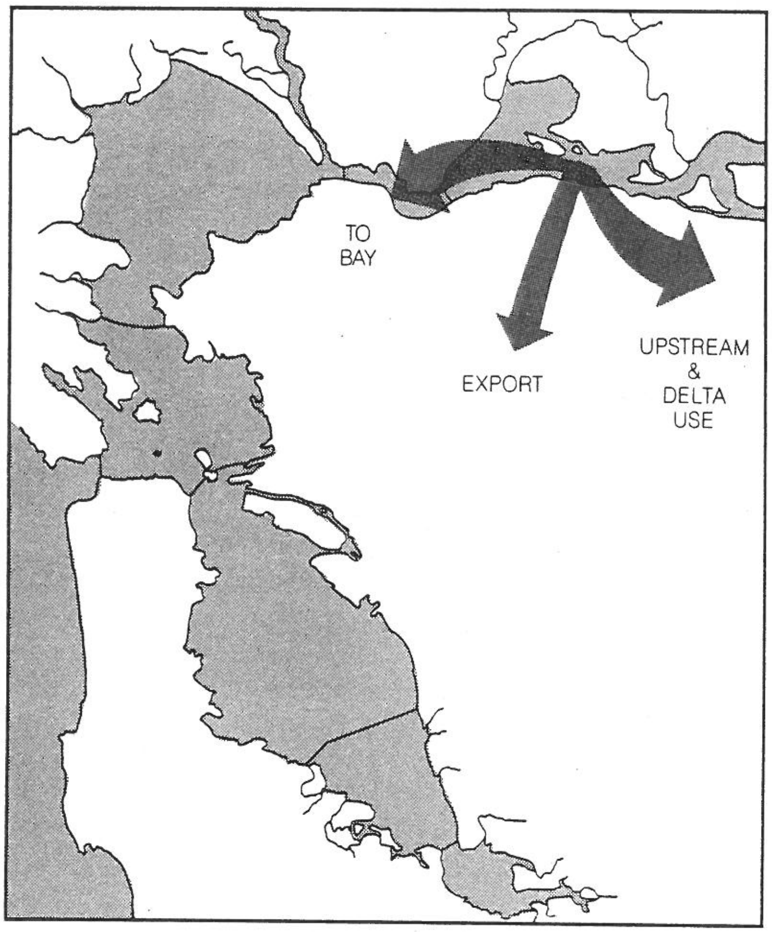
ANALYSIS OF THE INFLUENCE OF WATER WITHDRAWALS ON RUNOFF TO THE DELTA-SAN FRANCISCO BAY ECOSYSTEM (1921-83)



MAY 1987

Michael Rozengurt, Michael J. Herz & Sergio Feld

With preface by Joel Hedgpeth

Technical Report Number 87-7

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San Francisco State University
P.O. Box 855
Tiburon, California 94920

This report is one of a series highlighting estuarine research activities conducted at the Paul F. Romberg Tiburon Center for Environmental Studies, San Francisco State University.

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COMPARATIVE ANALYSIS OF NATURAL AND REGULATED RUNOFF CHARACTERISTICS OF THE SACRAMENTO-SAN JOAQUIN RIVER-DELTA SYSTEM

ACKNOWLEDGMENTS

The work discussed in this report grew out of a collaboration between the senior authors that began in 1981 and which is based upon their interest in and concern for water, both fresh and salt. The project could not have been undertaken without the consistent encouragement and support of Jane Rogers of the San Francisco Foundation. The Marin Community Foundation, the new administrator of the Buck Trust, has continued the financial support of the work as an indication of their dedication to the important resources represented by the Delta and San Francisco Bay.

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Despite all of this assistance, the authors take full responsibility for the analyses and conclusions contained in this report.

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PREFACE

Joel W. Hedgpeth

The Monache indians who lived along the San Joaquin among the sparsely wooded lands around North Fork at 500 to 1,000 feet above sea level before the white men came have a tribal memory of their origin on the east side of the Sierra. After they crossed the mountains and settled near the river, great storms came and three times the water rose, forcing them farther up into the hills. This suggests there must have been a very rainy period, perhaps something like the Great Flood of January 1862 that turned all of the Sacramento Valley into a lake and sent a river as large as the Amazon flowing into the sea. A flood like this, perhaps the result of a massive warm sub-tropical storm colliding with the usual winter storm pattern from the north, might happen only once in a thousand years, and it may be yet another nine hundred years before the next one. We have not been here long enough to know when or if such a flood would come again. So we do not think about it. What is more serious is that there are too many who in practice, if not belief, think that our present intricate system of dams and canals has solved the problem of drought in this semi-arid land.

So we continue to design and manage this marvelous system that extends the use of the water from a river that ranks only a poor ninth among the rivers of North America, and far down the third magnitude of the rivers of the world, to the burning fields of the San Joaquin Valley and over the mountains to the thirsty megalopolis of Los Angeles, and to allocate more water rights than water, as if there can be no end to the source. We have done all this without adequate knowledge of how the system works-not only with one system of dams, canals and pumps, but two.

There is ample evidence, both historical and in the present time in many parts of the world, that these practices lead to environmental degradation. The first step toward a serious approach to these problems is to understand the hydrologic system within which we are working. The techniques for analysis of the hydrologic problems of regulated (artificially-modified) water systems have been known for many years; they have been developed by scientists in the United States and the Soviet Union. The senior author of this report is an internationally-known oceanographer with over twenty years of experience with these problems, who has had an important part in influencing the present slowdown of potentially destructive water development projects in the Soviet Union. This report is the first analysis of the past and present water supply of the Sacramento-San Joaquin system as it relates to San Francisco Bay. It evaluates the cause of, and scale, of changes in the water supply during pre-project and present conditions, based on the basic features of the unimpaired runoff fluctuations as contrasted with the hypothetical "historic flow" concept in current use. The methods

used in this report lead to the conclusion that the water balance of San Francisco Bay cannot be separated from the runoff variables, one of the major elements in water and salt exchange between the Delta, the Bay and the adjacent coastal zone. From the flow statistics that reveal the scale of runoff modifications at this time, it is possible to establish for practical purposes, the seasonal patterns and trends of our water supply.

I.1 INTRODUCTION

Estuaries are the places where freshwater runoff from land meets the salt water of the oceans. They are among the most productive and important habitats in the world. Throughout history people have found such environments attractive places to live because they provide access to transportation, fishing, and recreation as well as to fresh water for drinking, manufacturing, irrigation, power production and waste disposal dilution.

Over half of the global population lives within 200 kilometers of a coast. Eighty percent of the world's fish catch comes from continental shelf areas, many of which are influenced by fresh water from rivers and streams, and many of the fish and shellfish species represented in this catch depend on the adjacent estuaries for at least part of their life cycles. In 1980, almost 5.2 billion pounds of commercial species with a dockside value of $1.8 billion and capitalized value over $35 billion, were caught in estuarine-adjacent coastal zone areas. The recreational expenditures were over $1 billion and the catch almost 190 million pounds (National Research Council, 1983).

Ever-increasing pressures of our contemporary, industrialized society - the urbanization process (Hedgpeth, 1970, 1977, White, 1977; Hamilton and MacDonald, 1980, Komarov, 1980; Cross and Williams, 1981) - make great demands on estuarine systems. The natural limits of estuaries which have evolved to respond with resilience to increasing water diversions, filling, and waste-loading have, in many cases, been exceeded. The resulting symptoms of stress - decreases in fish production and catches, increased residence time for pollutants, salinity increases and salt intrusion - have been seen in estuaries on all continents.

There are many different definitions of estuaries, proceeding from ways of origin of the hydrological, chemical and biological characteristics, and their spatio-temporal distribution in varieties of climatological and geographical areas (Cronin, 1975; Kennedy, 1982, 1983, Ketchum, 1983), etc... However, the one thing they have in common is that their past, present and future environment depends first upon the amount of fresh water discharged into the estuarine water body (GOIN, 1972; Rozengurt, 1969, 1974; Kalke, 1981; Bundy, 1981; Goodyear, 1985; Screslet, 1986) and the stochastic nature of runoff variables, and second, on the stochastic-periodic nature of water and salt exchange between estuary and the sea by tidal or wind action. From this point of view, the ecological definition of estuaries may be determined as follows: the estuaries are the intermediate complex link within the river-delta-sea ecosystem where continual variable confluence, interaction and mixing processes between river flow and seawater inputs take place (Pritchard, 1952, 1967; Schubel and Pritchard, 1972) that result in developing specific mixed water masses and, related to them, spatio-temporal distribution of their regime and biochemical characteristics (Olausson and Cato, 1980) and biological properties of limited diversities of estuarine organisms providing their unique biological productivities.

Thus, the major controlling factors of peculiarities of brackish water regimes of estuaries are the volume of fresh and saltwater inputs, participating in water and salt exchange between a river and sea (Rozengurt and Haydock, 1981; Rozengurt, 1983).

At the same time, they are the moving forces of this exchange as well as tides and wind (for non-tidal estuaries-river inflow and wind) which are responsible for development of specific circulation patterns in and out of ecosystems.

The interaction between controlling factors and moving forces of estuarine water masses is responsible for the intensity of advection, mixing and spatio-temporal distribution of any estuarine hydrological and biological characteristics around the optimal level for survival of their specific biota.

The seasonal complexity of physical and biochemical processes going on in the Delta as well as in the fluvial discharges affect the estuarine regime not over the course of decades and centuries, but in the process itself. At the same time, all the changes taking place the river watershed and the adjacent shelf zone affect the estuarine regime. For example, one unit of fresh water added to as many as one hundred units of salt water produces a mixture which still is lighter in specific weight than the ocean water, and consequently, tends to spread over the surface. Thus, the river sets in motion an amount of estuarine water which is many times greater than that of the river itself (Proudman, 1967; Bowden, 1967, Officer, 1976).

Each estuary is characterized by its own circulation patterns in space and time which depend upon the combined effect of hydrophysical and meteorological forces (Tolmazin, 1985), as well as morphometric characteristics of an estuarine basin (depth, length, width, channels, estuarine bed, distance from the ocean [sea] coastal zone, type of straits, etc.).

Their surface, intermediate (transition) and deep layers physical (temperature, density, turbidity, transparency, currents, internal waves, vertical stability, etc.) and chemical (salinity, pH, oxygen, alkalinity, organic and inorganic matter, etc.) characteristics distribution differs from season-to-season and year-to-year (Lauff, 1967; Skinner, 1962; Sutcliffe, 1973; Sutcliffe et al., 1977; Kjelson et al., 1981; Mann, 1982).

River discharges, tide oscillations and wind effect in different ways the vertical and horizontal mixing processes and water and salt exchange between an estuary and an adjacent coastal zone (Fisher et al., 1979). This, in turn, determines the majority of the characteristics of estuarine water masses, which make them unique, but vulnerable to external disturbances, individuals.

The frictional drag produced by fresh and salty water layers moving in opposite directions is associated not only with intensive mixing, but also affects salty estuarine deep waters through entraining (dragged along) processes moving in the direction of freshwater discharges.

This mixed estuarine water in the ratio 1:10 or much more (one part of fresh water, ten parts of mixed waters) is carried away by the river discharges, augmented in the case of the ebb, toward the strait and beyond it, and replaced by water from the intermediate and deep layers of an estuary. As a result of this salt water uplift, the salinity of estuarine surface water increases in a seaward direction as well as salinity (density) and temperature gradients accompanied by many other physical, chemical and biological changes in estuarine regime characteristics.

