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Harald D. Frederiksen

The World Bank
Washington, D.C.
FOREWORD

Many countries are confronting important water resources allocation issues. As populations and economic activities expand, conflicts over existing supplies are becoming more serious. Though the basic allocation issues are being confronted, the management of the resources under drought shortages is receiving little attention. Yet, as we reach levels of general constraint on the available supplies, the potential for social and economic crises under the next drought becomes even greater in frequency and severity.

The paper, "Planning for Droughts: An Essential Action," is intended to make people aware of the urgent need for a drought management plan in regions of high population or critical economic activities. The principal components of such a plan are outlined to help clarify the factors involved and to provide a guide to undertake the task of preparing a plan. The need for and the content of non-drought emergency water management plans are also reviewed.

It is essential that countries promptly prepare drought plans, and equally, that those plans be an integral part of the overall land-use and water resources plans. Sound, effective management of emergency conditions are critical to the social and economic well-being of the affected region and nation.

The second paper, "Discussion of Some Misconceptions about Water-Use Efficiency and Effectiveness," deals with a related topic, the efficiency and effectiveness of water use. Fundamental policies pertaining to the development and management of water resources have been formulated based on various assumptions regarding water use efficiencies. These policies reflect perceived actions and conditions that influence the portion of diverted water that is consumptively used in specific sectors. Major investments have been made in agriculture to improve on-farm and project efficiencies. Water measurement and service pricing have been devised and universally applied to encourage changes in use. Inevitably, these actions have compromised or been at the expense of other actions in the search to better manage the resources using the available funds.

Today, every effort must be made to pursue the most effective actions in managing the resources. Management in itself is becoming more difficult. Possible actions are becoming more inter-dependent, and as a consequence, the analysis leading to decisions must avoid generalizations, simplifications or mere popular thought.

This paper is intended for people dealing with policy and program issues in water resources management. It has sought to clarify some misconceptions and to indicate the relative importance of frequently proposed actions to improve efficiency. The paper presents background on the features of water use in key sectors, the water use efficiencies at different levels in those sectors and notes the difference between efficiency and effectiveness.

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Director
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PLANNING FOR DROUGHTS: AN ESSENTIAL ACTION

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ACKNOWLEDGEMENTS

The author is indebted to the officials of many U.S. local, state and federal agencies that have formulated drought plans and guidelines for their preparation. These constitute a source of in-depth information for anyone who is considering whether a plan is needed or wishes to formulate detailed drought management plans for a governmental jurisdiction. Specific information was obtained from the Proceedings of the 1989 Regional Meetings on "Planning for Water Shortages" held in St. Louis from October 19-21 and sponsored by U.S. Committee on Irrigation and Drainage.

The author also received valuable comments from individuals within Asia Technical Agriculture division and others both inside and outside the Bank. In particular, Mr. Richard Grimshaw, Division Chief, ASTAG, who was instrumental in launching the Asia Water Resources Study under which this was prepared, provided continuing support and close, critical guidance to the work. Mr. Jeremy Berkoff reviewed the paper from the broad perspective of resources development and management and gave many helpful suggestions that greatly improved its scope and applicability to our work.
The Asia Technical Department serving the South Asia and the East Asia and Pacific Regions of the World Bank has undertaken a study of the water resources problems and issues confronting regional borrowers. The purpose of the study is to formulate new policies and strategies to assist countries to better manage their water resources and the related sectors. To provide background on a number of specific topics important to the study, a series of Topic Papers have been prepared. These are not intended as an in-depth treatment of a subject, but rather constitute a synopsis that will serve as background to discussions associated with the regional efforts. Any conclusions on the specific applicability of concepts described in the Topic Papers will be reflected in the final approaches adopted for the region and the individual countries.
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PLANNING FOR DROUGHTS: AN ESSENTIAL ACTION

ABSTRACT: The problems of increasing competition for available water resources are evident as governments grapple with solutions. But the potential for severe impacts, from poorly managed responses to sudden shortages, is often unrecognized. Consequently, both users and agencies -- even the economy of large regions and whole countries -- are vulnerable to unnecessary disasters. Plans for a response to droughts and other unscheduled shortages must be devised in advance for the most effective measures to be applied and the distress from sudden water constraints held to a minimum. Many proven examples are available to guide their preparation. With an obligation to protect the public and the economy, governments must assign high priority to prepare for all possible events under their jurisdiction. Though governments are responsible, it is essential that the public and all water users participate in formulating workable plans. Elements of all shortage plans, particularly drought management plans (DMP), should be incorporated into normal basin and project planning. Firm policies to continue serving "non-essential" lower priority demands, determined by land-use plans during normal supply conditions, are necessary for a water supply cushion to be available to manage the unscheduled shortage. Such policies and planning are a key concept in sound drought management.

INTRODUCTION

Water shortages, in the sense that demands exceed resources, are increasingly common. The shortages of a more permanent nature, occurring under normal hydrologic conditions, are forcing basic reallocation of resources among competing users and increased effectiveness of the existing allocations. The water conditions that force permanent reallocation or increased efficiencies, however, evolve over a period of time, and responses are usually devised and applied in an orderly manner.

Water shortages of a transient nature -- most obvious those caused by droughts -- also occur, but with a sudden severe impact if imposed on an already strained demand/supply situation. Many users are vulnerable to facilities failure and polluting spills, too. In all instances, the measures available to deal with a sudden shortfall depend directly on the nature of uses under normal water conditions and the measures that may have been taken already to deal with any longer term demand/supply problems.

Though many debate policies and actions that best resolve evolving long-term shortages exist, too few recognize the even more urgent need to have plans in place for managing drought conditions. Phillips and Ludwig\(^1\) and Changnon\(^2\) document deficiencies in addressing recent emergencies in the United States. The fact that a sudden shortage does not allow for the usual debate dictates that the responsible government officials have legislation and comprehensive plans in place to meet any possible shortage. For when it occurs, actions, often drastic, must be taken immediately.

This paper describes the nature of drought events, the range of conditions that may prevail and the actions that have proven effective to manage water under drought conditions. It

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also outlines the general content of a drought management plan (DMP), the steps to prepare the plan and considerations for preparing plans for other types of emergency shortages.

DROUGHTS

The term drought implies a dry period, yet the deficiency in precipitation, duration and geographical extent can be quite different. It may be a series of days without rain during a normally wet season. It may be a season with below normal precipitation. It may be one or more years with sub-normal rainfall. And of course, it may be highly localized or extend over a large area or even a region of the world. Usually, the geographical area affected increases with the duration.

Rainfed forage and field cropping may be the only activity affected by the short periods. Further, such events are usually quite normal, and even frequent occurrences in the climate of most areas. As conditions of below normal precipitation persist and shortages worsen, permanent crops, irrigation in general and urban supplies are affected. Thus, the specific meaning of drought as translated into economic terms is site and event specific.

Figure 1 presents the annual precipitation record as inferred by tree-rings for the period 1600 to 1963 for southern California. The plot clearly depicts important information pertinent to a discussion of drought planning. The amount of precipitation that is "normal" depends on the period selected for reference. Rainfall amounts may vary dramatically from year to year. And long-term norms may also vary greatly.

In this plot, "normal" precipitation was the mean annual amount for the period 1901 to 1963. The seven-year period of below precipitation in the late 1920s and early 1930s is clearly evident. This period/precipitation pattern has been applied as the design condition under which water systems should be able to serve with severe, but not disastrous, impacts on the customers. The current period of low precipitation in California beginning in 1987 is not greatly different.

However, note on Figure 1 the 70-year period from 1755 to 1825. Rainfall for the entire 70 years was only 70 percent of the recent "normal", with 10-year periods reaching only 64 percent. During the 25 years from 1865 to 1890, it was only 75 percent of the recent "normal". Even more serious, the quantities available for economic use may have been only 30 to 50 percent of "normal", recognizing that it is the net runoff and groundwater recharge which is the main water source for economic use in many locations. The natural ecological uses in the watershed intercept substantial precipitation before excesses are available to flow to the streams and aquifers. Even rainfed crops, independent of runoff, suffer similarly.

