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ECONOMICS AND ADMINISTRATION  
OF WATER RESOURCES

by  
J. Ernest Flack

June 30, 1969

COLORADO WATER RESOURCES



RESEARCH INSTITUTE

Colorado State University  
Fort Collins, Colorado

Colorado Water Resources Research Institute  
Completion Report No. 10

ECONOMICS AND ADMINISTRATION  
OF WATER RESOURCES

Partial Completion Report  
OWRR Project A-005-COLO

June 30, 1969

by

J. Ernest Flack  
Professor of Civil Engineering and Director,  
Center for Urban Engineering Studies  
University of Colorado  
Boulder, Colorado 80302

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Colorado State University  
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## ABSTRACT

### ECONOMICS AND ADMINISTRATION OF WATER RESOURCES

This report presents a summary of the sub-project on Economics and Administration of Water Resources as conducted at the University of Colorado. The purposes and objectives of the research are outlined and abstracts, summaries and conclusions of the various sub-projects are given. A complete list of reference publications is presented covering the following phases of the research:

- a. Total Water Use Analysis by Cities
- b. Federal Reclamation Law
- c. Statistical Analysis of Low Flows
- d. Effects of Metering on Urban Water Demand

Flack, J. Ernest

ECONOMICS AND ADMINISTRATION OF WATER RESOURCES

Partial completion report to Office of Water Resources Research

U. S. Department of Interior, June 30, 1969, 5 p.

KEYWORDS--/cost analysis/\*water rates/water demand/Federal Reclamation Law/\*low flow/droughts/\*cities/municipal water/water works/\*measurement (metering)

Abstract

COMPLETION REPORT - ECONOMICS AND ADMINISTRATION OF WATER RESOURCES,  
A-005-Colo-CSU 1870, University of Colorado. January 12, 1970.

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This report presents a summary of the sub-project on Economics and Administration of Water Resources as conducted at the University of Colorado. The purposes and objectives of the research are outlined and abstracts, summaries and conclusions of the various sub-projects are given. A complete list of reference publications is presented covering the following phases of the research:

- (a) Total Water Use Analysis by Cities
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## Completion Report

Economics and Administration of Water Resources

University of Colorado Project

Period covered: July 1, 1964, through June 30, 1969, with an extension to Sept. 1, 1969.

### Scope and Purpose

This project covered several distinct phases, mainly dealing with water resources management problems. The scope of the project, in general, dealt with certain legal and hydrologic definitions of water rights especially with regard to urban communities. In the first years of the project research centered on definition and characteristics of water use by selected municipalities. Following one year of support of legal research on reclamation law, the next phase of the research support concentrated on probabilistic definition of low flows with special emphasis on those seasonal flows most closely related to water rights of highest priority and greatest legal and hydrologic certainty. In the last two years of research effort, main concern has again turned to urban water use, specifically to water demand under dynamic conditions as a result of metering.

The original purpose of the University of Colorado project was to develop, on a case study basis, the relationships that exist between the hydrologic characteristics of streams and their corresponding water rights with the ultimate view of interpreting the optimum method for municipalities, in appropriate states, to obtain additional water supply through reallocation. In the final analysis, portions of the ultimate goal were realized but the all encompassing analysis could

not be completed because the scope of the problem was much more complex and time-consuming than originally anticipated.

Considerable spin-off of related research has produced significant works or highly interesting results. These include, in particular, a portion of a major treatise on water law that deals with reclamation law and a greater understanding of the effects of metering urban water.

Results:

The results of this project are presented in the form of summary statements, abstracts and conclusions of the various papers, preprints, articles, theses, dissertations and reports published.

Analysis of Total Water Use by Selected Cities and Industries,

Fortunato Martinez - F. See Reference Publication No. 1.

"The purpose of this study was to determine the total water usage of selected municipalities, taking into consideration such factors as price and climate. The cities selected were Boulder, Denver, and Colorado Springs, Colorado, in the United States and Monterrey, Nuevo Leon in Mexico. The effects of metering, price increases, and climatic variables on total residential and industrial water demands were determined within limits prescribed by the scarcity of data. The net residential water use, which equals withdrawals less total return flow from lawn and garden irrigation, was estimated from data on outside-the-house residential use and consumptive use calculations.

"Urban Water Use Study," J. E. Flack and F. Martinez-F. See Reference No. 2.