Here, on a day-to-day basis, water and salt exchange through the Golden Gate between the Bay and Ocean may be markedly altered by tidal action which carries back and forth during each tidal cycle a portion of mixed estuarine water previously discharged to the adjacent coastal zone. That is why the tidal-prism (the differences between the volumes in an estuary at the highest and low tides) concept which states that tidal-prism can provide dilution and removal of waste from an estuary regardless of river discharges and is one of the most erroneous underestimations of the role of runoff in the maintenance of estuarine water quality.

If one follows the logic of this concept, the conclusion reached is that during 8-10 tidal cycles, the entire volume of San Francisco bay will be recycled and filled with new, clean ocean water (including the Delta). This assumption was proven to be grossly in error by Sverdrup et al, 1942, and later by Ketchum (1950, 1951) and Tyler (1950) as well as many other oceanographers. The fundamental finding made by Ketchum states that the element of mixing volume is bounded by the length of the tidal excursion. The tidal excursion in the San Francisco Bay is about 10 km (Conomos, 1979). This implies that only one tenth or even less of a tidal prism participates in the renewal of the Bay water, while the role of runoff on recycling estuarine water masses is two orders of magnitude higher.

When there is a strong flood, the fresh water gushes forth from the Golden Gate Strait and forms a vast zone of fresh or brackish water at the surface out to the Farallon Islands and 5-20 miles in width along the shoreline to the north and south of the strait. The strong demarcation line, called the hydrofront, distinguishes this surface water body which is brownish-gray in color, from the adjoining coastal ocean water. This turbid water may stay in the area beyond the strait for days and weeks until a recess of the flood takes place. The tide oscillations move this water body landward and seaward during each tidal cycle, providing vertical mixing and dilution of surface layers. The wind stress superimposed on the tide will speed up these processes.

SAN FRANCISCO BAY AND DELTA: THE ECOSYSTEM

The San Francisco Bay and ecosystem (Hedgpeth, 1975, 1983) is a complex of interconnected and interdependent components consisting of the Sacramento and San Joaquin Rivers and their joint Delta with sloughs, channels and marshes and several bays, the Suisun, San Pablo, Central and South San Francisco Bays, Carquinez Strait between Suisun and San Pablo Bays, and the adjacent coastal region outside the Golden Gate (Fig. I.1). The basic statistics for the Bay are presented by Conomos (1979) as follows (Table I.1):

Table I.1 Geostatistics of San Francisco Bay

Statistic	Value
Area (MLLW)	1.04×10^9 m^2
Including mudflats	1.24×10^9 m^2
Volume	6.66×10^9 m^3
Tidal prism	1.59×10^9 m^3
Average depth	6.1 m
Median depth	2 m
River discharge (annual)	20.9×10^9 m^3
Delta outflow	19.0×10^9 m^3
All other streams	1.9×10^9 m^3

The key component of this system is the region between Chipps Island and Carquinez Strait. In the scheme of estuarine classification, this is known as a partially mixed or "Type II" estuary (Fig. I.2). Mixing in this region is primarily a function of freshwater flow interacting with saline tidal waters (Fig. I.3). In contrast to this is the South San Francisco Bay which is much larger, but also shallower, in which exchange is accomplished by the flushing action of winter storms, and is usually of higher salinity. This type of exchange is characteristic of coastal bodies of water that lack a steady, perennial influx of river water. Such environments are known as lagoons.

Although San Francisco Bay is the largest estuary system on the western coast of the United States, its principal tributary, the Sacramento River, ranks about ninth in terms of annual flow of the major North American rivers, far behind the Columbia and several Canadian rivers.

Despite this modest standing, the Sacramento may have been a great river for a brief time in the winter of 1862, when a millennial downpour produced a flow as great as the Amazon, pouring through the Golden Gate in such volume that it even held back the tide (see Peterson et al., 1985). The watershed of San Francisco Bay is 163,000 square kilometers, and drains 40% of the total land area of California (Fig. I.4). In the north, this basin is drained by the Sacramento River and its tributaries (Feather, Yuba, Bear and American, which contribute 80% of Delta inflow), in the south by the San Joaquin River system (Merced, Tuolumne and Stanislaus, 15% of Delta inflow). The remaining 5% of Delta inflow is contributed by east-side streams (Mokelumne and Calaveras).

THE DELTA

The Delta is defined in Section 12220 of the California Water Code (Fig. I. 5) as a roughly triangular area extending from Chipps Island (near Pittsburg) on the west, to Sacramento on the north and to the Vernalis gauging station on the south (about 10 miles southeast of Tracy). The total area is about 738,000 acres (more than 1150 square miles), and the surface area of the Delta water area is over 75 square miles (approximately 48,000 acres) and contains approximately 700 miles of waterways, over 550 miles of which are navigable, some with channel depths of 50 to 60 feet. Although the mean tidal prism (the water between mean lower-low and mean higher-high tide) is approximately 1.3 million acre feet with present imports.

Before 1850, the Delta was a tidal marsh of approximately 400,000 acres surrounded by a 2-300,000-acre area of slightly higher elevation (ranging from sea level to 10-15 feet above it). Sacramento and San Joaquin River runoff, swelled by winter rains (from the Central Valley) and spring snow melt (from the Sierra Nevada and Coast ranges), created a vast inland lake. This water also brought nutrient-rich sediments which were deposited on Delta lowlands, creating natural levees separating flowing channels from marsh areas. This highly productive area was covered with dense tules, willows and cottonwoods which served as habitat for more than 250 species of birds and mammals (notably the tule elk), and surrounded by nutrient-laden water, rich in fish and invertebrates (California Department of Fish and Game/U.S. Fish and Wildlife Service, 1980).

The Federal Swamp and Overflow Act of 1850 transferred title of Delta lands to the State of California and, at prices as low as $1.00 per acre, reclamation began. One hundred thousand acres had been reclaimed by 1880; 250,000 acres (approximately one half the Delta) by 1900; and by 1930, about 450,000 acres (60 major islands) had been created. The various streams and rivers that flow into and through the Delta drain a 61,200-square mile watershed which carries 40-50% of the natural runoff of all of California (California Department of Fish and Game/U.S. Fish and Wildlife Service , 1980).

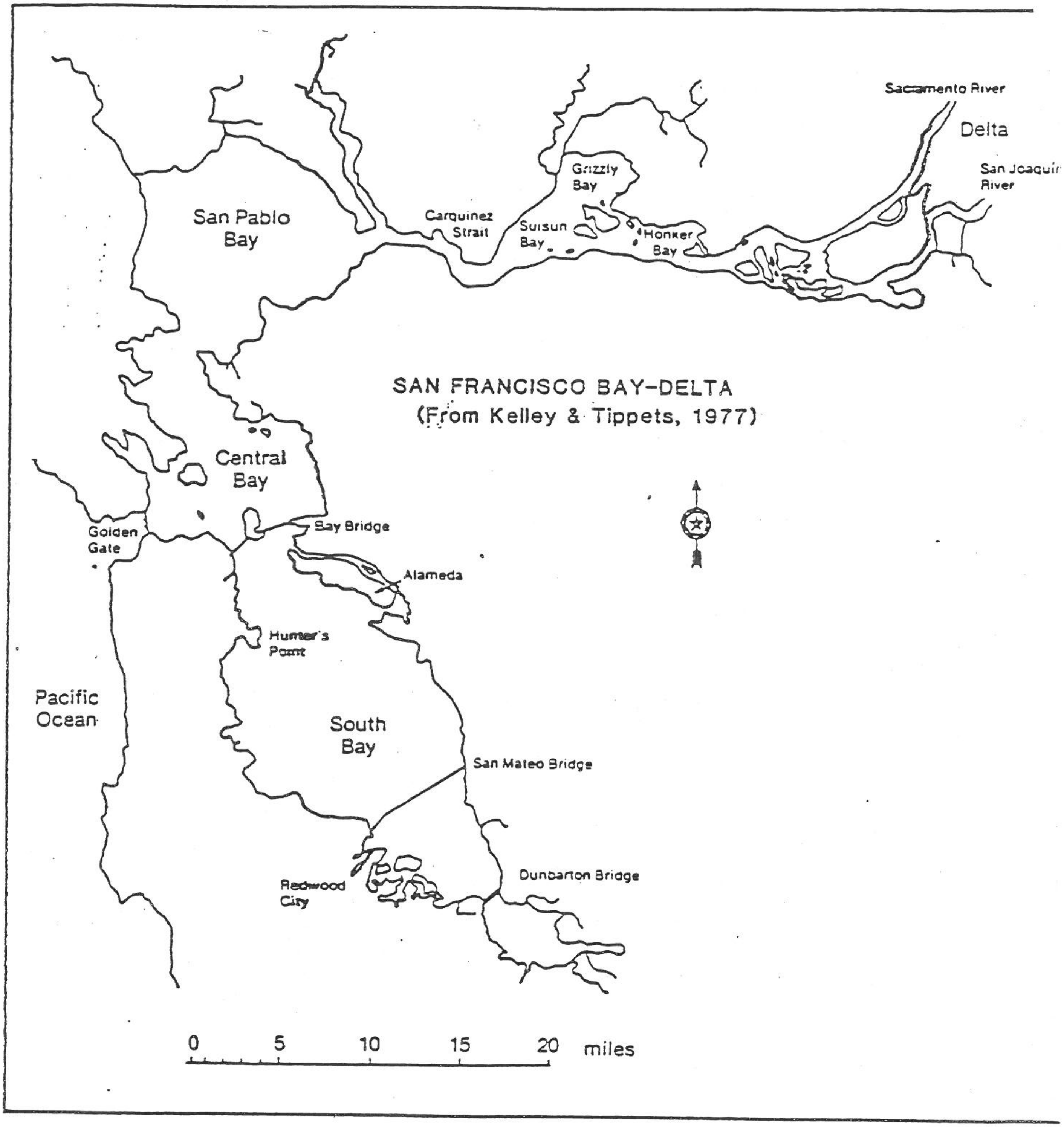


Fig. I.1 San Francisco Bay and Delta (From Kelley and Tippets, 1977)