Independent of the precision of the estimated precipitation values, the meaning of the charted data is obvious. Serious droughts of five to eight years duration will occur with certainty. Prolonged periods of much lower precipitation are also likely. Their occurrence, severity and duration are quite impossible to predict -- even when examining the preceding precipitation records with hindsight. And these precipitation patterns hold true for most regions of the world.

The urgent need for drought planning and the importance of incorporating this into national and basin water development and management programs is evident. The full economic development of a water source, as has occurred in several basins and even whole regions of the world, assures with certainty that there will be severe impacts from droughts. The range of economic, social, environmental and security consequences can be envisioned and, in some settings, even estimated.
Reconstructed Statewide Precipitation Index in Inches for California. Mean Line Drawn for 1901 to 1963 Water Year Total, 23.82 Inches.

Source: Harold C. Fritts and Geoffrey A. Gordon, "Reconstructed Statewide Precipitation Index in Inches for California, Mean Line Drawn for 1901 to 1963 Water Year Total, 23.82 inches." Annual Precipitation for California since 1600 Reconstructed from Western North American Tree Rings (Tucson, Arizona: Laboratory of Tree Ring Research, University of Arizona, July 1980).
CONDITIONS OF WATER SUPPLY AND USE

As noted, the severity and suddenness of drought impacts vary considerably. A distinction must be made between the degree of the deviation from normal precipitation constituting the drought and the severity and suddenness of the drought's impact on the users. Because it is the latter that determines the urgency of a plan and the options that may be available in preparing the plan. The primary factors determining the level of impact are:

1. Source of water supply: The degree to which groundwater, multiple river basins, large reservoirs and snow-pack serve the area directly affects drought consequences. Supplies derived from a single river basin with minimal storage or supplies relying on marginal aquifers are obviously most vulnerable.

2. Categories of water user: The percentage of domestic, urban, industrial and agricultural uses determines both the human and economic impacts, as well as the degree of flexibility for response to the shortages. If the dominant use of a water source is for basic domestic needs or an overstrained urban area, there is little cushion for the priority users. Large areas of irrigated field crops, on the other hand, may allow considerable choice in maintaining services to critical users. In such situations, domestic needs and key industries can continue with greatly reduced risk.

3. Level of water utilization: Areas where the normally available water resources -- groundwater and surface -- are essentially fully utilized and where each user already has a highly "effective" application require more complex "drought" management measures. Severe or prolonged shortages cause immediate economic dislocation under these conditions.

4. Water quality: High quality water resources can be transferred readily from one use to another. Immediate utilization at a high degree of effectiveness can be assured with no physical or monetary impacts due to quality. Polluted waters, however, cannot be transferred readily for different uses. Under drought conditions, the inevitable deterioration further limits use, in effect creating additional shortages. This factor is often overlooked in assessing an area's vulnerability, as well as the suitability of potential management measures.

5. Institutional: The nature of existing institutions is a factor in judging the need for a DMP and its provisions. For example, agency responsibilities and capabilities at central, provincial/state and local levels directly affects the response time. And, with increasing regulatory measures (including environmental), choices may have to be made in effecting new legislation for these purposes, foregoing the most effective measures and tolerating various levels of economic and human suffering.

DROUGHT MANAGEMENT RESPONSIBILITIES

Drought may affect the economy and the people's lives at all levels. The extent of the impact depends on the nature and duration of the drought impacts. But since the timing, severity and duration cannot be predicted, each level of government is responsible for the preparation of DMP in advance to effectively manage every conceivable type of drought condition.

Local governments and agencies are affected first and must take the most immediate actions. Though higher levels of government should render assistance, local governments must devise management plans that realistically reflect the potential situations and the support they receive from higher levels. Indeed, local governments that prepare and publicize (as discussed

later) realistic plans may do more to motivate all levels of government into action than does any ongoing exchange among agencies.

Regional, provincial/state and central agencies have major responsibilities in drought management. Only the senior levels of government can execute major transfers of water resources, give physical and financial support to local agencies and create measures to alleviate personal hardship. In order for leadership to be successful, rules, plans, staff and funds must be in place, which inevitably calls for special legislation in advance.

Unfortunately, many water (and non-water) agencies are indebted to individual user groups. Therefore, many agencies are not inclined to initiate debate or promote specific measures that may have negative consequences for their constituents. But responsibilities to the general public must over-ride these concerns. The legislative bodies must not only support but require agencies to produce effective, fair management plans to meet all possible conditions.

THE COMPONENTS OF DROUGHT MANAGEMENT

A DMP must be tailored to each specific area, event and entity. Certain components of drought management, however, are common to all, particularly at the more local levels. Two basic characteristics of all DMPs include a mechanism for frequent, periodic review and upgrading and a structure that integrates plans with the normal government management activities. The essential components of drought management may be presented in different ways, but for this discussion are grouped as following:

1. Monitoring, analysis and defining conditions: Water resources, water demand and the nature of water use are continuously changing. Yet, it is their absolute values that determine the degree of drought that has impact and the specific responses that may be available at a given time. The water quantity and quality may be deteriorating while the uses shift increasingly to priority purposes under "normal" climatic conditions. Thus, a given weather event will dictate earlier and more severe responses in the future than today. The DMP must include ongoing monitoring of these conditions and reporting in terms useful for informing the public and for applying the adopted drought management measures. Supply and demand forecasting is the critical activity affecting decisions in the implementation of measures.

2. Drought management measures: The DMP must describe every management measure necessary at each level of drought severity. Obviously, certain measures must be initiated even before the severity may be confirmed. Each government measure, whether it be physical or regulatory, must be described in terms clearly understood by agency staff, industry and the public. Each measure must be defined in terms easily suitable to enforcement. The means of enforcement and consequences of violation must be defined and publicized also. These measures must be continuously reviewed and adjusted to reflect the changing "normal" conditions identified by Macy\(^1\), the monitoring and the analysis effort.

3. Implementation criteria: The drought management measures are applied in a sequence pre-determined to meet the conditions. Indeed, the content of each measure generally relates to the time of application. Nevertheless, the importance of determining the timing of various measures warrants that this criteria be set out as a separate component of the management plan. The public -- users and individuals -- must know in advance what may occur so they can plan their actions. The public must support the actions, and the public must be prepared for its enforcement.

\(^1\) Peter Macy, "A Complete Plan '...Experiences from the U.S.'" Paper from the Proceedings of the 1989 Regional Meetings (St. Louis, Missouri: U.S. Committee on Irrigation and Drainage, October 19-21, 1989).
PREPARING A DROUGHT MANAGEMENT FRAMEWORK PLAN

A strong, inspired leadership is key to devising an effective DMP. Such leadership should be knowledgeable and capable of dealing with a range of issues, from political and technical matters to public involvement. The nature of the situation -- managing a resource essential to people's welfare during disaster and all the associated emotional, economic and physical consequences -- makes this a most difficult assignment.

In his paper, Macy1 describes four parts in preparing a DMP. Each part contains the essential tasks as inferred in the description of drought management and the related institutional responsibilities. Building on these steps, the following is an expanded list for general application in a wider range of settings.

1. Define the available resources: Water may be available from several sources to meet demands in time of drought. Possible supplies may include the normal sources, as reduced by the drought; reliable augmentation ranging from short-term over-draft of groundwater to transferring water from lower priority users and entities with surplus and adjusting deliveries to users. In many locations, particularly larger basins or where pollution is already serious, the quality aspects must be carefully assessed. Too often the ongoing pollution load degrades water disproportionately more than under normal circumstances. It must be remembered that resources are not reliable/useable unless they can be legally acquired, physically delivered and of suitable quality to the use.

2. Define the demand: The quantity, quality and location requirements of all users must be defined. Laws often set priorities for each category of use. But the categories should be sub-divided -- agriculture into livestock, aquaculture, permanent crops and annual crops -- industry and urban, likewise. Water allocated for environmental purposes should be subdivided by defined priorities also so that they may be properly weighted with the other needs. In some regions this allocation approaches that of irrigation and may afford similar flexibility. The demands must be presented weekly where seasonal variation exists -- common in agriculture and for some industrial and urban uses. It is particularly important to describe the domestic/urban use in terms relative to essential and non-essential needs. Ultimately, the users' quality and quantity demands must be displayed in terms of "normal" supply and decreasing units of delivery in steps suitable for applying available management measures.

