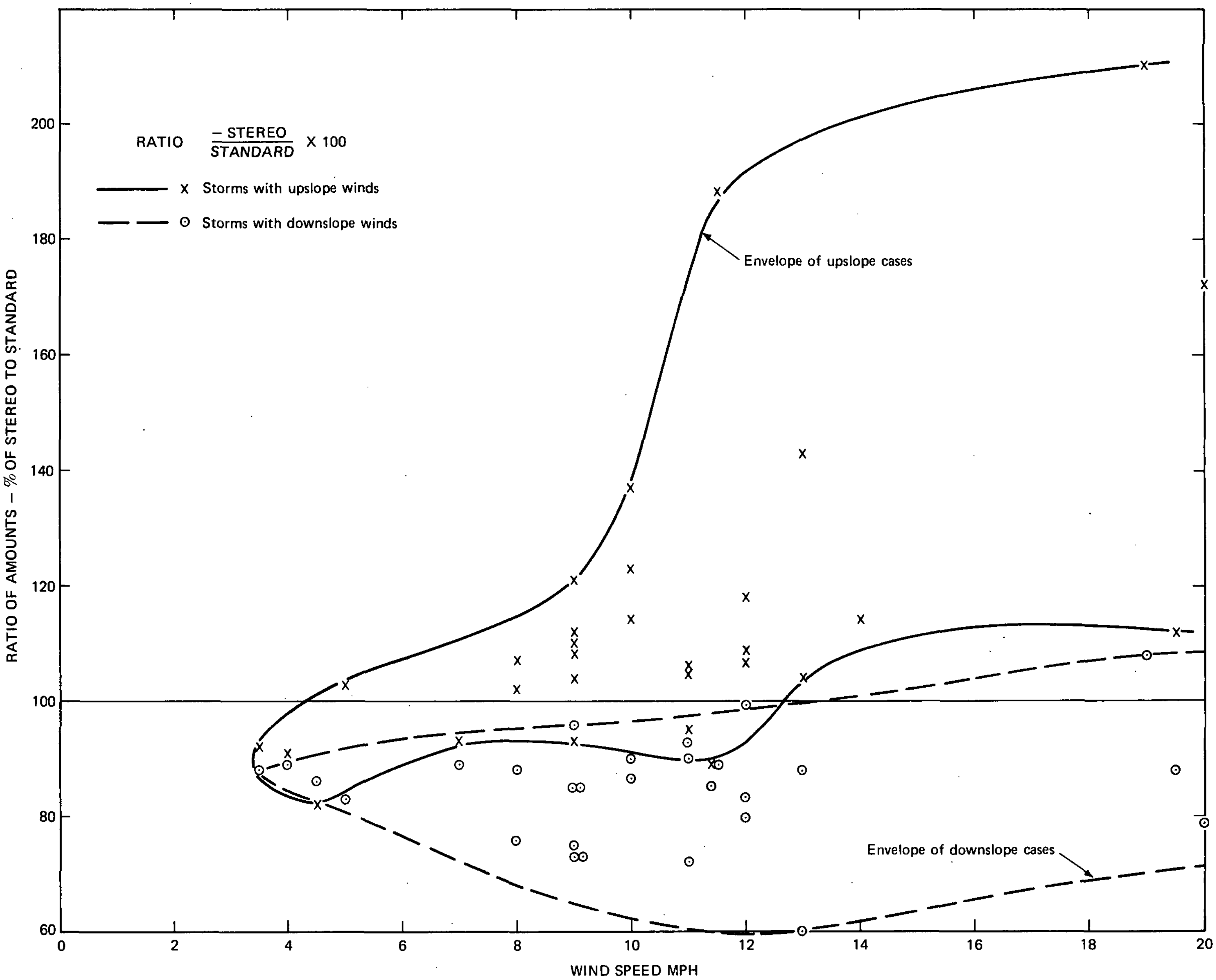
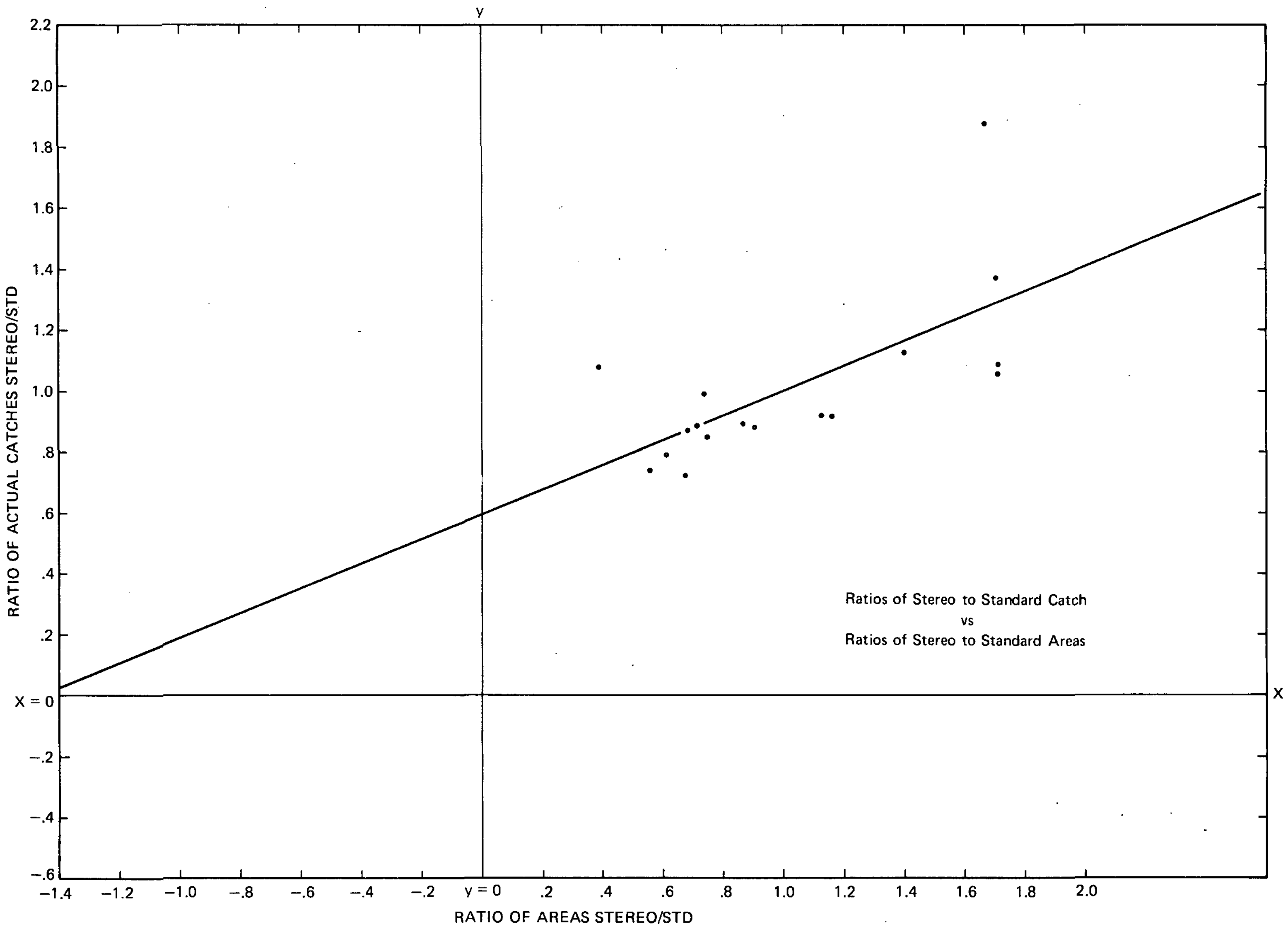