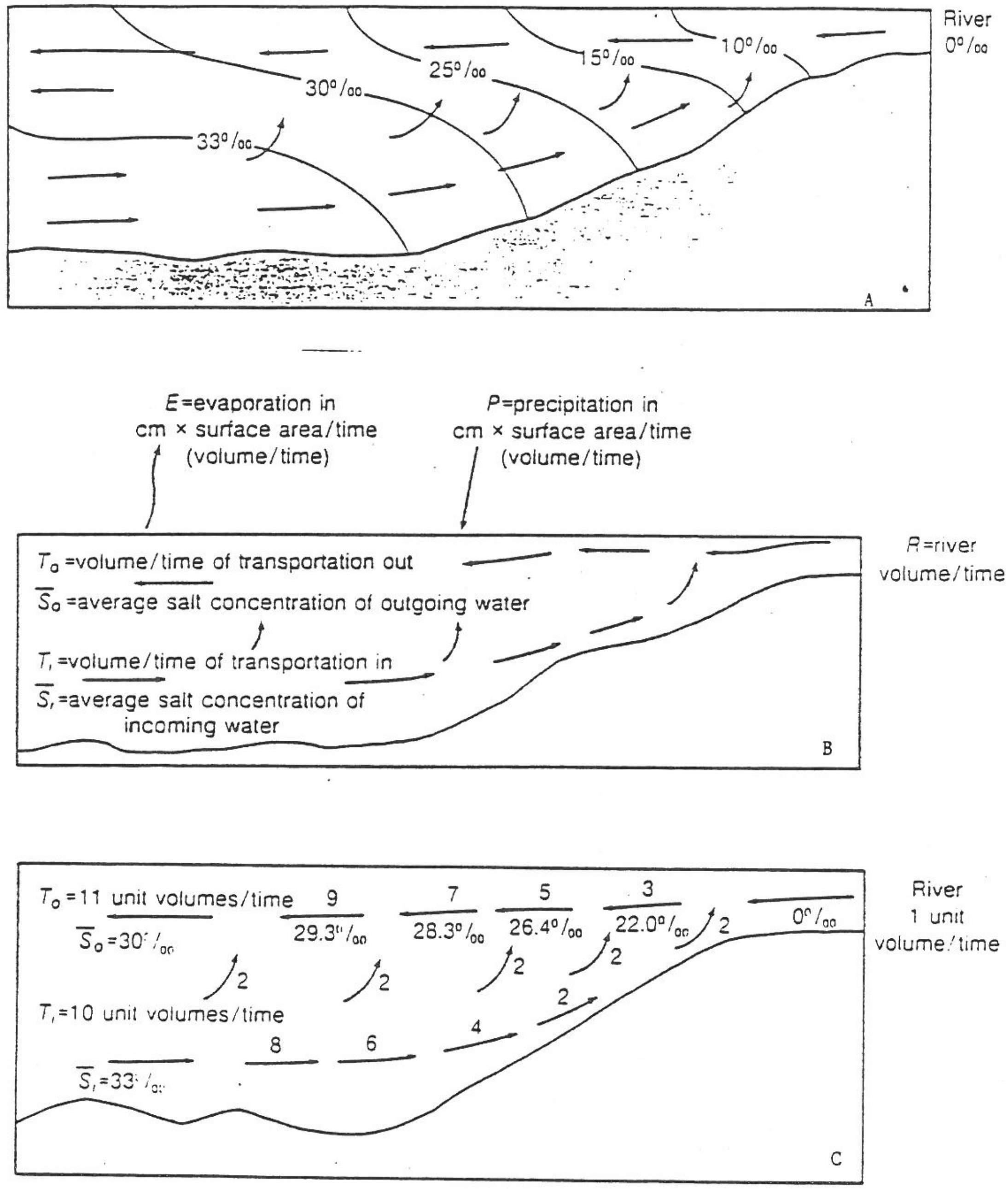


Fig. I.2 Salinity and mixing profiles in a partially mixed estuary (Type II), characteristic of the estuarine reach of San Francisco Bay from Chipps Island to Benicia. A: Sea water enters at depth with the tide, mixed water flows seaward at the surface. Seaward surface flow is larger than river flow alone. B: Water and salt enter and exit. C: The proportionate increase of flow volume. Upward mixing due to tidal turbulence is indicated by arrows in middle. For every two units of seawater mixed upward, the inflow decreases by the same two units. (From Duxbury and Duxbury, 1984, with permission.)

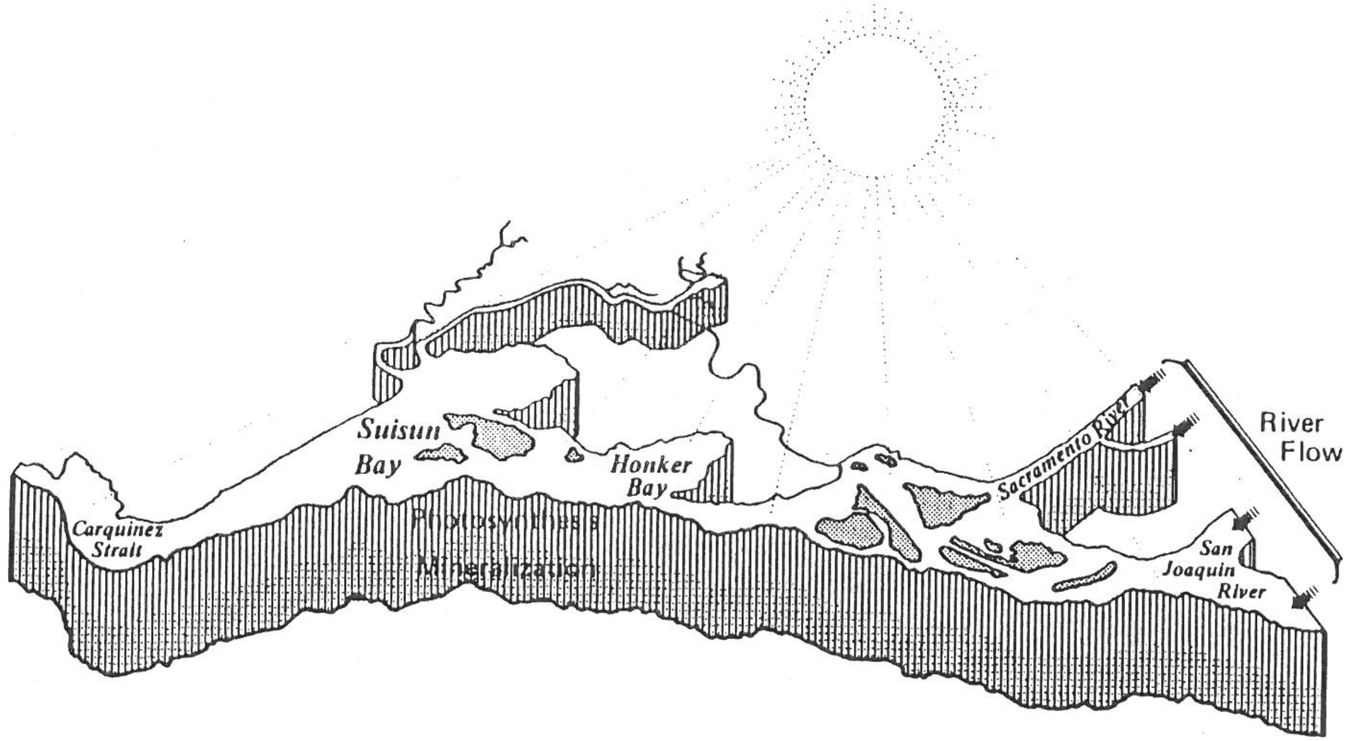


Fig. I.3 A simplified illustration of an estuary with an embayment (Suisun Bay), depicting light-driven photosynthesis near the surface and mineralization near the bottom. Sea salt typically penetrates into the Sacramento River during low river flows (summer), but only into Carquinez Strait during very high river flows (winter). (From Peterson et al., 1985)

