

World
Water
Resources
and their
Future

World
Water
Resources
and their
Future

by M. I. L'vovich

**English Translation
edited by
Raymond L. Nace**

World
Water
Resources
and their
Future

Translation © 1979 by the American Geophysical Union
Russian Edition © 1974 by Mysl'P.H., Moscow.

Standard Book Number: 0-87590-224-3

Library of Congress Catalog Card Number: 79-67029

Printed by
LithoCrafters, Inc.
Chelsea, Michigan

AGU gratefully acknowledges the assistance and encouragement of L.A. Heindl, who brought this volume to the attention of the AGU Translation Board and guided the production.

Published under the aegis of the AGU Translation Board: Alexander Malahoff, Chairman; Ven Te Chow, William H.K. Lee, Leonard Levin, Frank T. Manheim, and Foster Morrison.

Editor's Preface

The translation of Professor L'vovich's book was done expertly and editing was relatively easy. The global treatment of the hydrological cycle has been adopted by many Soviet hydrologists and a few others, but it is rare in many countries, including the United States. Therefore, this translation is a major contribution to the advance of knowledge about the hydrological cycle.

L'vovich began to publish papers on hydrology as long ago as the late 1920's. Many other papers followed during the ensuing decades. Indeed it was one of L'vovich's works, published in 1945, that sparked my own interest in global hydrology.

Owing to the breadth and depth of L'vovich's analysis of World Water Resources and their Future, the book should interest a wide spectrum of hydrologists and experts of water use. Chapters in the book deal with water balances at several levels, beginning with the earth as a whole and then turning to land areas and the world ocean, individual continents and each country. The book concerns not only theoretical aspects of hydrological science but also discussions that will aid approach to practical problems. No doubt some readers will question the realism of the L'vovich treatment of the future of water resources. He envisions complete treatment and recovery of all waste waters so that no wastes will be discharged into rivers, and treated sewage effluent will all be used in irrigation - both for ordinary field crops and for forests. Soil moisture will be enhanced by use of sewage effluent in grass lands. These goals already have been reached in a few areas, but chiefly on an experimental scale.

L'vovich envisions gradual complete cessation of discharge into rivers even of treated sewage. He also foresees complete recycling of water by industrial plants, thereby lessening the water demand and eliminating pollution. He also predicts considerably more use of groundwater, by developing groundwater reservoirs which would be commensurate with surface-water reservoirs. Artificial groundwater recharge will become large-scale and widespread.

For L'vovich determination of water balances and the water cycle is not an end in itself. It is only a means of obtaining a description of water resources and their genesis, of studying their transformation, and of seeking rational ways to use and conserve water.

L'vovich has travelled widely in the world and served as a consultant or investigator for various international organizations. His work during 50 years has been of inestimable value, not only for the advancement of hydrological science, but also aiding water development and use in countries of the Third World as well as in the USSR and socialist countries. In my opinion L'vovich is the dean of Soviet hydrologists and his book should be read by all hydrologists and experts of water use regardless of whether their concern is with local, regional, continental or global problems.

Raymond L. Nace
U.S. Geological Survey
Raleigh, North Carolina

Author's Note

The totals arrived at in scientific studies and summaries depend, of course, on how much initial data are available. But this dependence is not fully manifested in the results of the research. Experience in the science of hydrology demonstrates that the research method used compensates with some applied degree of accuracy for the absence of factual data. This rule was manifested quite vividly in the years of the first 5-year plans of socialist construction in the Soviet Union, when hydrological data were very scanty. The economy's demands upon hydrology were nevertheless fully satisfied by means of the research methods that were used at that time.

That kind of approach also has to be taken to hydrological studies of the earth's water balance and water resources.

Because information available about sizable parts of the earth is less complete than the information available about other parts, and because our knowledge of the individual phases of the water cycle and the water balance is somewhat limited, the results of hydrological research depend essentially on the research method used. Recalling A. I. Gertsen's metaphor to the effect that method is the embryology of truth, this was the reason why I have paid a great deal of attention to the methodological aspects of the problem in all my research projects.

The estimate of world water resources given in this book and the description it contains of the peculiarities of world water resources are based on the differentiated method of studying the water balance I have proposed. That method made it possible to obtain results for the world water balance and world water resources that differ essentially from all results previously obtained, including my own.

The science of hydrology cannot limit itself to assessing the natural properties of water resources. Hydrological transformations are important, but it is important not only to take note of their consequences, but also to forecast their future lines of development. This problem supplies another reason why the book devotes attention to the methodological aspects of long-range forecasts of water resources that allow us to draw certain new conclusions concerning rational ways of protecting water resources and of improving the water component of the natural environment.