STANDARD GAUGE #29
WILSON CREEK 1963–1969
0 .1 .2 .3 .4 .5 .6 .7 .8 .9 1.0
STEREO GAUGE #29
1.0 .9 .8 .7 .6 .5 .4 .3 .2 .1 0
5.0 4.0 3.0 2,0 1.0 0
SEE TOP OF PAGE
0 1.0 2.0 3.0 4.0 5.0
STANDARD GAUGE #29

Figure 5.



RATIO $\frac{-\text{STEREO}}{\text{STANDARD}}$ X 100
Storms with upslope winds
Storms with downslope winds
Envelope of upslope cases
Envelope of downslope cases
RATIO OF AMOUNTS – % OF STEREO TO STANDARD
WIND SPEED MPH
60
80
100
120
140
160
180
200
0
2
4
6
8
10
12
14
16
18
20

Figure 6.



y
RATIO OF ACTUAL CATCHES STEREO/STD
2.2
2.0
1.8
1.6
1.4
1.2
1.0
.8
.6
.4
.2
X = 0
−.2
−.4
−.6
X
−1.4
−1.2
−1.0
−.8
−.6
−.4
−.2
y = 0
.2
.4
.6
.8
1.0
1.2
1.4
1.6
1.8
2.0
RATIO OF AREAS STEREO/STD
Ratios of Stereo to Standard Catch
vs
Ratios of Stereo to Standard Areas

Figure 7.