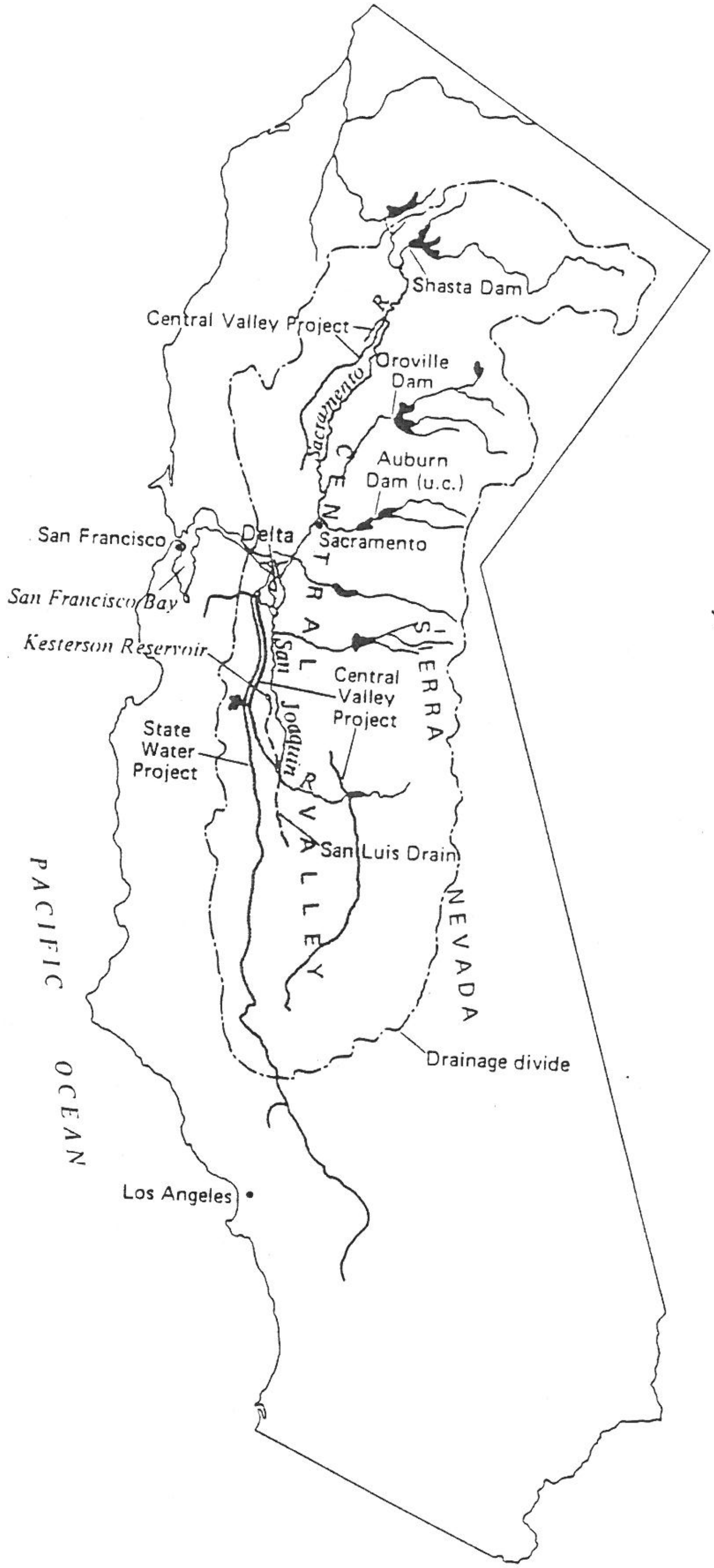


Fig. I.4 The Watershed of San Francisco Bay

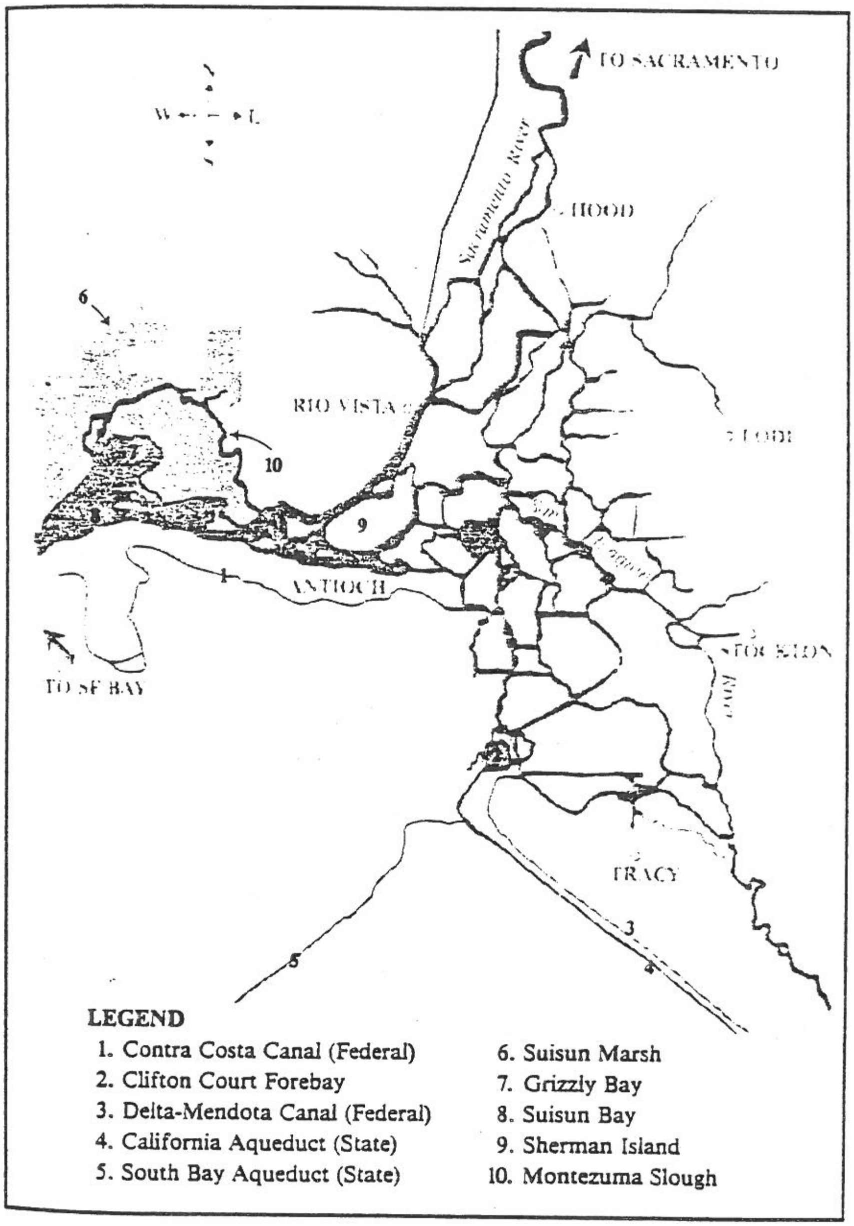


Fig. I.5 The Delta. (taken from Dennis, 1981)

THE BAYS

San Francisco Bay consists of two reaches which can be characterized separately both geographically and hydrodynamically (see Fig. I.1). The northern reach begins with Suisun Bay and extends westward through Carquinez Strait into San Pablo Bay; the southern includes the Central and South Bays. They join in the Central Bay near the Golden Gate, where they connect with the coastal zone of the Pacific Ocean. The northern reach or arm receives 90% of the total freshwater inflow to the Bay (from the Sacramento and San Joaquin River basin) and the remaining 10% of the fresh water entering the estuary is contributed to the southern arm primarily from local runoff which is insufficient to produce adequate circulation and mixing. Each of these separate components has unique hydrodynamic properties (Conomos, 1979, Cloern and Nichols, 1985) that reflect the interaction of topographic features, circulation and mixing in response to freshwater, sediment, and nutrient inflow, wind, tides, salinity, temperature and oxygen content (see Table I.2).

Table I.2 Hydrodynamic Properties of S.F. Bay Segments (After Rozengurt and Haydock, 1981)

	Area	Volume	Salinity Range (g/l)	
Segment	Km^2	Km^3	Historic	Present
San Francisco Bay	$1.14x10^3$	8.34		
Delta	159	1.57	0.01-1.8	0.5- 3
Suisun Bay	150	0.50	0.01-2.0	1.0-14
Carquinez Strait	14	0.23	0.10-2.5	1.0-20
San Pablo Bay	296	1.05		10.0-30
North S.F. Bay	230	3.39		15.0-33
South S.F. Bay	291	1.60		10.0-32

In all estuarine systems, the most important part is that where the incoming fresh water with its load of terrigenous sediments and nutrients interacts with the more saline waters from the sea, where a zone of "no net motion" is developed between the interacting waters, resulting in the concentration of nutrients, the settling of sediments and the maximum upstream creep of sea-derived minerals along the bottom from the sea and lower reaches of the estuary by tidal action. This is where the estuary is richest in plankton production (Cronin, 1975), where many euryhaline species of fish thrive as juveniles. This region is known as the "null zone", the "entrapment zone" or region of "maximum turbidity", where the action results in what has also been called the "nutrient trap" (Massmann, 1963; Peterson, et al., 1975 a,b; California Department of Fish and Game, 1980) In the San Francisco Bay system, this region is between Chipps Island and Benicia. Its most intense activity moves up and down the region with the seasonal changes in river flow and tidal intensity.

The surface salinity conditions in this zone have been described by Cheng (1986).

Although all of these factors play important roles in the functioning of the San Francisco Bay estuary, they are beyond the scope of the present report which places its primary emphasis on runoff changes which have occurred over the past sixty years as a result of California water management.

URBANIZATION OF THE DELTA/BAY SYSTEM

Over the past century, the San Francisco Bay system has become an example of an "urbanized" estuary. It has been surrounded by 5 million people. Over one third of its area (including 95% of its wetlands) has been filled for airports, homes and garbage dumps. More than 60% of the fresh water that once served as a barrier to salt intrusion and that provided nutrients, sediment, and flushing has been diverted from the system.

A number of symptoms of serious deterioration have resulted from this stress to the once-resilient Delta-Bay estuarine system (Rozengurt, Herz and Josselyn, 1987):

1) 75-80% reduction in populations of anadromous fishes (striped bass, salmon) over the past 30 years (Kjelson, et al., 1982)

2) 100% increase in residence times for pollutants since the completion of the Central Valley and State Water Projects,

3) Increased salt intrusion into the Delta (Orlob, 1977).

4) 60-70% reduction in sediment load to the Delta-Bay ecosystem (Krone, 1979).

Despite the more than $2 billion spent over the past twenty-five years on the evaluation and management of this ecosystem, the basic understanding necessary to preserve its health has not been achieved. Without a clear picture of the complex factors which influence Delta and Bay living resources and water quality, management decisions have been unable to reverse the decline of resources (Moyle, 1976; McHugh, 1976).

Although the system has been modified in a variety of ways, many experts agree about the importance of water diversions. "The most fundamental change which has occurred is a reduction in total freshwater outflow" (Chadwick, 1981, page 215). The research conducted at the Romberg Tiburon Center over the past three years was designed to provide in-depth evaluation of freshwater inflow to the Delta and Bay, the manner in which flow has been modified since the early part of this century (especially during the period following the completion of the major components of the Central Valley Project (CVP) and State Water Project (SWP) (Dennis, 1981), and to assess the impacts of flow modification on the salinity regime and living resources of the system.

This report, which is one of a series, is based upon descriptive statistical analysis of flow data collected by the Department of Water Resources (DWR) and Bureau of Reclamation (BR). It focuses on the 1921-78 period (although it also considers more recent information, when available) because it is designated as the "period of record" by the principal water agencies and is the focus of the State Water Resources Control Board's Bay/Delta (Decision 1485) hearings.

The report first analyzes the natural flow characteristics of the system and their variability in order to estimate the role of upstream and Delta diversion on runoff patterns. The amounts (and proportions) of water diverted from both the up- and downstream portions of the watershed during the 1921-78 period are analyzed by month, season and year (hydrologic, not calendar year). The report also presents this information in terms of running averages for 5-year periods in order to display longer term trends and to minimize the influence of year-to-year variations. Deviations are calculated for both natural and regulated outflows from mean natural flow for the period of record to better characterize the manner in which regulation has influenced natural flow patterns.

In order to better understand both the quantitative and qualitative changes brought about by physical modification of the system and artificial regulation of its water supply, the report compares various pre- and post-CVP/SWP flow characteristics and describes representative pre- and post-project wet, dry and normal year flows and diversions. To further illustrate the impacts of regulation on Delta and Bay water availability, probabilities of occurrence and recurrence intervals are presented for various pre- and post-project flow events.

The report also discusses various procedures for analyzing the cyclicity of runoff variability and the bases for past and present water-year-type classification systems. In order to illustrate the universality of the runoff characteristics of the Delta/Bay estuary, comparative data are presented for a variety of other river basin systems.

Although the report contains a significant amount of technical analysis designed to be of interest and value to hydrologists and water engineers, wherever possible, an attempt has been made to present various data and concepts in as simple a manner as possible to enable readers without extensive technical backgrounds to follow the discussion and data presentation. Since much of the information presented is graphic and tabular in form, frequent references to figures and tables should aid comprehension.

I.2 Methods and Procedures for Statistical Analysis of Sacramento-San Joaquin River Flow

I.2.1 Freshwater Balance

General Remarks

Our analysis will concern the management of the combined flows of the Sacramento-San Joaquin Rivers, which by and large are continuously renewed in the process of the water cycle. According to L'Vovich (1974) the volume of streamflow, which is replenished in the process of the water cycle, exceeds by thirty-fold or more the stationary reserves in river beds unless the water cycle is disrupted by man-induced runoff transformation. The water storages for power plants and irrigation control the most significant portion of the water supply for the purposes of creating optimum energy output and enhancing soil fertility. This approach to the development of water resources makes it possible to multiply the surface water whose suitability for use without regulation is limited (Smith, 1979). Therefore, its accumulation and seasonal redistribution among the various uses is advantageous to man's perceived needs. However, there are natural limitations in the water supply such as snowmelt and rainfall, climatological zoning and size of the watershed which should be taken into consideration when planning water diversions from the river basins in question (Vorovich, et al., 1981).

There has been much world-wide evidence over the last several decades of the importance of foreseeing the entire range of consequences of those transformations, usually a very complicated matter, especially when we are dealing with rivers emptying into estuaries or seas. Forecasting such consequences requires a thorough knowledge of the runoff cyclicity (i.e., alternation of phases of wetness) and the river-estuary interaction with the other components of the ecosystem (Lauff, 1967; Schubel, 1971; Officer, 1976; Hedgpeth, 1977; Kennedy, 1982, 1984; Ketchum, 1983). It also requires a knowledge of the natural and regulated behavior of seasonal runoff variables in light of their multi-purpose uses and conservation (Zhelesnikov et al., 1984).

Present-day specialists in water management are usually concerned with some specific water-related industry: hydroelectric power, drainage and irrigation, water supply (Hjelmfelt and Cassidy, 1975), or waterway navigation rather than the fisheries, recreational uses and water quality, etc. of estuarine systems.

However, since water is a kind of raw material important to all water users, it is important to analyze all hydrological and geophysical aspects of water development as well as the ecological consequences (Vendrov, 1970; White, 1977).

The lack of understanding of the complexity of the interrelation between the riverine-estuarine systems has resulted in deterioration of these systems as well as inland seas (Rozengurt, 1974; Hedgpeth, 1977; Komarov, 1980; Aleem, 1972; Bronfman, 1977; Hedgpeth and Rozengurt, 1987).

The current conditions in many estuaries support the statement that continuation of excessive use of water resources will inevitably cause the destruction of many estuarine complexes (Rozengurt and Herz, 1981; Rozengurt, 1983) reducing their ability to balance man's needs for water with the health of their living resources (Baidin, 1980; Volovic, 1986).

If we are to avert the destruction of these ecosystems, we must change our attitude that freshwater runoff is an inexhaustible gift of nature and bring our needs for water in line with the spatial and statistically-valid temporal availability of water resources. In California, there is a discrepancy: water needs in the south exceed the natural capacity of the Sacramento-San Joaquin Rivers system.