3. Describe possible shortfalls in supply: Managing the resources to best accommodate the shortfall in meeting demand under a given drought event calls for sound preparation. The measures applied must be effective and must be supported by the public. A key task is to carefully assess possible drought conditions, compare the potential user demands and define the shortfall. Such assessment must be carefully detailed so that the true magnitude is understood and confidently used in the subsequent steps.

4. Describe the management measures for potential events: This step entails defining the adopted measures necessary in response to projected shortfalls for various drought events. These measures must be realistic and of equal detail to match the results of Task 3. "Operating rules" are prepared to indicate the supply and demand conditions under the short-term climatic deviation when each measure is applied.

5. User and public involvement: It has been repeatedly proven that the success of drought management depends most on the understanding and support of the users and the public. This fact cannot be over-emphasized, particularly in an era of increasing tendency for the public to exert major influence on government for or against any actions. Many agencies have never sought

active participation of users in debating programs or actions. Few have the capacity, though user
and public involvement is increasingly essential to the success of even "routine" planning and
project operations. Experts must educate the users and the public and secure responsible rather
than emotional participation. The means depend on the area and level of awareness. But difficult
as this task may seem, it should commence with an announcement of the intent to prepare a
framework DMP and continue as a part of all subsequent tasks.

6. Securing legislation agreements, rules and procedures: Any water management
under conditions of shortage usually calls for new authority, rules and procedures. Most effective
drought management measures require even more -- new legislation and specific legal agreements.
For example, the usual priority definitions for categories of use are vague. Often re-allocation
requires legislation. Restriction may apply to the use of facilities for physical transfer of water.
Authority may be lacking to curtail pollution, hydro power, navigation or environmental protection
activities. Finally, standing legislation is necessary to effect emergency measures at the time
needed.

Phillips and Ludwig\(^1\) describe difficulties caused by lack of legislation in the United
States during recent emergencies. The most essential action in several countries is to secure
agreements among the states/provinces, which is particularly true where water rights are the
purview of the state/province rather than a central government. These agreements must relate to
very specific inter-state/provincial DMPs on the affected basins. But again, delaying or ignoring
agreements only courts conflict and further hardship.

Many international basins already stressed under normal conditions have no water
rights agreements, much less a detailed agreement linked to a DMP. Every effort should be made
to secure such agreements because the consequences resulting from a prolonged period of low
precipitation is serious in every respect -- not the least are relations, even national security among
the riparian countries.

7. Drought management event plan: Any drought requires a specific set of
management actions tailored to the specific event: a Drought Management Event Plan (DMEP). A
detailed current DMP serves as the framework for preparing the DMEP and implementing actions
during a specific event. The DMEP details the measures, the conditions that trigger the measures,
the dates for forecasting events to allow users and the public to plan and the units' implementation
responsibilities. Its main public thrust is to keep everyone aware of the dated actions and the
enforcement provisions.

A CAUTION: DMP'S AND NORMAL BASIN/PROJECT PLANNING

Evolving permanent supply conflicts and drought-induced shortages call for different
measures, but by the same users and with the same facilities. And the degree of water management
flexibility under normal conditions directly affects the range of measures available for application
under drought conditions. Most debate today demonstrates that this fact is not understood. If low-
water-use toilets, low water-use showerheads and "desert" landscaping rather than lawns are
already in place, a substantial degree of adjustment otherwise available under a given drought is
removed. If annual crops are replaced by tree crops and in-stream environmental conditions are
rigidly cast in law as highest priority use next to drinking, the vast majority of "user" adjustment
under drought is gone.

It must be understood that even severe, prolonged droughts are normal events. If all
water resources are committed to essential "survival" uses under average precipitation no DMP can

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the Proceedings of the 1989 Regional Meetings (St. Louis, Missouri: U.S. Committee on Irrigation and Drainage,
October 19-21, 1989).
prevent the imminent disaster of a sudden severe drought. **Tolerable conditions can only be sustained in drought management if government policies support a program of conscientious maintenance of supplies to a substantial cushion of non-critical use under conditions of normal precipitation.** Any infringement on the cushion assures economic and human disaster with risks of conflict at the regional, national and international levels. For example "water banking" by basin water users with agreed charge rates in time of shortage is an arrangement for resources commitments that provides flexibility in times of shortage. Urban users may dedicate water to drought use, but lease it to agriculture during periods of normal precipitation. Such arrangements are effective only as long as they are strictly adhered to and the supplies are not preempted by political pressures for diversion to high priority use under normal conditions.

Agencies and the public must recognize that policies and plans for water management are incomplete and will likely court disaster unless both normal and drought/emergency uses, allocations, rules and facilities -- basin water plans and DMPs -- are prepared together.

**OTHER NON-SCHEDULED SHORTAGES**

Droughts are the most common cause of non-scheduled water shortages and typically inflict the most severe impacts. But some urban areas and even rural areas risk serious interruptions in normal water services from pollution spills or facilities failures whether or not they are susceptible to droughts. The cause of the water shortage and the nature of the impact differs from droughts. However, the need for government and agency plans remains just the same. The term Water Emergency Plan (WEP) is descriptive of these plans and constitutes a series of plans for possible emergency events.

**CHARACTERISTICS OF NON-DROUGHT WATER SHORTAGES**

The characteristics of the cause and the measures involved in non-drought water supply shortages tend to be more technical and place more direct power in the hands of the water agencies. Preventive actions, including sound maintenance and regular, competent inspections can minimize facility failures. Most organizations use such preventive measures as a priority program with commensurate specialist and financial support. A program of this type is certainly the proven and prudent policy. However, countries that have undergone a rapid expansion of facilities, particularly, if coupled with a lower priority for facilities maintenance and inspection, often risk failures that may have severe consequences not realized by the agency, the civil government or the dependent water users. It is important to recognize that not only water supply facilities are of concern, but also the many waste treatment and waste generation operations of government and the private sector. Indeed, industrial and materials spills continue to be the principal cause of non-drought water supply emergencies in the developed countries.

**Preparing a (Non-drought) Water Emergency Plan**

The steps in preparing a WEP are similar to those for a DMP. The conditions of water supply and use should be defined. The quality and institutional factors should receive greater attention since the many regulatory constraints and water rights restrictions under emergencies of this type are even less formal than under droughts. But government and agency responsibilities follow the same as for droughts.

The WEP should have the same basic components as the DMP: (1) monitoring, analysis and defining conditions; (2) management measures; and (3) implementation criteria. However, they resemble the detail of the DMEPs -- or rather a series of DMEPs. The plan content is also more narrow in the range of measures and the response time than DMPs. It is these two features that dictate that these plans, similar to DMEPs, must be carefully conceived following thorough evaluation of each possible event and available management action. The proposed
measures should be tested by technical simulation of the event to test the plan. Droughts can cause such a wide range of events that each DMEP must be refined as the particular event unfolds. Most non-drought events are limited in number and can be pre-defined, fortunately, so that the plans are in place, ready to be promptly executed in response to the suddenness typical of these failures.

The degree of public involvement in the preparation of the WEPs varies. The public has little to contribute to most potential emergencies of a highly technical nature. Nevertheless, the water service users and the potential sources of pollutants in that class of failures must be involved and detailed responsibilities and procedures developed and agreed to as a part of the WEP. The responsibilities and penalties for those who contribute to a possible emergency must be set forth and made public. Such procedures do much to secure the cooperation and sufficient planning needed to reduce the risks of the event as well as facilitate actions to reduce losses, should they occur.
BIBLIOGRAPHY


DISCUSSION OF SOME MISCONCEPTIONS ABOUT WATER-USE EFFICIENCY AND EFFECTIVENESS

Harald D. Frederiksen
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We are indebted to the many individuals who have devoted their careers to the question of water-use efficiency and who have developed the information upon which this summary report is based. Of particular note is the work of the U.S. Soil Conservation Service, U.S. Geological Survey, U.S. Bureau of Reclamation, American Water Works Association, U.S. Council of Agricultural Science and Technology, Organization for Economic Co-operation and Development and the California Department of Water Resources that provided much of the factual data.