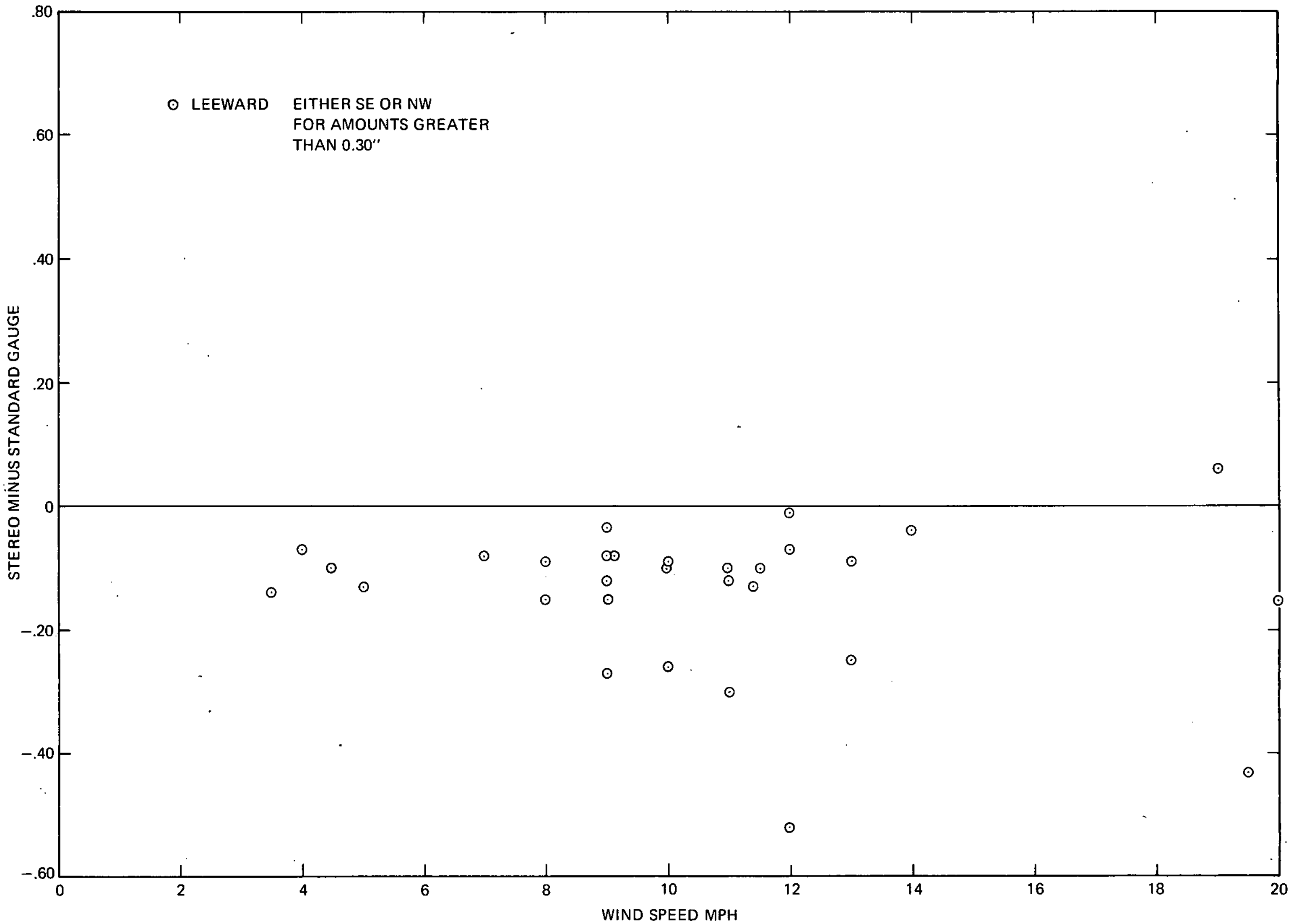

.80
.60
.40
.20
0
-.20
-.40
-.60
STEREO MINUS STANDARD GAUGE
0
2
4
6
8
10
12
14
16
18
20
WIND SPEED MPH
LEEWARD
EITHER SE OR NW
FOR AMOUNTS GREATER
THAN 0.30"

Figure 8.

