



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم

بسم الله الرحمن الرحيم



MONA MAGHRABY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم



شبكة المعلومات الجامعية التوثيق الإلكتروني والميكروفيلم



MONA MAGHRABY



شبكة المعلومات الجامعية
التوثيق الإلكتروني والميكروفيلم

جامعة عين شمس التوثيق الإلكتروني والميكروفيلم

قسم

نقسم بالله العظيم أن المادة التي تم توثيقها وتسجيلها
علي هذه الأقراص المدمجة قد أعدت دون أية تغييرات



يجب أن

تحفظ هذه الأقراص المدمجة بعيدا عن الغبار



MONA MAGHRABY



Cairo University

EFFECT OF GROUND GAUGES DENSITY ON AREAL REDUCTION FACTOR

By

Yehia Ahmed Adel

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
In
IRRIGATION AND HYDRAULICS ENGINEERING

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2020

**EFFECT OF GROUND GAUGES DENSITY ON AREAL
REDUCTION FACTOR**

By
Yehia Ahmed Adel Zaki

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY
In
IRRIGATION AND HYDRAULICS ENGINEERING

Under the Supervision of

**Prof. Dr. Alaa El-Din M. El-
Zawahry**

**Prof Dr. Ayman Georges
Awadallah**

.....
Prof. of Hydraulics
Irrigation and Hydraulics Department
Faculty of Engineering
Cairo University

.....
Prof. of Water Resources
Engineering
Civil Engineering Department
Faculty of Engineering
Fayoum University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2020

EFFECT OF GROUND GAUGES DENSITY ON AREAL REDUCTION FACTOR

By

Yehia Ahmed Adel Zaki

A Thesis Submitted to the
Faculty of Engineering at Cairo University
in Partial Fulfillment of the
Requirements for the Degree of
DOCTOR OF PHILOSOPHY

In

IRRIGATION AND HYDRAULICS ENGINEERING

Approved by the Examining Committee:

Prof. Dr. **Alaa El-Din M. El-Zawahry**, Thesis Main Advisor
Prof. of Hydraulics
Faculty of Engineering – Cairo University

Prof. Dr. **Ayman Georges Awadallah**, Thesis Advisor
Professor of Water Resources Engineering
Faculty of Engineering – Fayoum University

Prof. Dr. **Mohamed Mokhles Abou-Seida**, Internal Examiner
Professor of Hydraulics
Faculty of Engineering – Cairo University

Prof. Dr. **Ahmed Ali Hassan**, External Examiner
Professor of Environmental Hydrology
Faculty of Engineering – Ain Shams University

FACULTY OF ENGINEERING, CAIRO UNIVERSITY
GIZA, EGYPT
2020

Engineer's Name: Yehia Ahmed Adel Zaki
Date of Birth: 23/7/1984
Nationality: Egyptian
E-mail: Yehia_1984@hotmail.com
Phone: 01000077010
Address: 97 Emtdad El Amal- Autostrad Rd.-
Maadi- Cairo
Registration Date: 01/03/2012
Awarding Date: /.... /2020
Degree: Doctor of Philosophy
Department: Irrigation and Hydraulics Engineering



Supervisors:

Prof. Dr. Alaa El-Din M. El-Zawahry
Prof. Ayman Georges Awadallah
Professor of Water Resources Engineering-Faculty of
Engineering – Fayoum University

Examiners:

Prof. Dr. Alaa El-Din M. El-Zawahry (Thesis Main Advisor)
Prof. Dr. Ayman Georges Awadallah (Thesis Advisor)
Prof. Dr. Mohamed Mokhles Abou-Seida (Internal Examiner)
Prof. Dr. Ahmed Ali Hassan (External Examiner)
Professor at Faculty of Engineering-Ain Shams University

Title of Thesis:

Effect of Ground Gauges Density on Areal Reduction Factor

Key Words:

Areal reduction factor, rainfall gauges, runoff estimation, orthogonal sampling, Gauges density factor

Summary:

Rainfall ground gauges measures the rainfall depth only at the location of the gauges while the storm is natural phenomena with a variable intensity varying from the center to the edge of the storm. Usually, most of catchment areas have only limited rainfall gauges count as each gauge has capital and running costs and governmental agencies tends to minimize these costs. As such, it is important to enhance the estimation of runoff quantities and determine the optimum number of gauges to be built. Researchers studied the areal reduction factor concept in which a reduction factor is used to decrease the runoff estimation to account for the difference between the point rainfall measurement and the variable intensity of the rainfall across the watershed. However, the relation between the number of gauges used to determine the areal reduction factors and its value was not investigated. Thus, the main objective of this study is to identify the optimum rainfall gauges density required and introduce a new coefficient that can be used to consider the gauges' density. In this study, rainfall records from 90 gauges located in Walnut Gulch, Arizona, USA experimental watershed were used to study the effect of the rainfall gauges density within a watershed on the value of the areal reduction factor calculated. It was found that there the areal reduction factor values decrease proportionally with the increase of the rainfall gauges density. Optimum density of rainfall gauges was identified, and charts for the new coefficient GDC (Gauges Density Coefficient) were created.

Disclaimer

I hereby declare that this thesis is my own original work and that no part of it has been submitted for a degree qualification at any other university or institute.

I further declare that I have appropriately acknowledged all sources used and have cited them in the references section.

Name: Yehia Ahmed Adel

Date: / /

Signature:

Acknowledgements

At the beginning and end, thanks to Allah

I wish to thank the supervisors of this thesis; Dr Alaa El-Zawahry and Dr Ayman Awadallah for their guidance and patience. I appreciate the many chances they offered me to learn and benefit. Moreover, I would like to thank the Examination committee for their valuable comments and great effort in the review.

In addition, I would like to present my gratitude to Dar Al Handasah, Shair and partners office for allowing me joining the research and providing me with the needed time and tools.

My appreciation is due to the staff of the Department of Irrigation and Hydraulics for offering me the teaching assistantship to pursue my graduate studies.

Lastly, but by no means least, I would like to thank my parents, wife, daughter, son, and my whole family without whom this accomplishment would have not been possible. Their endless patience and encouragement is a blessing.

Table of Contents

Disclaimer	I
Acknowledgements	II
Table of Contents	III
List of Tables	VI
List of Figures	VII
List of Symbols and Abbreviations.....	X
Abstract	XII
Chapter 1: Introduction	1
1.1 General.....	1
1.2 Problem Statement	1
1.3 Research Objectives.....	2
1.4 Thesis Organization	2
Chapter 2: Literature Review.....	3
2.1 Areal reduction factor definition and importance.....	3
2.2 Factors influencing the areal reduction factor	3
2.3 Methods for ARF estimation	8
2.3.1 Empirical Methods.....	9
2.3.2 The US Weather Bureau method	10
2.3.3 Methods used in the United Kingdom	11
2.3.4 Annual-maxima centered method	13
2.3.5 Storm movement method.....	14
2.3.6 Radar data	14
2.3.7 Comments on the literature review	16
Chapter 3: Methodology	17
3.1 Research Plan.....	17
3.2 Areal Reduction factor calculation	17
3.3 Sampling of rainfall gauges	19
3.3.1 Latin hypercube sampling.....	19
3.3.2 Orthogonal sampling.....	21
3.3.3 Selection of Random Samples Number	22
3.3.4 Output samples.....	23
3.4 Selection of events to be studied.....	23
3.5 Regression Analysis.....	24
3.5.1 Simple Linear regression	24

3.5.2	Nonlinear regression	25
Chapter 4: Study Area and Data Collection.....		26
4.1	Study Area	26
4.2	Available Data	27
4.2.1	Precipitation data	31
4.3	Characteristics for Walnut Gulch.....	31
4.3.1	Climate.....	31
4.3.2	Storm Types.....	35
4.3.3	Precipitation variability.....	36
Chapter 5: Results and discussion.....		40
5.1	Data Preparation and analysis.....	40
5.1.1	Sampling	40
5.1.2	Arrangement of input data	46
5.1.3	Compiling the gauges data and generating shapefiles	47
5.2	Areal reduction factor calculations	48
5.3	Reduction for Number of Samples	52
5.4	Areal reduction factor calculations results.....	53
5.5	Optimum rainfall gauges density	55
5.6	Effect of sampling.....	56
5.7	Relation between ARF curves	59
5.7.1	Relation between ARF ratios and average distance between gauges	59
5.7.2	Nonlinear fitting for ARF curves.....	61
5.7.3	Gauges density coefficient (GDC) chart.....	66
Chapter 6: Verification and Comparison		68
6.1	Verification Criteria	68
6.2	Verification Results	68
6.3	Areal reduction curves comparison	70
6.3.1	Comparing produced areal reduction with the US Bureau curves.....	70
6.3.2	Comparing produced areal reduction factor to Institute of Hydrology UK areal reduction factor for Jeddah City	72
6.3.3	Comparing produced areal reduction with UK transport method.....	74
6.3.4	Comparing produced areal reduction with Walnut Gulch ARF curve produced by NOAA (1984)	76
Chapter 7: Summary, Conclusions, and Recommendations.....		79
7.1	Summary.....	79
7.2	Conclusions.....	79
7.3	Recommendations.....	81