The author appreciates the review and helpful comments of colleagues in the Asia Technical Agriculture division and other individuals both within and outside the Bank. In particular, Mr. Richard Grimshaw, Division Chief, ASTAG, who was instrumental in launching the Asia Water Resources Study under which this was prepared, provided continuing support and close, critical guidance to the work. Mr. Jeremy Berkoff reviewed the paper from the broad perspective of resources development and management and gave many helpful suggestions that greatly improved its scope and applicability to our work.
PREFACE

The Asia Technical Department serving the South Asia and the East Asia and Pacific Regions of the World Bank has undertaken a study of the water resources problems and issues confronting regional borrowers. The purpose of the study is to formulate new policies and strategies to assist countries to better manage their water resources and the related sectors. To provide background on a number of specific topics important to the study, a series of Topic Papers have been prepared. These are not intended as an in-depth treatment of a subject, but rather constitute a synopsis that will serve as background to discussions associated with the regional efforts. Any conclusions on the specific applicability of concepts described in the Topic Papers will be reflected in the final approaches adopted for the region and the individual countries.
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DISCUSSION OF SOME MISCONCEPTIONS ABOUT WATER-USE EFFICIENCY AND EFFECTIVENESS

ABSTRACT: Increased water-use efficiency (the volume of water consumptively used divided by the volume of water delivered) by irrigators and other like diverters is a frequently mentioned solution to regional water scarcity. Many assume that lining canals and introducing advanced water application technology frees additional water for other purposes. But efficiency of use at the user or project level is not a sound basis alone to judge potential regional water supplies, the effectiveness of its use, nor, indeed, the wisdom of proposed investments.

The efficiency of individual irrigation projects in the United States averages 41 percent while closer to 30 percent in developing countries. The results from urban systems is reversed with 10 to 20% percent efficiencies in the developed countries and 50 to 70 percent in the developing countries. The larger impact on a region's water supply by project efficiencies, however, is determined by the project's location within the river basin.

Through repeated reuse of return flows by lower basin users -- agricultural and non-agricultural -- the irrigation sector efficiency is 87 percent in the United States, as in most other countries, including the developing countries. Indeed, downstream users usually rely on the return flows from upstream diverters for their operations. When urban areas are located upstream of other users, the effects are similar to irrigation -- negligible net loss to the system. However, essentially all return flows are lost from users located near the sea, a common situation for many large urban centers. There the low user efficiencies cause true water loss to the nation.

It should be recognized that the net efficiency of all users within many large basins already approaches the maximum possible. There is no outflow. The efficiency and the potential for making "losses" available, and hence justifying any related expenditures, must be examined at the point of concern. For the region and the nation, efficiency of resource use is evident at the basin level. It is basin efficiency that matters most.

INTRODUCTION

Today, wherever water is scarce and new supplies are costly or environmentally controversial, many people focus on "water-use efficiency." Proposed solutions to water shortages inevitably include physical measures to improve "efficiencies" and laws or regulations to penalize "low-efficiency" users. People demand new allocation procedures, including basic changes in water rights laws to shift water from one category of use to another of higher "efficiency". Many seek free market pricing of water to attain "efficient" use.

Obviously, there are two quite different definitions of efficiency used in these debates -- economic efficiency and efficiency as applied to water consuming activities such as irrigation, industrial processes and residential use. One can also include energy efficiency in the use of water, but fortunately, this definition is treated usually as an energy consideration. Most of the inconsistent definitions of "efficiency" stem from the fact that people of quite diverse backgrounds are entering into the same debate. Unfortunately, some of the continued misuse of terms and the incompleteness of information prevent formulation of the most sound solutions to pressing issues.
The discussion and proposed approaches to attain economic efficiency in water use is wide ranging and is not treated in this paper. And though economic efficiency is sometimes linked in discussions to the traditional efficiency term describing consumptive uses, this paper is limited to discussing the nature and importance of the latter. Thus, hereafter in this paper "efficiency" means the ratio of the quantity of water consumptively used to the quantity supplied for such use.

A clear understanding of the efficiencies of various uses and the linkage to the hydrologic system is essential. More broadly, the differences between two classes of use -- consumptive and non-consumptive -- must be recognized. The direct impacts of one user's diversion of water and return of unconsumed water to the stream or aquifer on another user within the same hydrologic system and the real consequences of changing the individual users' efficiencies are frequently not considered.

Also, the concept of effective use -- meeting set objectives -- quite aside from efficiency, is important in clarifying the debate and devising actions for improving water management. Some very inefficient uses, as measured by some definitions, are sound and highly productive while others that appear highly efficient are wasteful.

The objective of this paper is to help clarify key aspects of the term and its application. This paper briefly describes the classes of water use and the characteristics of common categories of water users. It also outlines typical user efficiencies and the differences between "efficiency" and "effectiveness" of water use.

**CLASSES OF USE**

Water use may be classified by the change it makes to the water resource. The changes may be in quantity, quality or both. By these definitions, the general classes are, therefore, consumptive, non-consumptive and polluting.

**Non-Consumptive**

Hydro-generation is the major economic use that is generally classified as non-consumptive. This is true for run-of-the-river plants, but not strictly true of storage schemes where significant reservoir evaporation may occur. The same holds for in-stream uses such as recreation and fisheries; again, to the extent that changed stream flows for these purposes do not increase evaporation. Any changes in stream-bed percolation, of course, are reflected in the immediate loss of surface flow.

**Consumptive**

Any use of water that causes a physical removal of water from the hydrologic system is classified as consumptive. The evapo-transpiration (ET) incurred during crop irrigation, golf course irrigation and lawn watering are typical examples. Vegetative growth -- irrigated and unirrigated, including natural forests and wetlands -- is by far the dominant consumptive use. Indeed, changing from native vegetation to agriculture may significantly reduce consumptive water use in an area. For the same reason, reverting drained agricultural cropping to wetlands may increase the consumptive use of water. Sustained stream flows by storage releases often increase consumptive use through the support of additional riparian vegetation. The percolating flows from stream channels or fields incurred in the course of these uses, however, are not lost for beneficial use as they remain in the hydrologic system, unless they percolate to aquifers of unsuitable water quality or to the sea. Water evaporated in steel manufacture and thermal power plants with evaporative cooling towers are other examples of consumptive uses.
Polluting

Pollution is non-consumptive in the physical sense. However, it does alter the resource and may render it as unusable for subsequent consumptive uses. Thermal power plants may use water consumptively through evaporative cooling towers or merely cause thermal pollution by diverting river, lake or sea water through heat exchangers and returning it slightly warmed to the original body of water. A more common pollution occurs by waste discharge from urban uses that alters the quality of the receiving waters. The dilution and conveyance of wastes by discharging concentrated effluents into streams, lakes and oceans is a major water use in many locations. Properly treated wastes, however, may cause minimal problems. Groundwater pollution by percolating waters contaminated through urban land uses and by agricultural chemicals -- wastes from concentrated animal feeding operations and polluted drainage channels -- is more widespread geographically. Groundwater pollution may also occur through intrusion of poor quality waters as a result of overpumping an aquifer. In instances of groundwater pollution, storage capacity for seasonal and long-term surplus precipitation is lost and with it, that potential water for productive uses. This occurrence is much more difficult to remedy and far more serious as a long-term loss of a nation's resources.

Efficiency of Water Use

The term "efficiency" as a measure of water use has restricted application to water allocation and management measures. However, given its importance in discussions, it is essential to have a thorough understanding of the term, its value for various categories of use within the consumptive class of use and its value at different levels in the hydrologic system.

Data pertaining to water use efficiency for three key categories of users is provided: agriculture (irrigation), urban and industry. Little reliable data is available from the developing countries and most of the data used in this paper is derived from publications of the U.S. Geological Survey, U.S. Soil Conservation Service, California Water Resources Control Board, and American Water Works Association. Estimates for the developing countries were made using information from various sources. In spite of the lack of data, the relative values can be compared and the factors of consequence to water management can be described.