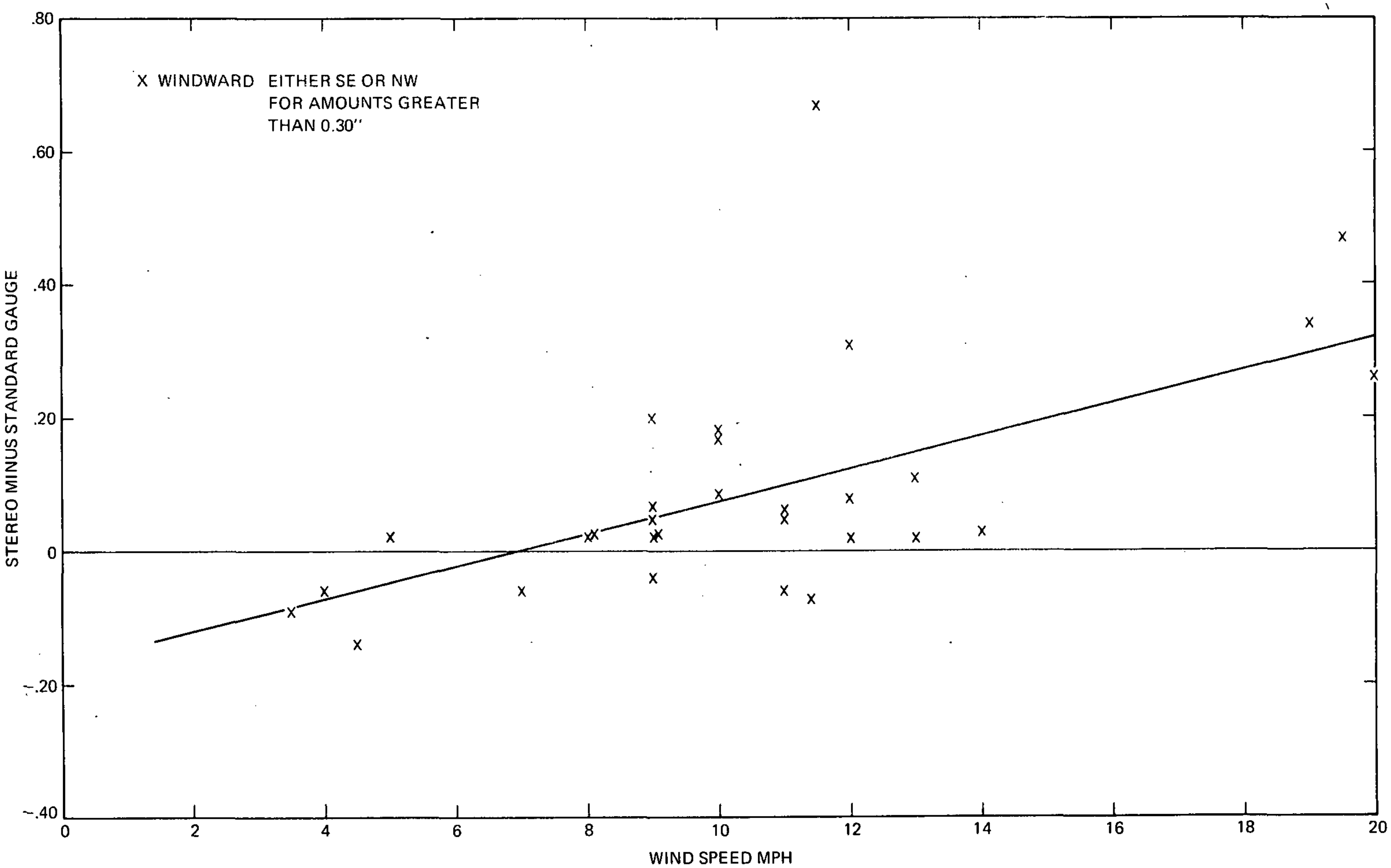

X WINDWARD EITHER SE OR NW
FOR AMOUNTS GREATER
THAN 0.30"
STEREO MINUS STANDARD GAUGE
WIND SPEED MPH
.80
.60
.40
.20
0
–.20
–.40
0
2
4
6
8
10
12
14
16
18
20

Figure 9.

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TEC-756 UDC: 551.508.77
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2. Manitoba

ABSTRACT: This study compares the relative catch efficiency of standard horizontal raingauges with stereo-topped (sloping orifice) raingauges on three slopes in Western Manitoba. The gauge sites are in a heavily instrumented basin where observations have been obtained for seven years. Respective catches were examined by seven year totals and also by separate storm totals. For identifiable upslope wind flows, the stereo gauges were more efficient by 13%. For downslope or lee winds, the stereo gauges caught 15% less than the adjacent standard gauges. The undercatch on lee slopes appeared to be independent of wind speed, whereas the efficiency on windward slopes increased with wind speed.

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