"The three cities in the United States -- Boulder, Denver, and Colorado Springs -- had almost the same per capita water demand for all

categories of users in 1964. The range and average per capita water demands that represent all three cities, for 1964, are as follows: for residential use the maximum value was for 144 gpcd (gallons per capita per day), the minimum value was 132 gpcd, and the average was about 137 gpcd; for industrial use the maximum value was 113 gped (gallons per employee per day), the minimum value was 87 gped and the average was about 104 gped; for total use the maximum value was 225 gpcd, the minimum value was 176 gpcd, and the average was about 207 gpcd .... A much lower per capita water demand was found for Monterrey -- total use of the city equalled 46.2 gpcd, residential use equalled 31.7 gpcd, and industrial use equalled 44.5 gped -- compared with the cities in the United States...

Land use surveys are needed ... For this study it was necessary to know the net lawn areas on an annual basis. Direct measurements of water inflow and sewer outflow from typical residential and industrial areas would be highly desirable ... It is important that water utilities make the necessary measurements and analysis to complete such surveys completely and accurately. Better basic data will make possible much more meaningful analysis of water use by municipalities and industry. This in turn will lead to much more accurate predictions of future water use, needed to plan any future economical development."

"Analysis of Urban Water Use in Developing Countries," J. Ernest Flack. See Reference Publication No. 3.

"This paper presents a comparison of the urban water use patterns of a medium-sized industrial city located in a developing nation with that of a similar city in the United States. The two cities -- Denver, Colorado, and Monterrey, Mexico -- are located in semi-arid regions ...

Variations of cultural patterns as related to standards of living must be taken into account when attempting to use water use data for cities in developed countries in the design of water systems for cities located in developing nations. This conclusion is verified and explained in some detail in this paper.

Recommendations are made regarding the need for basic data and the types of data required for urban water use studies ..."

"A Report on the Water Use Characteristics of Highland Park, 5th Addition Subdivision - Boulder, Colorado - 1964 - Including Discussions on Certain Aspects of Residential Water Use Versus Municipal Water Supply," Charles V. Hallenbeck, Jr., See Reference Publication No. 4.

"...The recent universal water metering within the city, and the increase in water rates, have caused a great deal of citizen discussion concerning water requirements for residences and water costs to householders. Lacking specific statistics, such discussion has centered around individual cases or around averages of dissimilar data.

Advance planning to serve new land with city water requires a knowledge of the water use, the water consumption and the return flow characteristics of the developed land.

This report pertains to a study occasioned by the above-mentioned considerations. ...

The study was financed in part by the City of Boulder, in part by an Interior Department grant ... and in part by certain individuals ..."

Federal Reclamation Law by Joseph L. Sax. See Reference Publication No. 5. Contents:

Introduction

The reclamation fund



Initiation and authorization of projects

Special problems in project planning

Public notice of projects

Construction contracts for project facilities

Acquisition of land for projects

Acquisition of water rights

Rights of water users

Actions involving the United States

Excess-land law

Residency and cultivation requirements

Water uses in reclamation projects

Repayment of costs to the United States

Federal-state relations

Special statutory provisions

Statistical Models of Annual Droughts, E. S. Joseph. See Reference  
Publication No. 6.

"This thesis presents the results of a study to establish certain statistical models for annual droughts in the Missouri River Basin.

An investigation was carried out to determine if annual droughts are randomly or nonrandomly distributed. The degree of dependence of low-flows in succeeding years at individual recording stations was determined by analyzing (1) power spectrum, and (2) distribution of the number of runs above and below median. The records of fifty-five stations were analyzed. The time series of low-flows at thirty-eight (or more) stations exhibited properties of randomness.

Using the data of the thirty-eight stations whose annual low-flows were found to be randomly distributed, a study was conducted to establish a suitable probability distribution of annual droughts.

The adequacy of five distributions was studied. They were the gamma, the lognormal, the square-root normal, the normal and the Gumbel's extreme value (Weibull) distributions. Three techniques were used to determine the goodness of fit; (1) the chisquared test, (2) the probability plots, and (3) a comparison of the skewness-kurtosis relation. On the basis of these tests it was shown that, for annual droughts, the gamma distribution is the best of the five models tested.

Finally, a method was proposed to estimate the design drought of a water resource project, using the established distribution shape of the annual droughts."

"Recurrence Intervals of Annual Minimum Streamflows" by E. S. Joseph. See Publication Reference No. 7.

"The paper proposes an analytical approach for estimating the magnitudes of annual droughts in a stream corresponding to specified return periods. The method is illustrated by a frequency analysis performed on the data of twenty-six streams in the state of Missouri. With the help of a computer program, this method yields the results readily and overcomes the disadvantages inherent in graphical procedures."

"Autocorrelation of Annual Minimum Streamflows" by E. S. Joseph. See Publication Reference No. 8.