This paper examines the irrigation and urban categories at four levels. This breakdown by level allows evaluation of a given situation and the selection of measures truly appropriate to meet any improvement objectives. Other uses, including environmental, that are becoming important in allocating resources are discussed also.

Agriculture (irrigation)

Agricultural use warrants close attention because of its dominating water use for economic purposes in many countries. One of the most concise, yet, thorough discussions of irrigation and related water issues is presented in the report "Effective Use of Water in Irrigated Agriculture" by the U.S. Council of Agricultural Science and Technology. The efficiencies related to irrigation may be measured at the four different levels identified as one progresses from the individual farm up to the sector as a whole: (1) on-farm; (2) the conveyance and distribution system; (3) the scheme/project to which the farm belongs; and (4) the country's irrigation sector.

On-farm irrigation efficiency is defined as the water consumptively used (ET) by the crop plus that evaporated from the soil divided by the water delivered to the field. On-farm losses result
from deep percolation and field run-off. Several factors affect on-farm efficiency including soil
texture/water holding capacity, variability of soils within the field, plant root depth, climate,
method of application and uniformity of application of the water across the field (uniform meaning
only minimal over or under application anywhere in the field from the theoretical depth provided by
the delivery).

Field evaluations show that water applications necessary for rice on heavy clay soils are
only 25 percent of that on light textured soils. Crop root depth, and hence, the soil depth for
holding water is shown on Table 1. As may be noted, alfalfa (and tree crops) has a far greater root
depth than vegetables and cereals, and hence, a far greater soil depth in which to store water.

Table 1: CROP IRRIGATION DEPTHS
(Soil Depth in Inches)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Humid Areas</th>
<th>Semiarid to Arid Areas¹</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Alfalfa</strong>..........</td>
<td>36-42</td>
<td>60-120</td>
</tr>
<tr>
<td><strong>Beans</strong>............</td>
<td>-</td>
<td>36-48</td>
</tr>
<tr>
<td><strong>Beets (Sugar)</strong>...</td>
<td>-</td>
<td>48-72</td>
</tr>
<tr>
<td><strong>Broccoli</strong>.........</td>
<td>-</td>
<td>24</td>
</tr>
<tr>
<td><strong>Cabbage</strong>..........</td>
<td>-</td>
<td>24</td>
</tr>
<tr>
<td><strong>Clover (ladino)</strong>.</td>
<td>-</td>
<td>24</td>
</tr>
<tr>
<td><strong>Corn (maize)</strong>....</td>
<td>24-36</td>
<td>48-60</td>
</tr>
<tr>
<td><strong>Cotton</strong>...........</td>
<td>24-36</td>
<td>48-72</td>
</tr>
<tr>
<td><strong>Grapes</strong>...........</td>
<td>24-30</td>
<td>48-72</td>
</tr>
<tr>
<td><strong>Orchards:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Citrus</td>
<td>-</td>
<td>48-72</td>
</tr>
<tr>
<td>Deciduous</td>
<td>36-60</td>
<td>72-96</td>
</tr>
<tr>
<td><strong>Pasture</strong>..........</td>
<td>18-36</td>
<td>36-48</td>
</tr>
<tr>
<td><strong>Peas</strong>.............</td>
<td>-</td>
<td>36-48</td>
</tr>
<tr>
<td><strong>Potatoes (White)</strong></td>
<td>12-24</td>
<td>26-48</td>
</tr>
<tr>
<td><strong>Small grain</strong>.....</td>
<td>18-30</td>
<td>48</td>
</tr>
<tr>
<td><strong>Sorghum</strong>..........</td>
<td>20-30</td>
<td></td>
</tr>
<tr>
<td><strong>Soybeans</strong>.........</td>
<td>18-36</td>
<td></td>
</tr>
<tr>
<td><strong>Tobacco</strong>..........</td>
<td>15-24</td>
<td></td>
</tr>
<tr>
<td><strong>Tomatoes</strong>.........</td>
<td>-</td>
<td>72-120</td>
</tr>
<tr>
<td><strong>Truck crops:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shallow-rooted</td>
<td>9-12</td>
<td></td>
</tr>
<tr>
<td>Medium-rooted</td>
<td>12-24</td>
<td></td>
</tr>
<tr>
<td>Deep-rooted</td>
<td>24-30</td>
<td></td>
</tr>
</tbody>
</table>

The irrigation efficiency value in a climate where irrigation supplements rainfall, obviously
also depends on the farmer's ability to avoid irrigating immediately prior to or during substantial
rain or, conversely, depends on the contribution to plant growth assigned to the rain. (Planners

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¹ Larger figure applies to arid areas.
often assign overly optimistic values to both of these factors.) Carefully shaped fields or mechanized water application helps farmers attain higher field efficiencies. Studies have shown, however, that the overall level of the farmer's on-farm water management skill is more important to attaining high efficiencies than the method of application.

Typical values of on-farm irrigation efficiencies (50 to 85 percent), in the more intensively developed areas of the United States are presented in Table 2. The values in some regions may average 10 to 20 percent less than shown, with the national average about 53 percent.

Table 2: IRRIGATION EFFICIENCIES

A. Field Efficiencies by Method of Irrigation

<table>
<thead>
<tr>
<th>Method of Irrigation</th>
<th>Range of Efficiency, Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Graded borders</td>
<td>60 to 75</td>
</tr>
<tr>
<td>Basins and level borders</td>
<td>60 to 80</td>
</tr>
<tr>
<td>Contour ditch</td>
<td>50 to 55</td>
</tr>
<tr>
<td>Furrows</td>
<td>55 to 70</td>
</tr>
<tr>
<td>Corrugations</td>
<td>50 to 70</td>
</tr>
<tr>
<td>Subsurface</td>
<td>Up to 80</td>
</tr>
</tbody>
</table>

B. Average Efficiencies for Selected Crops in California

<table>
<thead>
<tr>
<th>Crop</th>
<th>Average Efficiency Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alfalfa and irrigated pasture</td>
<td>85</td>
</tr>
<tr>
<td>Citrus</td>
<td>80</td>
</tr>
<tr>
<td>Deciduous</td>
<td>85</td>
</tr>
<tr>
<td>Truck</td>
<td>70</td>
</tr>
<tr>
<td>Vineyard</td>
<td>80</td>
</tr>
<tr>
<td>Walnuts</td>
<td>85</td>
</tr>
</tbody>
</table>

C. Sprinkler Efficiencies

<table>
<thead>
<tr>
<th>Climate</th>
<th>Efficiency, Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hot dry</td>
<td>60</td>
</tr>
<tr>
<td>Moderate</td>
<td>70</td>
</tr>
<tr>
<td>Humid or cool</td>
<td>80</td>
</tr>
</tbody>
</table>

Source: U.S. Soil Conservation Service and California State Water Rights Board

The on-farm efficiencies in regions of some developing countries approach the highest U.S. field values. For example, the rice irrigation on shallow soils over hard-rock areas in eastern India indicate project-wide field efficiencies over 85 percent. Elsewhere, poor system delivery
scheduling and inadequate volumes in the individual deliveries to the farm reflect significantly lower efficiencies as sound on-farm water management becomes impossible. The increasingly marginal areas coming under irrigation today -- shallow soils, light soils and steeply sloping lands -- coupled with the limited investment in improved application methods, may display field efficiencies of less than 35 percent. The majority of on-farm efficiencies in developing countries may range from 30 percent to 75 percent with an average of about 40 percent. However, this can be deceiving since under-irrigation that produces poor quality products may display high irrigation efficiencies. But the effectiveness of the water under these conditions as measured in weight and quality of product may be unacceptably low.

Irrigation system conveyance and distribution efficiency is defined as the water delivered to the farm divided by the water diverted from the prime source. The losses (seepage, operational and evaporation) depend on a number of factors including the type of conveyance (pipe or canal, lined or unlined), foundation material, groundwater elevation relative to the land surface, length of canals in proportion to area served, climate and system capability compared to the service attempted.