It is not uncommon to hear that the water problem can be solved by adopting some particular measures (SWRCB, 1978), like diversion of water from a region that has a surplus to a region with a deficit, or increasing the number of small storage facilities, or transforming the upper Delta in plumbing facilities or enlarging the capacity of existing storages, barriers, etc. There is nothing new in these measures themselves if their merit is kept within the optimal range of the natural water supply which would be able to provide and maintain a set of hydrological and biological standards and criteria adequate to preserve the environmental quality of the riverine-estuarine system.

There have been many forecasts in recent years based on the simple linear extrapolation of quantitative consumption of water resources in the past projected several decades ahead (up to the year 2040). This approach produces unreliable results the uncertainty of which increases as the period of the forecast is lengthened (L'Vovich, 1974; Vendrov, 1979; White, 1976). It is a known fact that as the length of a forecast increases, up to 2-3 decades, its reliability sharply decreases (Vorovich et al., 1981).

The sizable hydrological data for the Sacramento-San Joaquin Rivers necessitates that we pay exceptionally close attention to the methods of obtaining adequate characteristics of runoff which are unavoidable in studying the water balance of the estuary. The method set forth in the report is a key for obtaining information on how and in what degree man's activities transformed the Sacramento-San Joaquin water supply.

A sound inventory of water resources is possible only on the basis of a study of variability of the natural and regulated (Kisiel, 1969; Chow, 1964, 1978; Chebotarev, 1975; Hjelmfelt and Cassidy, 1975; Haan, 1977) water balance due to the fact that regulation of water resources inevitably has an effect on the condition of the other links of the estuarine system. For example, retention of surface runoff in storages in order to increase the specific yield will reduce streamflow and increase the residence time of water masses of riverine-estuarine systems; salt intrusion and salinization of deltas, pollution of estuaries and intensive use of groundwater may, in many cases, bring about a reduction of the subterranean feeding of rivers and consequently of the resources for stable streamflow.

It has long been known in hydrology that runoff consists of two genetically different parts: surface runoff which makes up the peak flow, and groundwater drained by the rivers. But surface runoff and groundwater runoff, taken together with atmospheric precipitation, which engenders all the fresh water of the land area, are not the only elements of an area's water balance.

The system of equations of an area's water balance for computing the water balance is written as follows (L'vovich, 1969):

$$P = S + U + E; \quad S + U = R; \; W = P - S = U + E;$$

$$K_U = U/W; \quad K_E = 1 - K_E = E/W$$

in which P = precipitation,
S = surface (flood) streamflow,
U = underground flow into rivers (the stable part of streamflow),
E = evapotranspiration,
R = total runoff,
W = total wetting of the area,

K_U and K_E = groundwater runoff and evaporation coefficients, respectively, which show what parts of annual infiltration go to groundwater runoff and evapotranspiration.

This system of equations is in line with present ideas concerning formation of an area's water balance.

Meanwhile, in a less complicated form, the water balance of river basins or areas of whatever source have been studied since the end of the last century by means of the equation (Sokolov and Chapman, 1974):

$$R = P - E$$

This equation does not include the soil link in the water balance, nor does it include the groundwater and surface components of runoff.

However, this equation is used rather frequently to determine runoff from precipitation and evapotranspiration computed by different methods and to illustrate differences between the normal and modified balance of any particular year or seasons when change in water storage in the river has taken place.

When natural runoff manages to reach the Delta, it is losing a small volume of its water on inner Delta consumptive natural use (evapotranspiration of about 1-3.0% of the mean annual flow). Then, the river inflow to the Delta enriched by organic and inorganic matter produced by the Delta, discharges its water to an estuary. It is then referred to as Delta outflow, the regime behavior of which is very important in the formation of hydrophysical structure and spatio-temporal variability of estuarine regime characteristics. The stage of dynamic equilibrium of any type of estuary for mean sea level can be described by the simplified equations (Bowden, 1967; Proudman, 1967; Pritchard, 1967):

where $$W_1 S_1 = W_2 S_2$$

$$W_1 = P+Q-E+W_2$$

$$N = P+Q-E$$

or $$W_1 = N + W_2$$

and $$S_1 = \frac{W_2 S_2}{N + W_2}$$

$$S_E = f(S_r, S_1, S_2)$$

Where: P = precipitation; Q = runoff; E = evaporation; N = total freshwater volume of an estuary; W_1 = the estuarine "buffer" outflow; and W_2 = the ocean inflow; S_1 and S_2 = the salinity of the estuarine outflow and ocean inflow, respectively, participating in the water and salt exchange between an estuary and adjacent ocean coastal zone; S_E = salinity of estuary; S_r = salinity of runoff from the Delta.

From the equation it is obvious that if Q was less than E-P (E>P), then N will be negative, i.e., there will be a deficit in freshwater supply. Consequently, to maintain the condition of continuity, $W_1 S_1 = W_2 S_2$, salinity of an estuarine outflow has to be equal to the salinity of adjacent coastal zone water S_2 (in the case of San Francisco Bay, the S_1 would be equal to 33 g/l, or even slightly more, because evaporation from the bay surface is almost three times higher than precipitation); $W_1 = W_2$.

Meanwhile, inasmuch as S_E depends on freshwater discharges (Q) and intimately relates to S_r, S_1 and S_2, then substantial runoff reduction will result to increase S_E during some period time, measured by 'n' years.

However, in the case in which diversion has already begun, the new equations for S_1* and S_E* will be needed to evaluate a cumulative component of the increase of salinity in the estuary:

$$S_1^* \Big|_{i=1}^{n} = S_{1\,n-1}^* \pm \Delta S_1^* \Big|_{i=1}^{n}$$

$$S_E^* \Big|_{i=1}^{n} = S_{E\,n-1}^* \pm \Delta S_E^* \Big|_{i=1}^{n}$$

Where 'n' = the number of years during which salt accumulation in the Delta-Bay ecosystem takes place. Where ΔS_1* and ΔS_2* are a cumulative component of salt intrusion for $i = 1, 2, 3....n$ years.

This scheme obscures some features of an exceedingly complex process of salinization of estuaries, but it outlines the following major regularities (Bronfman, 1977; Rozengurt, 1969, 1974, 1983):

a. The reduction of runoff leads to a gradual increase of salinity in every part of the estuary and renewal time of its water bodies.

b. The cumulative effect of salt intrusion into the estuary and Delta described by $\pm\Delta S$ will fluctuate until diversion takes place.

c. The increases in salinity in every part of the estuary will continue until $\Delta S=0$, i.e., if diversion has been stopped by a given year, then the new salinity of the estuary S_E* will reach its dynamic equilibrium within a given period of time (n years), though $S_E* > S_E$.

d. However, if diversion starts to increase, the whole process of salt pollution will repeat itself again until a new level of salt balance is reached, i.e., $W_1* S_1* = W_2* S_2*$.

Such processes of salt pollution of estuaries have been observed and documented in many different areas where large-scale artificial disruption of seasonal and annual flow occurs. It should be noted that an increase in salinity concentration results in the creation of a very strong interface and increase in the vertical stability of the water volume that reduces the efficacy of entraining and mixing strength of regulated freshwater discharges (Volovic, 1986).

Therefore, the entire estuarine ecosystem adheres to a certain range of flow fluctuations which determines the variations of physical parameters and their complicated interactions with biological features of estuarine ecosystems which may or may not be linear. It may explain the fact that most estuarine characteristics are determined by exceptionally slow cumulative changes in seasonal and annual values resulting from many years of runoff that maintain the dynamic equilibrium of the ecosystem and provide the optimum level for population survival.

I.2.1.1 Procedures for Statistical Analysis of Sacramento-San Joaquin River Flow

General Remarks

In order to analyze the natural historical past and present behavior of natural and regulated runoff variables and the possible effect of man-induced environmental impacts on the riverine-estuarine system, the methods of a descriptive statistical analysis were used. Their effective use is based on fulfillment of the following three major requirements:

1. Appropriate statistical computation of annual and seasonal characteristics of runoff for a period of observation of not less than 50-60 years of the natural regime, i.e., at a representative database;

2. Critical analysis of the obtained results in comparison with similar developments in other river basins;

3. Objective estimation of documented "cause-effect" changes in hydrological and biological properties of the riverine-estuarine system in connection with natural and man-induced factors.

The conditions in number 3 would be best performed if one attempted to rank, in descending order, the importance of the causes and consequences.

For example, what is more important to the spawning success of striped bass: to have more water in spring, or at the end of summer and in the autumn; to halt the Delta pumping stations or to increase upstream water withdrawals. Could the returning water discharges to the Delta improve the water quality if 60-85% of the total spring runoff were diverted from the system?

The hydrological phenomena of the Sacramento-San Joaquin River Delta-Bay ecosystem to be considered are:

1. The combined Sacramento-San Joaquin natural river inflow

(NRI) to the Delta.

2. The regulated combined river inflow (RRI) to the Delta.

3. The natural Delta outflow (NDO) to San Francisco Bay.

4. The regulated Delta outflow (RDO) to San Francisco Bay.

5. The combined intra-annual unimpaired inflow-Delta outflow to the Bay.

6. The combined intra-annual impaired inflow/Delta outflow to the Bay.

7. The perennial dynamics of monthly and annual upstream and downstream water withdrawals.

8. The 5-year running deviations of the normal water supply to the riverine-estuarine system (perennial annual and monthly).

9. The impact of diversion on the fishery of the river-Delta-estuary system.

10. The standard criteria for seasonal and annual river discharges to the Bay ecosystem.

By definition, the natural runoff (inflow/outflow) describes the unimpaired flow characteristics over the course of a river during the historical past.

Streamflow which has been subjected to strong modification due to water withdrawals for the operation of power plants and irrigation systems, industrial and municipal intakes, etc., is considered to be the regulated runoff in and out of the river-Delta system. Its annual and seasonal values are determined by natural factors as well as those brought about by man through operational diversions and releases (storage and conveyance systems, returning waters from agricultural fields, industrial and municipal intakes, etc.). It is known that these types of human activities have a pronounced effect on the range of fluctuations in hydrological, chemical and biological regime characteristics. That is why the long-term trends of their "cause-effect" changes might be effectively detected initially through studies of the unaltered values of flow. The latter are considered as random variables of stochastic origin (climatological and geophysical global and local factors) fitted for the statistical analysis on the basis of the distribution laws.

From that point of view, the regulated runoff no longer represents a homogeneous hydrological time series, but a database which has to be considered as a hydrological "mixture" of two regimes: deterministic, i.e., modified by intakes and releases, and stochastic.

The integral sum of those regimes results in formation of a regulated (impaired) river inflow/Delta outflow. The cumulative, gradual impact on the estuarine environment, as documented elsewhere, is strong enough to make it necessary to provide a quantitative comparison between natural and regulated water supply deviations if detection of the spatio-temporal changes in the runoff regime and their role on the riverine-estuarine environment is of concern (Rozengurt, 1969, 1974; Sutcliffe, 1973; Bronfman, 1977; Tolmazin, 1985).

This analysis of the annual and monthly natural variables of combined river inflow to the Delta and the Delta outflow to San Francisco Bay in comparison with their impaired characteristics helps us avoid the confusion that has resulted from considering the regulated Delta outflow, e.g., the "Delta Outflow Index," as the historic record of runoff, as it is considered in many reports and articles.

I.2.1.2 Database

1. The first precipitation records were made in the city of Sacramento in 1849.

2. The first hydrological station to maintain a flow record in California began in 1878 and was located at the mouth of the Sacramento River at Collinsville.