"An investigation is carried out to determine if annual minimum flows in streams are randomly or nonrandomly distributed with respect to time. A time series consisting of observations collected serially in time is said to be randomly distributed if each event is statistically independent of all preceding and following events. To determine whether the annual low-flows in succeeding years at individual recording

stations are auto-correlated, tests are performed using ( ) serial-correlation coefficients, (B) power spectrum, and (C) distribution of the number of runs above and below sample median. The records of fifty-five stations are analyzed. It is found that the time series of low-flows at eighteen stations exhibit properties of non-randomness."

"Frequency of Design Drought," E. S. Joseph. See Reference Publication No. 9.

"Certain problems associated with a drought frequency analysis are exposed and their solutions are proposed. The techniques are based on a probabilistic framework. Return period of a project's design drought -- the annual drought for which a water resource project such as a treatment plant or a low-flow augmentation system has to be designed -- is treated as a function of the project's useful life and the desired level of assurance. A method is shown for estimating the probability and return period associated with the design drought of a project. The paper presents a chart which gives recurrence intervals of design droughts for various combinations of the estimated useful life of a project and the desired level of assurance."

"Probability Distribution of Annual Droughts," E. S. Joseph, See Reference Publication No. 10.

"The object of this investigation was to establish a suitable probability distribution for annual droughts of 14-day periods. The approach employed was to fit certain theoretical distributions to the observed data and to select, by suitable criteria, the distribution which best described the data. The relative adequacy of five distributions was studied. They were the gamma, the log-normal, the square-root normal, the normal and the Bumbel's extreme value (Weibull)

distributions. Two techniques were used to determine the goodness of fit: (1) the chi-squared test and (2) a comparison of the skewness-kurtosis relation. Tests were performed using the data of thirty-seven stations whose annual droughts in succeeding years were found to be randomly distributed with respect to time. The results of the tests showed that, for annual droughts, the gamma distribution is the best of the five models tested."

"Effects of Metering Urban Water," Steve H. Hanke and J. Ernest Flack, See Reference Publication No. 11.

Recent emphasis on metering and pricing of water reflects changing attitudes toward hydrologic and economic conditions under which water utilities must operate. Water has evolved from a free good to an economic good in which sacrifices of other goods are required to attain. Savings of water is an alternative to increased imports or development of storage. Efficient utilization of existing supplies becomes a more desirable alternative under conditions of sharply increasing costs of additional development.

A description of studies of effects of metering on house-hold use and lawn sprinkling use is made. Limitations of existing cross-sectional data analysis in making time series predictions are outlined.

The use of benefit-cost analysis as applied to costs of metering versus savings in water use is described.

A rational basis for water management decisions regarding selection of alternatives for meeting water demands is presented.

The Demand for Water Under Dynamic Conditions, Steve H. Hanke, See Publication Reference No. 12.

The research reported here was supported by a grant from Resources for the Future, Inc. Funds made available under OWRR sponsorship were used to support the principal investigator at times while an advisor on this thesis and OWRR funds were used to publish the dissertation with the support of the Center for Urban Engineering Studies, the Director of which is the principal investigator, J. E. Flack.

"This dissertation is a study in the dynamics of the demand for water for residential uses. An examination of pertinent literature reveals that no studies of this nature have been made. The opportunity to make this study arose during 1961-1963 when metered rates for residential water replaced flat rates in Boulder, Colorado. The period under study began in 1955 and ended in 1968. The purpose of this study was to analyze the effects of a dynamic shift from a commodity charge of zero to a positive charge for residential water.

Several models and techniques were utilized to analyze the time series data generated by Boulder's water metering experience. These included the following:

(1) Graphical techniques were utilized to relate actual sprinkling use before and after metering to calculated values of ideal use.

(2) To facilitate the analysis of trends, similar methods were employed to display the cumulative percentages of actual use to the calculated ideal use.

(3) More specific quantitative relationships between actual and ideal uses were estimated by using a single equation model that incorporated dummy variables to represent the temporal effects of changing from flat to metered rates.

(4) A dynamic model of demand was used to lend more precision to the temporal analysis of sprinkling demand. This model was based on the generally recognized observation that current actions are based in part on past behavior. It was assumed that over time lawn sprinkling at any moment is dependent on current climatic conditions, the price of water, and a "state variable" which represents the influence of past sprinkling on the present use. In this case the "state variable" measured habit formation or a psychological stock of habits for lawn sprinkling.

(5) Extensive field interviews of water customers chosen at random determined the specific types of alterations made after metering. Customers' retrospective responses were validated by the available quantitative data.

The empirical findings derived from the application of the aforementioned methods include:

(1) The sprinkling behavior of Boulder's water customers was markedly altered by the installation of meters. The actual sprinkling use was greater than the ideal under flat rates and less than the ideal under metered rates.

(2) The estimated functions relating the actual sprinkling use and the calculated ideal use also reflect the same conclusion. Their loci vary significantly. Upon the introduction of meters, the actual sprinkling use decreases by approximately seven thousand gallons per dwelling unit per month at all levels of ideal use.