System seepage losses vary for many reasons other than the water tightness of the delivery channels. For example, seepage losses are usually low from unlined canals that distribute water within large rice areas. The percolation from the flooded fields maintain the water table near the surface of the surrounding lands or the soils are tight clays. In either case, canal losses are minimal in relation to field losses. Canals passing through coarse materials, as commonly found in alluvial fans at the foot of mountain ranges and lands adjacent to rivers, however, can lose huge quantities of water unless effectively lined. Intermittent canal flows can greatly increase seepage from unlined canals by alternate wetting and drying causing the silt coating or surface soils in the channels to dry out and crack. Unfortunately, canal loss calculations based on ponding tests are often misleading as measurement is difficult and conditions do not simulate the important effects of groundwater or channel surfaces existing under normal operations.

System operating losses depend on the degree of flow control, adequacy of scheduling deliveries and farmer discipline. Mismatching canal flows with the tertiary and farm turnouts, whether due to poor scheduling or farmer actions, can result in substantial water wastage from the system. Huge system operational losses are common where farmer indiscipline and operator tolerance of illegal acts or corruption causes excessive deliveries at the head end of the system or uncontrolled flow through illegal turnouts. The effectiveness with which return flows from sub-areas within the project are re-used internally reflects directly in the scheme's overall operational efficiency.

System evaporation losses are usually not a significant amount in proportion to the water delivered. Supplemental irrigation systems may show zero or even a gain from rainfall. At the upper limit, systems in arid climates may loose from less than 2 percent up to 8 percent in long canals.

Total conveyance and distribution losses vary significantly within most countries. Well operated, lined systems in dry climates delivering to well disciplined farmers often exhibit less than 5 to 10 percent total losses (90 to 95 percent efficiency). Systems involving river diversions and unlined canals in coarse materials, typical in the mountain areas, can lose over 30 to 35 percent (60 to 70 percent efficiency). The U.S. national average for combined conveyance and distribution losses is 22 percent of amount diverted or a conveyance and distribution efficiency of 78 percent. Firm data is lacking on conveyance and distribution losses in developing countries. But indications are that such losses may range from 15 to 45 percent with national averages of 25 to 40 percent, which gives a conveyance and distribution efficiency of about 68 percent. Groundwater-supplied irrigation commonly incurs minimal system losses since conveyance facilities are usually short and often in pipe. Further, the operation can be more directly linked to the farmer's operation.
Project irrigation efficiency is defined as the overall efficiency of water use on an individual project; consumptive use for production divided by the amount diverted from the primary sources. This definition encompasses operations, conveyance, distribution and on-farm losses. As may be seen from the range of values of the component losses, project efficiencies differ widely.

Individual project efficiencies in the United States range from 30 to 80 percent (with pipe delivery) with a national average of 41 percent. Individual project efficiencies in developing countries are estimated to range from 25 to 40 percent with national averages in the vicinity of 30 percent.

Irrigation sector efficiency is defined as the ET water volume (productively used to grow irrigated crops) used by the entire irrigation sector divided by the net water volume made available to the sector. This value depends most on the physical location of all users in relation to one another and their location relative to the final water disposal site; usually the ocean or a desert sink.

The sequential location of irrigation projects following irrigation project from the upper reaches down the basin tributaries and then down the rivers, allows recovery and reuse of most water termed as losses in the efficiency calculations at the on-farm, delivery facilities and project levels. Most surface return flows and deep percolation to groundwater from individual farms and operational spills of the individual systems become available for subsequent use for downstream irrigation, urban or other beneficial purposes. Indeed, downstream users, irrigators and non-irrigators alike, may depend on return flows for their survival. In such situations, increased on-farm or system efficiencies with further consumptive use on a given project may encounter social, if not legal, objections from downstream water users. Canal linings are usually selected to help reduce system seepage losses, though the larger benefits may be maintenance savings and service reliability. In practice, some farmer-owned systems are intentionally unlined and the facilities are operated in a manner to increase seepage recharge of the local groundwater for conjunctive surface/groundwater operations, particularly for long-term carryover storage.

In the 17 western states of the United States, 46 percent of the water diverted for irrigation is returned to sources where it can be re-used. Considering the supply derived from these return flows and subsequently used consumptively for beneficial purposes -- crop and non-crop -- only 13 percent of the total diversion is not used productively or made available for further diversion. This practice results in an irrigation sector efficiency of 87 percent in the United States. Figure 1 displays the situation graphically.

Though firm data is not available, the sector-wide efficiency for developing countries is estimated to be not far different from that found in the United States, even though the on-farm, delivery facilities and project efficiencies are much lower. An examination of the dry season flow in the lower reaches of many rivers often shows, essentially, a near 100 percent efficiency during the critical runoff periods. Several rivers in western and southern India and northern China are dry soon after the monsoon rains stop. Streams in Indonesia are inadequate to serve the coastal lands and cities during the low flow season, as is evident in the cases of Jakarta and Surabaya. The groundwater levels in the North China plain, as in many countries, are dropping.
A major part of the difference between the crop production that results under irrigation in some developed countries and the developing countries is the "effectiveness" of the water use. The lower crop productivity is in large part due to poor control -- amount and timing -- of the water deliveries.

**Urban and Industrial Use**

Water-use efficiency of the urban and industrial sectors may be examined in a manner similar to that used for agriculture. A considerable amount of information is available in the developed countries, but again, little firm data exists in the developing countries. Four levels are considered: the individual user, conveyance facilities, overall scheme and sector.

**Residential/commercial efficiency** depends on the water used consumptively by residents and commercial establishments in a metropolitan area. Use is primarily for domestic purposes, garden maintenance (to the extent that is done), restaurants, offices, parks and commercial establishments. In developed countries, consumptive use may be 10 to 20 percent of the 350 to 600 liters per capita per day delivered, depending on the climate. Table 3 shows the 1985 results for the United States. However, results are far different in developing countries because of few lawns and gardens, few household conveniences and the low income levels. Deliveries for domestic use may average only 15 to 40 liters per capita per day -- Indonesia has set 100 liters per capita per day as its objective for new systems -- with a consumptive use of 35 to 85 percent.
Table 3: DOMESTIC WATER CONSUMPTION
DOMESTIC FRESHWATER USE IN THE UNITED STATES, 1985
(Includes water for normal household purposes, such as drinking, food preparation, bathing, washing clothes and dishes, flushing toilets and watering lawns and gardens. By state, figures may not add to totals because of independent rounding.
Mgal/d = million gallons per day; gal/d = gallons per day)

<table>
<thead>
<tr>
<th>Self Supplied Water Withdrawals, in Mgal/d</th>
<th>Public Supply Per Capita Population Water Deliveries, Use, in Mgal/d</th>
<th>Total Per Capita Withdrawals and Deliveries, Use, in Mgal/d</th>
</tr>
</thead>
<tbody>
<tr>
<td>Population in Thousands Source Water Surface Total Ground Water</td>
<td>Per Population Capita Use, in gal/d Served, in Thousands Water Deliveries, Use, in Mgal/d</td>
<td>200,000 21,000 105 24,300 5,680</td>
</tr>
<tr>
<td>TOTAL 42,500 3,250 62 3,320 78</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


*Industrial* water-use efficiency varies greatly within a country and even more among countries. The U.S. industrial and mining sector consumes 16 percent of flows diverted for that purpose. But this reflects the great strides made in reducing use in the heavy industry sub-sector through process change and recycling. Table 4 shows changes from 1968 to 1983 and the status in 1983. The older processes found in developing countries require much higher diversions, and much larger quantities are used consumptively per unit of product. The absolute amount used consumptively, however, is not large nationally, though it may be of major importance to regional and local supply.

*Urban conveyance and distribution efficiency* depends mostly on the condition of the network facilities. Old systems, poorly constructed pipelines and inadequate corrosion protection can cause substantial losses and deteriorated operational control. Incomplete or faulty delivery measurement, though not causing physical losses, cloud the situation as well as precluding measurement of customer services. Urban system efficiencies displayed on Table 5 show unaccounted urban water -- losses and unmetered uses -- experienced in the United States. These average 14 percent in all systems, exceeding 17 percent in cities over one million inhabitants. The unaccounted water in developing countries averages are estimated to vary from 25 to over 50 percent. The physical losses may constitute one-half of the quantity, confirmed by measurements of night-time flows.