References.....	83
Appendix A: MATLAB Scripts.....	85
A.1 Orthogonal Sampling Script.....	85
A.2. Arrangement of Data script.....	86
A.3. Calculating average ARF curves Script.....	87
A.4. Average distances between gauges script.....	89

List of Tables

Table 1: ARF values corresponding return periods as per Bell (1976)	13
Table 2: Calculation of ARF corresponding to a rainfall event.....	18
Table 3: Examples for output matrix for a group of 20 gauges	23
Table 4: Example for downloaded data	31
Table 5: Gauges Primary information.....	41
Table 6: Example for input data matrix	47
Table 7: Example for attributes of shapefiles.	48
Table 8: Example for ARF output table.....	52
Table 9: Change in ARF for 100 and 200 samples.....	53
Table 10: Gauges distance matrix.....	60
Table 11: Calculated area shift for different ARF curves.....	60
Table 12: Nonlinear regression coefficients and ARF equations for 50% percentile.....	63
Table 13: Nonlinear regression coefficients and ARF equations for 90% percentile.....	64
Table 14: Gauges densities	66
Table 15: Areal Reduction factor equations for Walnut Gulch Watershed.....	80

List of Figures

Figure 1: ARFs generated by Desbordes et al. (1984).....	4
Figure 2: ARFs generated by Skaugen (1997).....	4
Figure 3: ARFs generated by Asquith and Famigiletti (2000)-Part a.....	5
Figure 4: ARFs generated by Asquith and Famigiletti (2000)-Part b.....	6
Figure 5: ARFs generated by Ramos et. al (2005).....	7
Figure 6: ARFs generated by Mineo et al. (2019).....	8
Figure 7: ARF as per the US weather Bureau 957-1958- Technical Paper no. 29.....	11
Figure 8: Areal reduction factor (after NERC 1975).....	12
Figure 9: ARF generated using Radar data for 1 hr duration near the edge of the catchment (after Durrans et al., 2002).....	15
Figure 10: ARF generated using Radar data for 1 hr duration away from the edge of the catchment (after Durrans et al., 2002).....	15
Figure 11: Sample of Isoheytal maps.....	19
Figure 12: Example 1 for a Latin hyper cube sampling.....	20
Figure 13: Example 2 for a Latin hypercube sampling.....	21
Figure 14: difference between sampling techniques.....	21
Figure 15: Example 1 for a possible bad random selection for 6 gauges.....	22
Figure 16: Example 2 for a possible bad random selection for 6 gauges.....	22
Figure 17: True and estimated linear relation between x and y.....	25
Figure 18: Walnut Gulsh Experimental Watershed (after www.tucson.ars.ag.gov/dap).....	27
Figure 19: Measuring instruments and their distribution in the watershed (after www.tucson.ars.ag.gov/dap).....	28
Figure 20: Walnut Gulch Geology.....	29
Figure 21: Walnut Gulch Soil Series.....	29
Figure 22: Walnut Gulch Soil Group.....	30
Figure 23: Walnut Gulch Vegetation Map.....	30
Figure 24: Monthly Precipitation at Walnut Gulch Experimental Watershed (after www.tucson.ars.ag.gov/dap).....	32
Figure 25: Monthly Temperature at Walnut Gulch Experimental Watershed.....	33
Figure 26: Monthly Pan Evaporation at Walnut Gulch Experimental Watershed (after www.tucson.ars.ag.gov/dap).....	33
Figure 27: Jan, Feb, March Total Annual Precipitation at Walnut Gulch Experimental Watershed (after www.tucson.ars.ag.gov/dap).....	34
Figure 28: Monthly and Annual Precipitation at Walnut Gulch Experimental Watershed (after www.tucson.ars.ag.gov/dap).....	34
Figure 29: Annual Peak Flow Rate and Total Flow Volume at Walnut Gulch Experimental Watershed (after www.tucson.ars.ag.gov/dap).....	35
Figure 30: Flume 6 location.....	35
Figure 31: Example for the shape of clouds formed by convection.....	36
Figure 32: Example for the shape of frontal clouds.....	36
Figure 33: Precipitation (mm) Storm Event August 27, 1982 (after www.tucson.ars.ag.gov/dap).....	37
Figure 34: Precipitation (mm) August 1982 (after www.tucson.ars.ag.gov/dap).....	38
Figure 35: Precipitation (mm) Summer 1982 (after www.tucson.ars.ag.gov/dap).....	38
Figure 36: Precipitation (mm) Total 1982 (after www.tucson.ars.ag.gov/dap).....	39
Figure 37: Gauges zoning.....	41