(3) Sprinkling demands not only declined with the installation of meters, but subsequently continued to decline.

(4) The results of the dynamic model indicate that consumers using water for sprinkling purposes do possess habits, but that these are very weak. Consumers react shortly after meter installation.

(5) The domestic (in-house) demand for water was reduced by thirty-six percent upon the introduction of a positive commodity charge. These demands also stabilized at their new lower levels.

(6) The most significant alterations in water use that followed metering included: watching sprinklers more carefully, permitting yards to turn brown, watering at night and reducing the size of yards. Consumers also intensified their conservation practices over time.

The significance of this dynamic approach to urban water demand is that it lends empirical validity to many standard hypotheses of economic theory. Although the results of this singular study cannot be considered conclusive, they do question the validity of the "requirements approach" to demand and of the results obtained from analyses based upon static cross section data."

"Multi-Family Residential Water Use Characteristics - Correlated with Rate Structures," Charles V. Hallenbeck, et.al., See Reference Publication No. 13.

This sub-project was financed cooperatively with funds from the Office of Water Resources Research, the City of Boulder, the University of Colorado and from the Work-Study program.

The report cited as reference publication number 12 will be published by April, 1970.

"The purposes of this study were:

(a) to determine time characteristics of water demand for residential units as functions of season, population, population density, household

characteristics, fixture units, gross area, irrigated area and water pressure,

(b) to determine appropriate meter and service sizing based on demand and pressure,

(c) to determine the cost of capital facilities and of operation and maintenance for various demands, and

(d) to relate costs of capital facilities to various fee systems.

The procedure was as follows:

(1) daily meter readings on multifamily units were made over a one year period,

(2) facility and population characteristics of multi-family unit properties was determined,

(3) single family demand characteristics were made,

(4) various rate structures were characterized,

(5) system costs, replacement costs and cost recovery were calculated,

(6) correlation of multi-family water use with costs of service and rate structures to be completed."

Reference Publications (resulting from this project).

1. Analysis of Total Water Use by Selected Cities and Industries,

by Fortunato Martinez-F., M.Sc. thesis, Department of Civil Engineering, University of Colorado, 1965, 67 pp.

2. "Urban Water Use Study," by J. Ernest Flack and Fortunato Martinez-F., Conference Preprint 350, ASCE Water Resources Engineering Conference, Denver, Colorado, May 16-20, 1977, 38 pp.



3. "Analysis of Urban Water Use in Developing Countries," by J. Ernest Flack, Proceedings International Water for Peace Conference, Dept. of State, Wash. D. C., May 23-31, 1967.
4. "A Report on the Water Use Characteristics of Highland Park, 5th Addition Subdivision -- Boulder, Colorado - 1964 - Including Discussion on Certain Aspects of Residential Water Use Versus Municipal Water Supply," by Charles V. Hallenbeck, Jr., April, 1966, 23 pp.
5. Federal Reclamation Law, by Joseph L. Sox, reprinted from Volume Two, Waters and Water Rights, The Allen Smith Company, Indianapolis, Indiana, 1967, p. 11-p. 291 inclusive.
6. Statistical Models of Annual Droughts by E. S. Joseph, Ph.D. dissertation, Department of Civil Engineering, University of Colorado, 1969, 125 pp.
7. "Recurrence Intervals of Annual Minimum Streamflows," by E. S. Joseph, unpublished paper submitted to ASCE for possible publication, 1969, 15 pp.
8. "Autocorrelation of Annual Minimum Streamflows," by E. S. Joseph, unpublished paper, 1969, 17 pp.
9. "Frequency of Design Drought," by E. S. Joseph, unpublished paper, 1969, 11 pp.
10. "Probability Distribution of Annual Droughts," by E. S. Joseph, unpublished paper, 1969, 24 pp.
11. "Effects of Metering Urban Water," by Steve H. Hanke and J. Ernest Flack, Journal American Water Works Association, Vol. 60, No. 12, Dec. 1968, p. 1359-1366.

12. The Demand for Water under Dynamic Conditions: A Case Study of Boulder, Colorado, by Steven H. Hanke, Ph.D. dissertation, Dept. of Economics, University of Colorado, 1969, 254 pp. Published under the same title by the Center for Urban Engineering Studies, College of Engineering, University of Colorado, Sept. 1969.
13. "Multi-Family Residential Water Use Characteristics - Correlated with Rate Structures," (tentative title) by Charles V. Hallenbeck, Jr., Edwin R. Bennett, K. Daniel Linstedt and Howard Cox, to be published by the Center for Urban Engineering Studies, College of Engineering, University of Colorado, spring 1970.