*The urban sector efficiency* in the United States has not been assessed as such. However, coastal zones can be expected to discharge 80 to 90 percent of the delivered water to the sea; a resulting efficiency of only 10 to 20 percent. The efficiency of inland metropolitan zones, however, would match the irrigation sector when vegetation (trees and landscaping) is assumed beneficial. If urban vegetation was not considered beneficial, the efficiencies would be perhaps 3 to 5 percent in hot arid location with the many times greater volume used by the vegetation counted as wastage. By weighting the proportion of urban centers discharging to the sea compared to the population in the interior irrigated areas, the urban sector efficiency of the western United States is in the order of 45 percent. This reflects the very low efficiencies of the substantial coastal metropolitan zone offset by the interior areas where effluent is fully reused within the basins.
Table 4: WATER USE IN MINING AND MANUFACTURING IN THE UNITED STATES, 1968 TO 1983, AND BY INDUSTRY GROUP, 1983

(Based on establishments reporting water intake of 20 million gallons. This represented 95 percent and 96 percent of the total water use estimated for mining and manufacturing industries. Water intake refers to that which is used/consumed in the production and processing operations and for sanitary services.)

<table>
<thead>
<tr>
<th>INDUSTRY</th>
<th>Establishments Reporting/ Total</th>
<th>Water Intake (bil. gal.)</th>
<th>Water Recycled (bil. gal.)</th>
<th>Water Discharged (bil. gal.)</th>
<th>Water Pollutants Abatement</th>
<th>Percent Untreated</th>
<th>Capital Expenditures (mil. dol.)</th>
<th>Operating Cost (mil. dol.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>MINING</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1968</td>
<td>1,801</td>
<td>3,694</td>
<td>2,051</td>
<td>1,408</td>
<td>n.a.</td>
<td>1,365</td>
<td>78.8</td>
<td>n.a.</td>
</tr>
<tr>
<td>1973</td>
<td>1,687</td>
<td>3,965</td>
<td>2,330</td>
<td>1,665</td>
<td>2,300</td>
<td>1,605</td>
<td>54.3</td>
<td>38</td>
</tr>
<tr>
<td>1978</td>
<td>1,525</td>
<td>3,554</td>
<td>3,366</td>
<td>1,473</td>
<td>2,430</td>
<td>1,592</td>
<td>67.3</td>
<td>244</td>
</tr>
<tr>
<td>1983 total</td>
<td>154</td>
<td>3,238</td>
<td>3,169</td>
<td>1,197</td>
<td>2,121</td>
<td>1,037</td>
<td>31.9</td>
<td>182</td>
</tr>
<tr>
<td>Metal mining</td>
<td>15</td>
<td>735</td>
<td>5,444</td>
<td>170</td>
<td>564</td>
<td>133</td>
<td>39.8</td>
<td>22</td>
</tr>
<tr>
<td>Anthracite mining</td>
<td>16</td>
<td>313</td>
<td>2</td>
<td>3</td>
<td>8</td>
<td>12.5</td>
<td>z</td>
<td>1</td>
</tr>
<tr>
<td>Bituminous coal, lignite mining</td>
<td>275</td>
<td>119</td>
<td>343</td>
<td>45</td>
<td>73</td>
<td>116</td>
<td>26.7</td>
<td>14</td>
</tr>
<tr>
<td>Oil and gas extraction</td>
<td>555</td>
<td>1,452</td>
<td>2,616</td>
<td>602</td>
<td>850</td>
<td>476</td>
<td>31.1</td>
<td>131</td>
</tr>
<tr>
<td>Nonmetallic minerals, exc. fuels</td>
<td>553</td>
<td>1,018</td>
<td>1,841</td>
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<td>875</td>
<td>76</td>
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<td>63</td>
<td>63.5</td>
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<td>7</td>
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<td>Fabricated metal products</td>
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<td>49.2</td>
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<td>587</td>
<td>120</td>
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<td>105</td>
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d=Withheld to avoid disclosing individual company data; n.a.=Not available; z=Figure does not meet publication standards; s=Less than $500,000.

1/ Establishments reporting water intake of 20 million gallons or more. These counts do not apply to water pollutants abatement columns for manufacturing in 1983.
2/ Refers to water recirculated and water reused.
3/ Data estimated; not strictly comparable to other years.
Urban sector efficiencies in the developing countries are usually significantly higher than in the developed countries primarily because of less vegetation in the cities; and far less water is delivered to the residences, as explained earlier. This difference is somewhat offset by the poorer performance of industry. Nevertheless, return flows in the interior of these countries is reused, as from irrigation schemes, while the coastal urbanized zones discharge without reuse to the sea.

A summary of information on efficiencies at the various levels in the agriculture, urban and industrial sectors is presented in Table 6.

Table 5: **UNACCOUNTED FOR WATER IN PUBLIC WATER SUPPLY SYSTEMS IN THE UNITED STATES**

<table>
<thead>
<tr>
<th>Population Served</th>
<th>Un-accounted for Water Percent</th>
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<td>10,000-25,000</td>
<td>17.1</td>
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<td>25,000-50,000</td>
<td>14.5</td>
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<td>50,000-100,000</td>
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<td>100,000-500,000</td>
<td>12.2</td>
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<td>500,000-1,000,000</td>
<td>12.8</td>
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<td>&gt;1,000,000</td>
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Table 6: **WATER-USE EFFICIENCIES 1/**

<table>
<thead>
<tr>
<th>Category of Use</th>
<th>User Delivery</th>
<th>Scheme Delivery</th>
<th>US %</th>
<th>Dev %</th>
<th>US %</th>
<th>Dev %</th>
<th>US %</th>
<th>Dev %</th>
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<tbody>
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<td>Irrigation</td>
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<td>78</td>
<td>41</td>
<td>28</td>
<td>87</td>
<td>85</td>
<td></td>
<td></td>
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<tr>
<td>Urban</td>
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<td>85</td>
<td>13</td>
<td>25</td>
<td>45</td>
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<td>Industrial</td>
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<td>n.a.</td>
<td>n.a.</td>
<td>n.a.</td>
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</tr>
</tbody>
</table>

1/ Values from developing countries estimated based on various sources
2/ Western United States
3/ Coastal cities
Other Major Uses by Economic Activities

There are sizable quantities of water used by other activities. Thermal power plant cooling is the largest diverter of water in the United States, even exceeding irrigation. However, it consumes only 3.3 percent of its diversions. This percentage is still substantial as thermal cooling consumptively uses 62 percent as much water as all domestic and commercial consumption in the country.

Environmental Uses

Substantial water resources are allocated for environmental purposes that are not accounted for in the usual economic sense. The specific purposes vary from maintaining in-stream water conditions and supporting stream fisheries to restoring water quality in coastal waters and setting aside entire rivers in wilderness areas. This practice is more common in some developed countries. The merits of allocating water to the various environmental purposes in competition with other purposes is not commented on here; that being an appropriate consideration for a country when it establishes its overall water allocation and environmental objectives. However, the environmental category of use, particularly when causing a change to existing conditions, should be defined in the same manner as others since sound water management requires full accounting of all aspects of every water use and the impacts of that use on the resource.

For example, the maintenance or expansion of forests, natural vegetation and wetlands has similar consumptive impacts on the available water as agricultural cropping. Plant maturity, areal extent and species are the determinants. However, such uses should help maintain quality. In-stream flows have obvious impacts similar to the non-consumptive uses discussed earlier, except where stabilized flow regimes in arid regions create expanded riparian vegetation.

Some countries have decided to augment natural flows to attain additional environmental benefits. And overall, the water allocation for environmental purposes may exceed all other uses, even in arid regions. For example, though irrigation uses approximately 80 percent of the surface and groundwater diverted for economic purposes in California, an amount equal to 85 percent of agriculture's is allocated to the type of environmental purposes just cited -- water dedicated for wild rivers and in-stream and estuary water quality.