Yet I am not inclined to overestimate the accuracy of the conclusions I have framed concerning the world water balance, the earth's freshwater resources, nor the long-range forecasts (for approximately the year 2000) of world water resources. I think it is indicative of the trend and suggest that values of the various elements of the world water balance are still not a sufficient indication that research has been successful. A large role is played by the development of research methodology, whose level can be taken as the basic criterion of progress.

Many sources in the literature had to be studied in this work on problems of world water resources and ways of using and protecting them. But as a rule the sources from which initial data were extracted for the research on the water balance and water resources by the methods I used (for example, the large number of sources used concerning daily river discharge, which was used in determining groundwater runoff and surface runoff) are not referred to in the text

because there are too many of them, and the notes would become cumbersome. But all the sources used for these purposes are listed in the bibliography.

This book generalizes the results of the author's research over many years. It also uses material and data obtained by the author and his coworkers over the last several years in the hydrology division of the Geography Institute of the USSR Academy of Sciences. I express my profound gratitude to all those who prepared material used in the book and who helped with the technical aspects of their presentation, as well as to those who read the parts of the book for their valuable recommendations concerning its contents.

WORLD WATER RESOURCES AND THEIR FUTURE

CONTENTS	PAGE
PREFACE	iv
AUTHOR'S NOTE	v
INTRODUCTION	1
PART I. THE WORLD WATER BALANCE	
CHAPTER 1. The Hydrosphere	13
CHAPTER 2. The Water Cycle	23
General Outlines of the Water Cycle	23
The Atmospheric Link	25
The Oceanic Link	26
The Lithogenic Link	28
The Soil Link	32
The River Link	39
The Lake Link	42
The Biological Link	43
The Human Link	49
CHAPTER 3. The Earth's Water Balance	51
The Development of Conceptions of the Earth's Water Balance	51
The World Water Balance	54
The Rate of Water Exchange	58
PART II. WORLD FRESHWATER RESOURCES	
CHAPTER 4. The Method of Studying the Water Balance and of Compiling an Inventory of Water Resources	61
The System of Water Balance Equations	61
Determination of Groundwater Runoff	66
The Extent to Which the World Has Been Studied by Hydrologists ...	70
Interpolation Formulas Based on Proportionality and Altitude	75
Hydrological Mapping	91
Lines of Future Research Into the Water Balance of Land Area	97
CHAPTER 5. The Water Balance of the Earth's Land Area and Its Patterns	103
Runoff and Its Underground Component	104
Equatorial Belt	104
Tropical Belt	107
Subtropical Belt	136
Temperate Belt	139
Subarctic Belt	143
Surface (Flood) Runoff	144

Surface Wetting and Evapotranspiration.....	148
Peculiarities of the Water Balance in the Mountain Regions.....	154
Zonal Proportional Patterns in the Water Balance.....	170
The Water Balance of the Continents.....	200
CHAPTER 6. Elements of the Regimes of the World's Rivers.....	205
Types of Streamflow Regime.....	205
Sediment and Ion Yield.....	222
PART II	
CHAPTER 7. World Freshwater Resources.....	245
General Background.....	245
Water Resources of the Countries of the World.....	249
Water Resources of the Soviet Union.....	266
PART III. FUTURE WATER RESOURCES	
CHAPTER 8. General and Theoretical Aspects of the Use and Conservation of Water Resources.....	269
Problems in Long-Range Forecasting Methodology.....	269
Main Lines of Pursuit in Solving the Water Problem.....	273
The Water Component of the Human Environment.....	281
Ways of Combating Qualitative Depletion of Water Resources.....	287
Some Economic Considerations.....	295
Basic Proposition to Be Honored in Developing Principles to Govern the Use and Conservation of Water Resources.....	297
CHAPTER 9. The Present State and Future of the Human Link in the Water Cycle.....	299
Water Supply Problems.....	299
Expenditures of Water for Ordinary (Nonirrigation) Agriculture.....	316
Hydropower and Navigation.....	320
Fishery.....	322
Use of Water Resources for Recreation and Tourism.....	324
Variants of the Long-Range Forecasts.....	325
CHAPTER 10. Ways of Controlling the Water Cycle.....	333
Directions in Which Transformations Are Possible.....	333
The Transformation of River Regimes by Reservoirs.....	336
Underground Reservoirs.....	341
The Transport of Water.....	343
Transformation of the Local Water Balance.....	347
Transformation of the Water Balance of River Basins Resulting from the Anthropogenic Effect on the Soil.....	355
Water Resources and Wetting Patterns.....	362
Long-Range Forecasts of the World Water Balance.....	363
Chapter 11. (Conclusion) World Water Resources in the Year 2000 ..	367
BIBLIOGRAPHY.....	385
REFERENCES.....	404