3. The first full-scale organized observation of inflow to the Delta started in 1919 (Sacramento River Basin, Bul. No. 26, 1931.)

Later, the number of hydrological and meteorological stations increased many times, and some of them were located at key positions where major water facilities were built between 1943-1967.

Runoff records between the 1870's and 1919 are not considered much of a database. It consists, partially, of direct measurements taken at gauging stations, located primarily in mountain and foothill areas, which are calculated by using the correlation between the index of wetness (precipitation) and, in some locations, known runoff. This procedure, the mass-curves method, may restore the missing records on adjacent streams.

Therefore, the monthly and annual runoff records obtained from 1871 to 1919 might be used for approximate estimates of historical runoff fluctuations.

Due to this fact, in our analysis we rely upon a verified, primarily gauged, time series database of annual and monthly runoff characteristics from 1921 to 1984 and published by the California Department of Water Resources.

Some parts of this material have been widely used by resources agencies, scientists and numerous private environmental investigators engaged in water planning and development in California as well as in setting forth the standards and criteria for the Delta-Suisun Bay ecosystem since 1965. In addition, some materials related to other river basins were used:

No.	Database	Period	Source
1	Natural (unimpaired) Sacramento-San Joaquin River Basin Inflow to the Delta (abbreviated in the Report as NRI)	1921-1983	California Central Valley Natural Flow Data, DWR Division of Planning, April 1980, 1983
2	Natural (unimpaired) combined Delta Outflow to San Francisco Bay (abbreviated in the Report as NDO)	1921-1983	..........."..............
3.	Regulated (residual) Sacramento-San Joaquin River Basin Inflow to the Delta (abbreviated in the Report as RRI)	1919-1931	Sacramento River Basin, Dept. of Public Works, Div. of Water Resources Bul. No. 26, 1931.
		1923-1958	Division of Irrigation and Power. Report of Operations, Region 2. Bureau of Reclamation, Dept. of the Interior, Sacramento, 1960.
		1955-1984	Dayflow Data, DWR, Central District, Sacramento, 1986
4.	Regulated (residual) combined Delta outflow to San Francisco Bay (abbreviated in the Report as RDO)	1922-1971	The DWR, Table-Historic Delta Outflow. Delta Outflow and San Francisco Bay, D.W. Kelley and W.E. Tippets, April 1977.
		1955-1984	Dayflow Data, DWR Central District, Sacramento, 1986
		1919-1931	Sacramento River Basin, Dept. of Public Works, Div. of Water Resources, Bul. No. 26, 1931. Sacramento.
			Economic Aspects of A Saltwater Barrier. Dept. of Public Works, Div. of Water Resources, Bul. No. 28, 1931. Sacramento.

5.	Computed fluctuations of precipitations;		The Metropolitan Water District of Southern California. Planning concepts used in determining the water supply available from the State Water Project Report No. 935, January 1979.
	Sacramento River area:		
	Redding	103 Years	
	Mt. Shasta	91 Years	
	Red Bluff	101 Years	
	Feather River Area:		
	Chico	108	
	Quincy	83	
	Yuba River Area:		
	Lake Spaulding	84	
	Nevada City	115	
	American River Area:		
	Colfax	109	
	Auburn	108	
	Rocklin	107	
	Placerville	99	
	Sacramento	129	

*Note (MWD): Rainfall years are recorded from July 1 through June 30 of the following year, whereas runoff years are recorded from October 1 through September 30 of the following year.

6.	Computed fluctuations of runoff of Four-River Index:		MWD, Report No. 935 January 1979
	Sacramento River, above Bridge near Red Bluff	1921-1978	
	Feather River, at Oroville Reservoir	"	
	Yuba River, at Smartville	"	
	American River, at Folsom Reservoir	"	
7.	Natural and regulated inflow to Chesapeake Bay:		U.S.G.S. Water Resources Data, Pennsylvania and Virginia
	Susquehanna River, at Harrisburg, PA	1891-1984	
	Potomac River, near Washington, DC	1931-1985	
	James River, at Cartersville, VA	1925-2985	
8.	Natural and regulated inflow to Delaware Bay:		U.S.G.S. Water Re-ources Data, Maryland and Delaware
	Delaware River, at Trenton, NJ	1913-1985	

9. Additional graphic material on runoff fluctuations since 1900 and later up to 1978 for <u>USSR</u>:	
Don and Kuban Rivers (Sea of Azov)	Rozengurt et al., 1987
Danube River (Black Sea)	Baydin, 1980
Volga River (Caspian Sea)	
Northern Dvina (Arctic Basin)	
The major eleven rivers of the Soviet Far East, including Amur River (Pacific Ocean)	Grigorkina, T. Ye., 1980
<u>USA</u>:	
Apalachicola River (Gulf of Mexico)	Meeter et al., 1979

I.2.2 Methods

To assess the interrelation of the discussed flow characteristics, the following statistical models and procedures were implemented:

1.

Number of Years	Q_i	K_i	K_i-1	$(K_i-1)^2$	$(K-1)^3$	Probability of Exceedence, % =
N						$\frac{m-0.3}{n+0.4} \cdot 100\%$

Where,

Q_i = annual (monthly) mean flow for a given year in descending order (MAF or cfs); and km^3/year or m^3/sec.

(One MAF = 1.233 x 10^6 km^3/year; One cfs = 0.028 m^3/sec; One km^3 = 1,000,000,000 m^3)

Q_N = annual (monthly) normal flow for N years,

K_i (modular coefficient) = $\frac{Q_i}{Q_N}$.

$K_i-1.0$ = deviation of modular coefficient of a given year from the normal, K = 1.0

Normal runoff, Q, calculated as an arithmetic mean from the series of observed values, is a statistical concept. Variations of runoff with time can therefore be fitted to statistical distributions and may be investigated by means of probability theory methods (Chow, 1964; Hjelmfelt and Cassidy, 1975; Haan, 1977; Yevjevich, 1976).

For statistical treatment it is essential to have homogeneous time series, i.e., the physiographic factors that affect runoff formation must not change during the period to be studied. The normal or mean annual runoff should be determined for a long observational period (50-60 years) which includes several wet and dry cycles of stream flow (Luchsheva, 1956, 1976; Hall and Dracup, 1970; Chow, 1964; Sokolov and Chapman, 1974).

The normal runoff is computed from:

$$\bar{Q}_N = \frac{\sum_{i=1}^{N} Q_i}{N}$$

where $\bar{Q}_N$ = the normal runoff and Q_i = the annual runoff in the i-th year of a long-term period of N-years, such that further extension of the series has only a slight effect on the value of $\bar{Q}_N$.

2.

$$C_v = \sqrt{\frac{\sum_{i}^{n}\{(K-1)\}^2}{n}}$$

C_v = the variation coefficient which characterizes the degree of fluctuations of annual (seasonal, others) runoff values around their mean.

The less C_v the more representative is the database. The value C_v depends upon $\bar{Q}$ inversely from the duration of observation.

3.

$$C_s = \frac{\sum_{i}^{n}\{(K-1)\}^3}{nC_v^{3}}$$

C_s = the skew coefficient which characterizes and measures the lack of symmetry (asymmetry) of data distribution. It is a very unstable coefficient, and, as such, it can be refined by different methods.

The normal runoff (Q), the variation coefficient (C_v), and the skew coefficient (C_s) are parameters of the distribution curve of annual (or seasonal, monthly and daily) runoff.

4.

$$\sigma_Q = \pm\sqrt{\frac{\sum_{i}^{n}\{(Q_1-\bar{Q})\}^2}{n-1}}$$

where $\frac{Q_i - \bar{Q}}{n - 1}$ = the mean deviation;

σ_Q = the standard deviation and is the measure of dispersion of a set of observed $Q_{i=N}$ relative to the normal $\bar{Q}$ and reliability of the latter.

The less the σ_Q, the more reliable Q_N.

Table I.3 presents the relative standard error of Q as a percentage, computed from:

$$\frac{\varepsilon}{Q_N} = \frac{C_v}{\sqrt{N}}$$

where "N" is the sample size (or the length of a time series) and C_v is the coefficient of variation, and   is the standard error, i.e.,

$$\varepsilon = \frac{\sigma}{\sqrt{N}}$$

Table I.3 Relative standard errors of mean values, depending on the number of observations (N) and the coefficient of variation (C_v), expressed as a percentage of the arithmetic mean for N observations)

	YEARS					
n / Cv	10	20	40	60	80	100
0.10	3.2	2.2	1.6	1.3	1.1	1.0
0.20	6.3	4.5	3.2	2.6	2.2	2.0
0.30	9.5	6.2	4.7	3.9	3.4	3.0
0.40	12.6	8.9	6.3	5.2	4.5	4.0
0.50	15.8	11.2	7.9	6.5	5.6	5.0
0.60	19.0	13.6	9.5	7.7	6.7	6.0
0.70	22.1	15.7	11.1	9.0	7.8	7.0
0.80	25.3	17.9	12.6	10.3	8.9	8.0
0.90	28.5	20.1	14.2	11.6	10.1	9.0
1.00	31.6	22.4	15.8	12.9	11.2	10.0
1.10	34.8	24.6	17.4	14.2	12.3	11.0
1.20	37.9	26.8	19.0	15.5	13.4	12.0
1.30	41.1	29.1	20.6	16.8	14.5	13.0
1.40	44.3	31.3	22.1	16.1	15.7	14.0
1.50	47.4	33.5	23.7	19.4	16.8	15.0

(From, Luchsheva, 1956; Klibashev and Goroshkov, 1970; Sokolov and Chapman, 1974.) The above statistical methods for evaluation of random errors are equally suitable for all components of the water balance which are obtained as arithmetic means of observed values. .pa

5. Probability of exceedence, P% (Chow, 1964; Hjelmfelt and Cassidy, 1975; Chebotarev, 1975; Yevjevich, 1976)

$$P = \frac{m-0.3}{N+0.4} * 100\%$$

Where P is the measure of chance or likelihood in percentage based on observed data for the period of n-years;

m = order number (1, 2, 3....m) of the analyzed value of runoff arranged in descending magnitude, i.e., m = 1 for the highest maximum, m = 2 for the next maximum, and so on, regardless of the year when data was sampled.

The "P" interprets a past record of runoff fluctuations in terms of future possible probabilities of exceedence, assuming that there will not be essential changes in climatological factors governing the occurrence of the years of different wetness. This method known as frequency analysis (and its plotted runoff frequency curve) is one of the important tools in applied hydrology dealing with storages, water quality, drought, floods, etc.

P% is a probability of exceedence (in percentage) of the corresponding runoff during some period of time in the past. In other words, if the probability of exceedance is equal to 1, 5, 10, 25 and 50% it will imply that the historical wet (wettest), critical wet, abnormal and close-to-normal (median) runoff of these probabilities occur at least once per:

$$N = \frac{100}{1};\quad \frac{100}{5};\quad \frac{100}{25};\quad \frac{100}{50}$$ Years, i.e., one and several more times per hundred, or 20, or 4, or 2 years.

Otherwise, if a probability of exceedance of runoff is equal to 75, 90, 95, 99 or 99.9%, it means that years of recurrence of the corresponding sub-normal and lower than sub-normal, dry and critical dry and drought years (months, etc.) runoff will be equal:

$$N = \frac{100}{100-75};\quad \frac{100}{100-90};\quad \frac{100}{100-95}\ \text{and}\ \frac{100}{100-99.9};$$ or 4, 10, 20 and 1000 years.