Figure 38: Sampling distribution effectiveness	46
Figure 39: ARF for the whole data and ARF using the 50 maximum storms	49
Figure 40: Areal reduction factor tool box	50
Figure 41: Flow Chart for ARF calculation process using GIS.....	51
Figure 42: ARF for various groups at 50% percentile.....	54
Figure 43: ARF for various groups at 75% percentile.....	54
Figure 44: ARF for various groups at 90% percentile.....	55
Figure 45: Difference between ARF created via sampling and arbitrary selected ARF curve for a group of 3 gauges	56
Figure 46: Difference between ARF created via sampling and arbitrary selected ARF curve for a group of 6 gauges	57
Figure 47: Difference between ARF created via sampling and arbitrary selected ARF curve for a group of 10 gauges	57
Figure 48: Difference between ARF created via sampling and arbitrary selected ARF curve for a group of 20 gauges	58
Figure 49: Difference between ARF created via sampling and arbitrary selected ARF curve for a group of 40 gauges	58
Figure 50: Relation between AVG Dist. Ratio and ARF ratio - 90% percentile.....	59
Figure 51: ARF curves after applying horizontal and vertical shifts-90% percentile	61
Figure 52: Nonlinear regression for ARF curves.....	62
Figure 53: Calculated versus predicted ARF curves using nonlinear regression- 50% percentile.....	62
Figure 54: Calculated versus predicted ARF curves using nonlinear regression- 90% percentile.....	63
Figure 55: Relation between regression coefficient a and number of gauges – 50% percentile	64
Figure 56: Relation between regression coefficient b and number of gauges – 50% percentile	65
Figure 57: Relation between regression coefficient a and number of gauges – 90% percentile	65
Figure 58: Relation between regression coefficient b and number of gauges – 90% percentile	66
Figure 59: GDC chart - 50% percentile	67
Figure 60: GDC chart - 90% percentile	67
Figure 61: Verification using ARF 15 and ARF 25-50% Percentile.....	69
Figure 62: Verification using ARF 15 and ARF 25-90% Percentile.....	69
Figure 63: ARF as per the US weather Bureau method (after US weather Bureau 1957-1958- Technical Paper no. 29)	70
Figure 64: US Bureau method vs Walnut Gulch ARF 50 percentile.....	71
Figure 65: US Bureau weather curve vs Walnut Gulch ARF 90 percentile	71
Figure 66: Institute of Hydrology, Wallingford areal reduction factor curves	72
Figure 67: Institute of Hydrology, Wallingford vs Walnut Gulch ARF 50 percentile.....	73
Figure 68: Institute of Hydrology, Wallingford vs Walnut Gulch ARF 90 percentile.....	74
Figure 69: Areal reduction factor curve using UK transport curve	75
Figure 70: UK transport method vs Walnut Gulch ARF 50 percentile	75
Figure 71: UK transport curve vs Walnut Gulch ARF 90 percentile	76
Figure 72: Station pairs and groups used to estimate ARF for Walnut Gulch as per NOAA research (1984).....	77
Figure 73: ARF ratios as per NOAA research (1984)	77