Use and Efficiencies by User Category

The sources of water, classes of use and efficiencies of the different categories of use may be compared in analyzing allocation impacts and evaluating alternative water management policies and measures. Figure 2 shows the diversions, sources and consumptive use of water by key sectors, except environmental, in the United States compiled by the U.S. Geological Survey. Trends in water use from 1950 to 1985 is shown in Table 7. No comparable data has been prepared for developing countries.
Figure 2: SOURCE, USE AND DISPOSITION OF FRESHWATER IN THE UNITED STATES

Figure 2  Source, use, and disposition of freshwater in the United States, 1985. For each water-use category, this diagram shows the relative proportion of water source and disposition and the general distribution of water from source to disposition. The lines and arrows indicate the distribution of water from source to disposition for each category: for example, surface water was 78.3 percent of total freshwater withdrawn, and, going from the “Source” to “Use” columns, the line from the surface-water block to the domestic and commercial block indicates that 0.2 percent of all surface water withdrawn was the source for 1.6 percent of total water supplied withdrawals and public-supply deliveries for domestic and commercial purposes. In addition, going from the “Use” to “Disposition” columns, the line from the domestic and commercial block to the consumptive use block indicates that 19.5 percent of the water for domestic and commercial purposes was consumptive use: this represented 7.5 percent of total consumptive use by all water-use categories.
### Table 7: TRENDS IN WATER USE IN THE UNITED STATES, 1950-1985

(In thousands of million gallons per day; data are rounded to two significant figures; percentages are calculated from unrounded numbers)

<table>
<thead>
<tr>
<th>Year</th>
<th>Population, in millions</th>
<th>Off-stream use:</th>
<th>Percentage Change</th>
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<td>1985†</td>
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<td>1980-85</td>
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<tr>
<td></td>
<td>-6</td>
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#### Off-stream use:

- **Total withdrawals**
  - 1950: 180
  - 1955: 240
  - 1960: 270
  - 1965: 310
  - 1970: 370
  - 1975: 420
  - 1980: 440
  - 1985: 400
  - Change: 10

- **Public supply**
  - 1950: 14
  - 1955: 17
  - 1960: 21
  - 1965: 24
  - 1970: 27
  - 1975: 29
  - 1980: 34
  - 1985: 37
  - Change: 7

- **Rural domestic and livestock**
  - 1950: 3.6
  - 1955: 3.6
  - 1960: 3.6
  - 1965: 4.0
  - 1970: 4.5
  - 1975: 4.9
  - 1980: 5.6
  - 1985: 7.8
  - Change: -39

- **Irrigation**
  - 1950: 89
  - 1955: 110
  - 1960: 110
  - 1965: 120
  - 1970: 130
  - 1975: 140
  - 1980: 150
  - 1985: 140
  - Change: 0.6

#### Industrial:

- **Thermoelectric power use**
  - 1950: 40
  - 1955: 72
  - 1960: 100
  - 1965: 130
  - 1970: 170
  - 1975: 200
  - 1980: 210
  - 1985: 190
  - Change: 0.13

- **Other industrial use**
  - 1950: 37
  - 1955: 39
  - 1960: 38
  - 1965: 46
  - 1970: 47
  - 1975: 45
  - 1980: 45
  - 1985: 31
  - Change: 0.33

#### Source of water:

- **Ground:**
  - **Fresh**
    - 1950: 34
    - 1955: 47
    - 1960: 50
    - 1965: 60
    - 1970: 68
    - 1975: 82
    - 1980: 83
    - 1985: 73
    - Change: 0.12

  - **Saline**
    - 1950: 1
    - 1955: 6
    - 1960: 4
    - 1965: 5
    - 1970: 1
    - 1975: 0
    - 1980: 0
    - 1985: 0
    - Change: 0.29

- **Surface:**
  - **Fresh**
    - 1950: 140
    - 1955: 180
    - 1960: 190
    - 1965: 210
    - 1970: 250
    - 1975: 260
    - 1980: 290
    - 1985: 260
    - Change: 0.8

  - **Saline**
    - 1950: 10
    - 1955: 18
    - 1960: 31
    - 1965: 43
    - 1970: 53
    - 1975: 69
    - 1980: 71
    - 1985: 60
    - Change: 0.16

- **Reclaimed sewage**
  - 1950: 0.2
  - 1955: 0.6
  - 1960: 0.7
  - 1965: 0.5
  - 1970: 0.5
  - 1975: 0.6
  - 1980: 0.6
  - 1985: 0.6
  - Change: +0.22

- **Consumptive use**
  - 1950: 0
  - 1955: 0
  - 1960: 61
  - 1965: 77
  - 1970: 87
  - 1975: 96
  - 1980: 100
  - 1985: 92
  - Change: 0.9

#### In-stream use:

- **Hydroelectric power**
  - 1950: 1,100
  - 1955: 1,500
  - 1960: 2,000
  - 1965: 2,300
  - 1970: 2,800
  - 1975: 3,300
  - 1980: 3,300
  - 1985: 3,100
  - Change: 0.7

---


---

*48 States and District of Columbia
*50 States and District of Columbia
*50 States, District of Columbia and Puerto Rico
*50 States, District of Columbia, Puerto Rico and Virgin Islands
*Revised
*Data not available
*Freshwater only
The Importance of Efficiency and Effectiveness

Evaluating efficiencies and effectiveness serve two different purposes in formulating water resources management policies and measures. Efficiency is primarily used as a measure to compare alternative irrigation facilities and operations at the farm and project level or within an industrial process. Efficiency is a proper energy concern when supplies are pumped. Field efficiency may infer effectiveness of water and nutrient management by the farmer. Project efficiency may imply potential for groundwater management opportunities or problems. And certainly, the efficiency of any user -- situated near the ocean, overlying a saline groundwafer or discharging into a salt sink -- is of concern as a water loss to the region. The efficiencies of various users indicate the possible benefits of system improvements or the potential benefits of water reclamation in areas near the coast.

An examination of information on water use and related efficiencies, however, readily illustrates the distortions and unwise decisions from using "efficiency" as the single measure of sound use. For example, should water be reduced to thermal plants because their efficiency is only 3.3 percent? Hydroelectric generation exhibits essentially zero water-use efficiency. Is that bad? The water is inevitably used again downstream. To spend large sums on improving irrigation project efficiency, which does not mean that effort should not be spent on increasing its effectiveness, on a local project within a watershed that does not pass water to the sea may be little more productive than prohibiting hydro generation or curtailing thermal plant cooling. But investing in reclaiming urban effluent or coastal irrigation return flows in the coastal zone or when situated over saline groundwaters produces water for other uses or, in the case of coastal zones, possibly control saltwater intrusion. This point is important to sound water management.

"Effective" use relates to the productivity of the use relative to production goals, its impact on the resource (quantity and quality) and extent of resources waste that reasonably could be prevented. Hydro generation and thermal plant cooling are sound uses. Waste dilution and transport may be also, but treatment is warranted in situations of scarcity or undesired degradation of the receiving waters. Serving urban needs is a sound use, but discharging metropolitan return flows into the ocean is wasting a resource unless there is no alternative to dilution of the effluents.

Whether irrigation should be allowed or whether a given crop should be grown to consumptively use water is largely a question of its "effectiveness" in utilizing water relative to the set objectives, quite different from irrigation efficiency. Even if irrigation is an adopted objective, the effectiveness of the water use also depends on the supply adequacy during plant growth. High on-farm efficiencies may be recorded, yet, the effectiveness of water application as reflected in the yield and quality may be very poor. This is noted by example in the report, "Effective Use of Water in Irrigated Agriculture" where it states, "For example, under limited soil water conditions, grain sorghum, a drought-resistant crop, in one case produced 6.1 bushels per acre-inch of water compared with 3.9 bushels per acre-inch for corn (maize), a drought-susceptible crop. [But] under well-watered conditions, corn will produce as much grain per unit of water as grain sorghum." Further, some crops are more efficient in producing the desired product per unit of water than others. Sugar beets produce more sugar per unit of water than sugar cane. The same may be found for vegetable oils, starch and cereals.

Effectiveness in meeting a nation's broader goals depends most on how water and land-use is developed and managed at the basin level. Then the combined "effectiveness" of all water-related actions in meeting all objectives can be assessed and mutually supportive mixes of non-consumptive and consumptive uses, of "efficient" and "inefficient" uses can be combined within the geographical and geological characteristics of the basin.
BIBLIOGRAPHY


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