Runoff for a given probability can be computed from :

$$Q_{p\%} = K_{p\%} \times Q_N$$

These relatively rough estimations can be refined by the use of theoretical frequency curves (Figs. I.17 and II.16-21) prepared for the unimpaired annual and monthly runoff patterns. The rest of the information on natural and regulated runoff statistics are grouped in the Tables I.8, II.1, 11, 26, 27, Appendix 1-7.

The knowledge of the probability of exceedance and years of recurrence of the events, in our case, the natural river inflow/Delta outflow, gives specialists wide opportunities for obtaining statistically-valid information about behavior of runoff in time (and many other regime characteristics), regardless of origin.

It must be emphasized that, as a rule of thumb, it is impossible to pursue water development and allocation of water resources for different water users if a statistical evaluation of runoff behavior (daily, monthly and annual) is not performed. The construction, maintenance and operation of any water facilities, particularly dams, multi-purpose storages and water conveyance systems, levees, etc., rely entirely upon the probability of occurrence relative to definite values of runoff. At the same time, the living and non-living resources of riverine-estuarine systems, their favorable and tolerance limits for survival and reproduction also depend on a water supply of preferable probabilities (or frequency) discharged to the system (under a preferable probability of water supply, we mean the average runoff whose predominant annual and seasonal, say, spring, fluctuations have a pronounced range of $\pm$ 30% of the perennial mean calculated for the period of 50-60 years of observation. (This will be discussed in Part III.)

More to the point, the unimpaired flow frequency curves can be used as indispensable tools, acceptable in water engineering practices, in the evaluation of regulated flow characteristics and, indirectly, the estuarine environment.

In this case, the regulated runoff is considered in the same way as runoff observed under unimpaired flow conditions. That is not an improper assumption because natural annual and seasonal runoff fluctuations (with the exception of late summer-fall, when returning waters may mask the common regularities) are still much higher than the regulated values.

Therefore, in this report, we have used this approach to arrive at a statistically-valid evaluation of regulated runoff variables. It gave us an opportunity to show in a very simplified manner how water withdrawals (monthly and annual) managed to shift the probability of occurrence of years of natural runoff of the highest, normal and sub-normal wetness to the regulated runoff of years of low wetness, sub-normal, critical dry or even drought.

As one would expect, this replacement of wetness (which will be amplified later) has not brought about any improvement in water supply to the Delta-San Francisco Bay ecosystem.

In a statistical sense, such replacement means that under natural conditions, the majority of low-wetness years of current controlled runoff would have an insignificant frequency of occurrence and their appearance would be considered as rare phenomena.

The physical effect of this wetness alternation at present is a prolonged water deficit in the estuarine system (this will be amplified later).

6. Distribution and frequency histogram.

The monthly and annual (the same for 5-year running means) natural and regulated runoff variables (inflow/outflow) for Sacramento-San Joaquin River were grouped in class intervals to obtain a clear graphic description of temporal changes in unimpaired and impaired runoff distribution during the time between 1921 and 1983.

This histogram turns out to be useful in highlighting the case of the shifting of runoff statistics from one class interval to another for almost all months of the hydrological year.

7. In order to determine the general trends in the fluctuation of water supply to the system, running averages (for 3, 5, 7 and 11-year periods) of natural and regulated Delta outflow were calculated. This procedure is recommended to reduce the influence of short-term (year-to-year) variations in runoff resulting from extreme deviations in annual precipitation or snowmelt factors.

These methods permitted us to smooth out the impact of all fluctuations having the period less than 3, 5 or more years and, and at the same time, to determine the low frequency trend in monthly and annual runoff fluctuations under would-be (assumed) natural and current regulated flow conditions (Chow, 1964).

For example, our principal time series database consists of the 58 years, Q_1, Q_2, $Q_3 \ldots\ldots Q_{58}$; this succession of data may replaced by a new series consisting of the terms:

A: $$\frac{Q_1 + Q_2 + Q_3}{3}; \quad \frac{Q_2 + Q_3 + Q_4}{3} \ldots\ldots \quad \frac{Q_{56} + Q_{57} + Q_{58}}{3}$$

B: or $$\frac{Q_1 + Q_2 + Q_3 + Q_4}{5} \quad \ldots\ldots \frac{Q_{53} + Q_{54} + Q_{55} + Q_{56} + Q_{57}}{5}$$

and so on, which will be considerably smoother in terms of annual and monthly runoff fluctuations.

Therefore, gradual change of the variable over the whole period of investigation (1921-1978) depicts the trend which is the part of oscillations with periods long compared to the annual-to-annual record.

8. The resulting differences between natural Delta outflow (a stochastic process) and regulated Delta outflow (a deterministic-stochastic process dominated primarily by deterministic factors, e.g., diversions, withdrawals and releases) represent the quantitative trends of the consumptive use of the water in the upper (upstream diversions, above the Delta) part of the watershed and downstream (Delta and out-of-Delta diversions). These calculations were also performed for annual, seasonal (spring) and monthly flows in chronological order from the equations (Chebotarev and Klibashev, 1956;

Klibashev and Goroshko, 1970):

$$\Delta Q_{ups} = \int_0^t (Q_{NRE} - Q_{RRI})\ dt$$

$$\Delta Q_D = \int_0^t (Q_{NDO} - Q_{RDO})\ dt$$

$$\Delta Q_{total} = \int_0^t (\Delta Q_{ups} + \Delta Q_D)\ dt$$

In some cases it is not important to prove the periodicity of fluctuations. What is important is to determine the significance of non-random fluctuations. This is achieved with respect to white noise by adding up the deviations of the terms of the series (integral-difference curves) from normal with subsequent comparison of the actual accumulation of deviations with the accumulation obtained in a random incoherent series. In this case, one can explain the predominance not only of long fluctuations (from an anomalously large sum of anomalies) but also of relatively short fluctuations (or fluctuations of enhanced regularity) from an anomalously small accumulation of the sum of fluctuations.

9. In order to substantiate the statistical and regime validity of the basic period chosen for analysis of runoff variables, the trend of normalized cumulative modular coefficients (annual and monthly) was analyzed.

10. In order to obtain information on flow diversions and modified behavior of natural runoff variables during 1921-1978, we normalized the natural and regulated 3 and 5-year running mean monthly and annual mean runoff fluctuations by means of the following equation:

$$D\ \% = \frac{(Q_{i=5})}{Q_N} \times 100 - 100\%.$$

Where, D - the deviation in percentage of the $Q_{i=n}$ = the average for a given period, and Q_N - the normal runoff calculated as the perennial mean for the period of 1921-1978 for given months of the 58 years of record.

Therefore, the use of the normal (which corresponds to 100%, or 1.0 in parts) as the uniform basis for computing deviations regardless of absolute values of water withdrawals has made it possible to determine:

1. The scale of water supply changes brought about by upstream and downstream regulations of the combined Sacramento-San Joaquin River inflow to the Delta and the Delta outflow to the San Francisco Bay, for the pre-project (1921-1943) and the post-project (1944-1978) periods during different phases of natural wetness; and

2. The predominant rate of natural annual and seasonal 5-year running river water supply fluctuations. (The five-year period is considered the most adequate in an analysis of runoff and precipitation fluctuations; this will be discussed in Part III.)

This procedure has opened the way for assessing, with some approximation, the optimal limit of runoff regulation beyond which the river-Delta-Bay ecosystem regime characteristics may experience a great deal of negative transformation unseen or unknown under natural conditions.

11. Some special statistical analysis was performed for the combined Don and Kuban river flow to the Sea of Azov (USSR) as well as for the major rivers of the Chesapeake Bay (Susquehanna, James, Potomac) and Delaware River (Delaware Bay) to support the hypothesis that runoff of some large rivers emptying into the estuaries have pronounced and almost the same range of water supply deviations of the normal during cycles of wetness of 12-16 years and for running phases of the 5-years in the Northern Hemisphere. This phenomena is considered to be a universal aspect of the riverine-estuarine environment.

I.3 Runoff Cyclicity

Since for any given time period variations of runoff occur, one of the possible approaches for determining normal runoff is to average it over the longest possible period.

The pragmatic way of obtaining mutually-comparable series of runoff observations and comparable figures for normal runoff is to analyze the fluctuations. Taking Shnitnikov's (1968) basic idea that fluctuations in lake level are a good indication of fluctuations in runoff, A.V. Agupov (1960) adopted the following formula as an index that makes it possible to define cycles and to evaluate fluctuations of stream flow rates from deviations of modular runoff coefficients from the normal annual level as a running total:

$$A_n = \sum_{i=1}^{i=n} (K_i - 1)$$

in which $K_i = \frac{Q_i}{Q_n}$ = the modular coefficients of the individual year, Q_n-normal runoff (perennial mean),

n = number of years from the beginning of the period under consideration, in our case, n = 58 years.

From the resulting cycles of fluctuations in stream flow rates, it was suggested that a period containing at least two complete cycles be chosen to determine the true normal annual runoff. This approach has been used and recommended by many hydrological researchers (Chebotarev, 1975; Grigorkina, 1980; Baydin, 1980).

Comparison of the theoretical error of the norm, which is a function of the coefficient of variation and the length of the period of observation, with the actual error, consisting of the deviation of the average value over the number of years adopted from the true norm objectively ascertained for a rounded-off period of cyclical variation showed (L'vovich, 1974) that 20-30 year-series did not correspond to rounded-off cycles.

Numerous investigations of perennial runoff fluctuations have demonstrated significant discrepancies in obtaining values for normal runoff when an insufficient time series is used to evaluate cycles (Kisiel, 1969; Hall and Dracup, 1970; Vendrov, 1970; Davidov et al., 1973; Sokolov and Chapman, 1974; L'vovich, 1979; Gleick, 1986).

For example, the State Water Quality Control Board considers that the period 1922-1944 is appropriate for the analysis of runoff and for recommendations regarding the preservation of Delta-Suisun Bay water quality. (Delta Plan, 1978, Chapter IV-B; p. IV-2; The First and the Second Triennial Review; 1981, 1984.) However, the 23 year time series is not statistically valid for two reasons:

<u>First</u>: This period is too short to be used as the basis for any type of water quality management.

For example, Hall and Dracup (1970) state that "<u>many engineers would question the wisdom of a development proposal based on streamflow records of less than 40 years</u>." More to the point, Sokolov and Chapman (1974) and Linsley and Franzini (1979) emphasize that natural runoff variables and their normal can be adequately analyzed and defined if the record of 50 or even more years is used for the statistical analysis of unimpaired streamflow behavior.

In addition, the SWQCB 23-year database uses the two lowest segments (the end and the beginning) of two different phases of very different cycles (Fig. I.6) which itself may lead to an erroneous conclusion about water availability, or about the role of runoff in prevention of salt intrusion to the Delta, etc.

<u>Second</u>: The standard deviation of the "normal" annual and seasonal inflow to the Delta based only on the 23 years of pre-project conditions is more than 18%. However, standard deviations must be not more than ± 5-10% for seasonal flow and +5-6% for annual flow if the period of observations is at least 58-60 or more years. In the latter case, the absolute range of flow deviation + 0.1-0.3 MAF per month, and about 1.6 MAF for the "normal" inflow of Sacramento-San Joaquin river watershed is acceptable.

But in the case of the Board's recommended period, the range of standard deviation will be four times higher i.e., beyond any reasonable value for practical implementations.

Table I.4 Procedure for Calculation of Runoff Parameters

N Years	Q_i Runoff descending order	$k = \frac{Q_1}{\overline{Q_N}}$	$K_i - 1$	$\sum_{i=1}^{T} (K-1)$	$\sum_{i=1}^{T} \frac{(k-1)}{C_v}$
	1	2	3	4	5

T - Time scale

The conclusion is that the period of runoff observations has to be at least 50-60 years in order to yield the true normal runoff. A lengthy period that would cover several cycles of observations might yield a comparable norm.

Based on this approach (Table I.4, see Methods I.2) the integral deviation of modular coefficients was computed and plotted for the Sacramento-San Joaquin River (Table I.4, Column 4, Fig. I.6).

It is possible to come up with the following information from these curves:

A. The period of time between the K lowest and K highest points of curve corresponds to the wet phase of a cycle. Consequently, the period of time between the K highest and K lowest points of curve corresponds to the low wetness phase.

B. The value of the average modular per a phase and per cycle can be determined from the following equation:

per wet phase:

$$K^{W}_{avr} = \frac{K_{L(1)} - K}{N} + K$$

per low wetness phase:

$$K^{L}_{avr} = \frac{K_{H} - K_{L(2)}}{N} + K$$

per cycle

$$K^{C}_{avr} = \frac{K_{L(1)} - K_{L(2)}}{n} + K$$

where K^{W}_{avr} and K^{L}_{avr} = the average modulars of wet and low wetness phases, respectively.

$K_{L(1)}$ and $K_{L(2)}$ = the lowest values of modulars at the beginning and the end of a cycle, respectively;

K_H = the highest modular of a cycle,

N = the number of years comprised between $K_{L(1)}$ and K_H, K_H and $K_{L(2)}$ and $K_{L(1)}$ and $K_{L(2)}$

n = a total number of years per each cycle, comprised between $K_{L(1)}$ and $K_{L(2)}$; N-number of years per phase.

K = modular of the perennial mean (annual or monthly) value of runoff; K = 1.0.

The curve of Fig. I.6 displays quite clearly the three full cycles. Each of them is divided into the two phases: high and low flow of varying duration (Table I.5).

Table I.5 Phases and cycles of the Sacramento-San Joaquin unimpaired inflow oscillation

#	Period of Phase, Rise	Phase Duration (Years)	Mean Modular Coefficient	Period of Phase, Decline	Phase Duration (Years)	Mean Modular Coefficient	Cycle Period
1.	---	---	---	1922-37	16	0.79	---
2.	1937-43	6	1.34	1943-50	7	0.78	1937-50
3.	1950-58	8	1.27	1958-64	6	0.78	1950-64
4.	1964-75	11	1.24	1975-77	2	0.51	1964-77
5.	1977-?						

It is interesting to point out the following phenomena:

1. The Sacramento-San Joaquin natural river flow oscillation is confined by cycles which manifest the same duration (13-14 years) regardless of the duration of phases of different wetness.

2. The average volume of runoff for the cycles tends to approach the normal annual runoff, computed for the periods of 1921-1978 (the average deviation of a mean modular coefficient from the normal, i.e., k = 1.0, is insignificant).

3. The average deviations of a modular coefficient of phases of high (rising) and low (declining) wetness from normal are equal to +0.28 and -0.22, respectively, with the exception of an atypical but more than critical dry and the shortest period 1976 and 1977.

It must be emphasized that these relatively stable deviations reveal the one striking regularity of runoff fluctuations observed in many rivers of the Northern Hemisphere, namely, that the predominant range of deviations of water supply calculated as the 5-year running mean from the normal is equal to ± 30% (the five- year period is the favored one among meteorologists and hydrologists inasmuch as the precipitation manifests this scale of variability).

This predominance of the scale of deviations (more details will be discussed in Part III) tends to support our hypothesis that each natural cycle tends to maintain the dynamic equilibrium in the River-Delta-Estuary hydrological and biological characteristics regardless of the number of wet or low wetness years per cycle.

This, in turn, implies that the well-known resilience of estuaries in response to external disturbances (too much or too little runoff; strong winds and no winds, etc.) is based on the cumulative nature of the estuarine environment, acquired thousands of years ago.

Although a complete discussion of this matter is beyond the scope of this report, it is interesting to note that a comparison of cyclical fluctuations of stream flow ascertained by this method shows that there are synchronous variations with certain deviations for the north and south within the European part of the USSR (L'vovich, 1974, 1979), while asynchronism prevails in variation of streamflow of rivers to the east and west of the Urals. Cyclical variations of Siberian rivers display almost the opposite direction from the variations of the streamflow of European rivers (Baydin, 1980).

The results of a study by G.P. Kalinin (1968), who constructed maps of isocorrelates of the annual streamflow of the Volga and Mississippi with the annual streamflow of about fifty other rivers in Europe, Asia and North America, lead to a similar conclusion. His analysis demonstrates that there are positive correlation coefficients for rivers in Europe, and North America (up to the Florida parallel). In order to have the revealed cyclicity for the combined Sacramento-San Joaquin River comparable with the fluctuations with other river runoff, it is necessary to exclude the effect of C_v. (It is known that the C_v characterizes the degree of variability of runoff. That, in turn, exerts the influence of C_v on the values of the modulars.) To do so, the cumulative sum of modular deviations for each year of different rivers has to be divided by C_v, i.e.,

$$f(n) = \frac{\sum_{i=1}^{n} (K-1)}{C_v}$$

Where, f is a dimensionless ordinate which makes it possible to plot normalized modular's deviations obtained from different river runoff variables using the same scale (column 5, Table I.5).

From the trend of normalized modular variables presented in Figs. I. 7,8, it follows that synchronous runoff fluctuations prevail in the Sacramento-San Joaquin River flow and combined runoff of several major rivers of the Far East of the USSR, emptying into the Pacific Ocean (Fig. I.7) as well as with combined runoff variables of the Sea of Azov (Fig. I.8 (Rozengurt et al., 1987; Grigorkina, 1980), i.e., their runoff fluctuations are almost in phase.

It must be emphasized that the normal values of runoff for rivers of the Far East and South of the USSR were computed for almost the same period as was done in the case of the Sacramento-San Joaquin River in this report as well as other runoff statistics per each phase and cycle.

Therefore, the one solution from these investigations which, in our opinion, has proved to be reliable, consists of ascertaining the norm for several complete cycles of variations of streamflow. In this regard, we consider the values obtained by the DWR for the normal annual and monthly unimpaired Sacramento-San Joaquin River inflow as well as the Delta outflow to be closest to the true ones.

At the same time, we would like to emphasize that when we are dealing with regulated runoff fluctuations which reflect the natural cyclical variations as well as varying intensity of water development into the watershed, we may come across a level of changes that might be commensurate with the scale of cyclical variations.

A.V. Shnitnikov (1968) analyzed secular rhythms over a period of 1,800 to 2,000 years and noted that there is a general decline in wetness now occurring (Fig. I.9) The basis for his analysis was fluctuations of lake levels and the geomorphology of their shoreline, transgressions and regressions of the seas, fluctuations of mountain glaciation, and concentration of pollen in layers of peat, archaeological findings, etc. A cross analysis of all these phenomena by Shnitnikov made it possible to ascertain that the present-day secular rhythm over a period of several centuries, beginning about 500 years ago, was first characterized by high wetness, which lasted until the end of the 18th and beginning of the 19th century; since the second half of the 19th century, this phase has been replaced by a decline in the wetness of the continent. The intensity of this decline is such that it has been making itself felt for several decades. Shnitnikov traced these variations beginning in the 14th to 12th centuries B.C. to our own time.

These two causes--anthropogenic factors and natural rhythmic fluctuations--have been causing changes in the same direction, which have been superimposed on one another and have been intensifying the trend toward a gradual reduction of river flow in lakes, estuaries and seas.

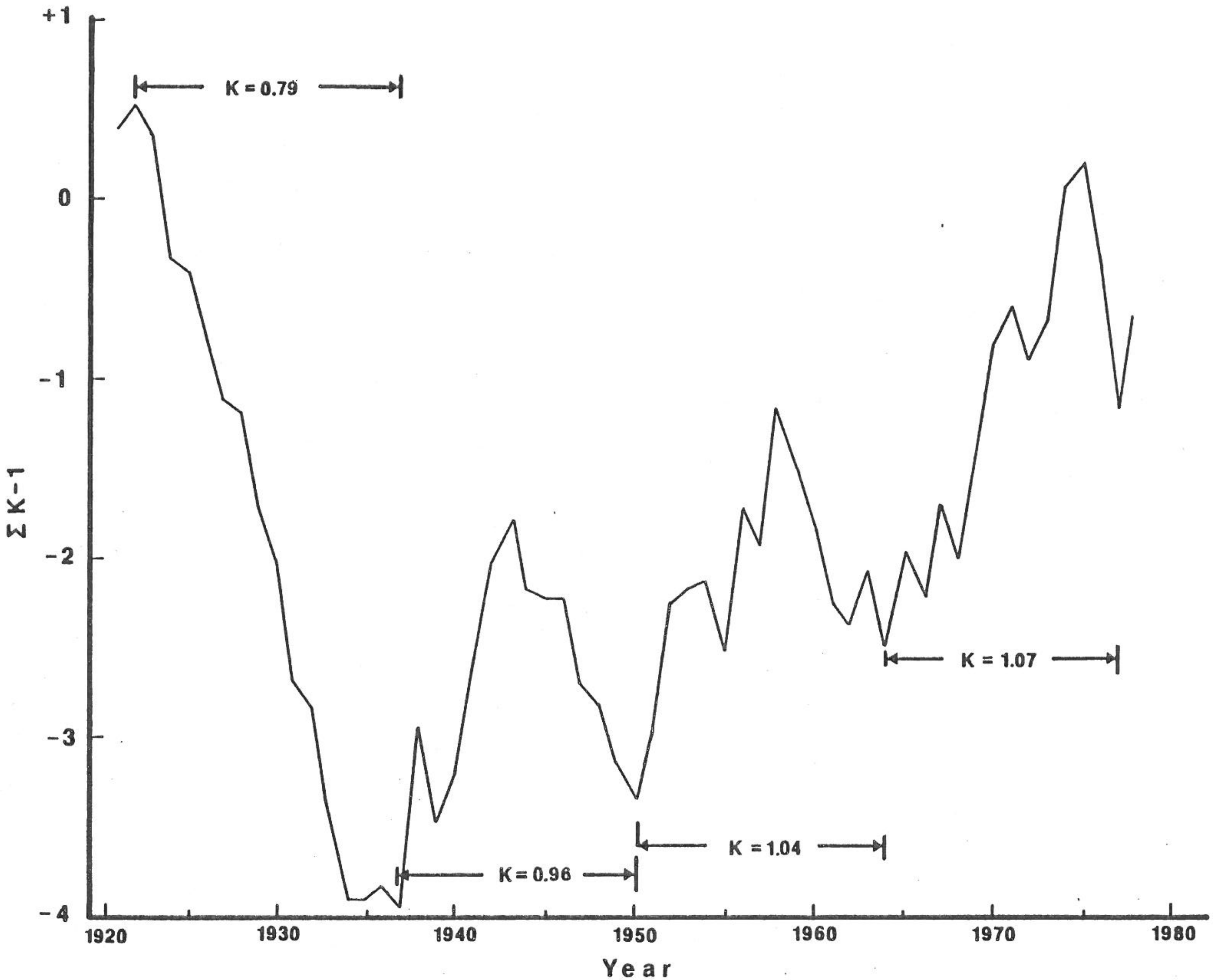


Fig. I.6 normalized integral curve of the modulus of natural river inflow to the delta, 1921-1978.

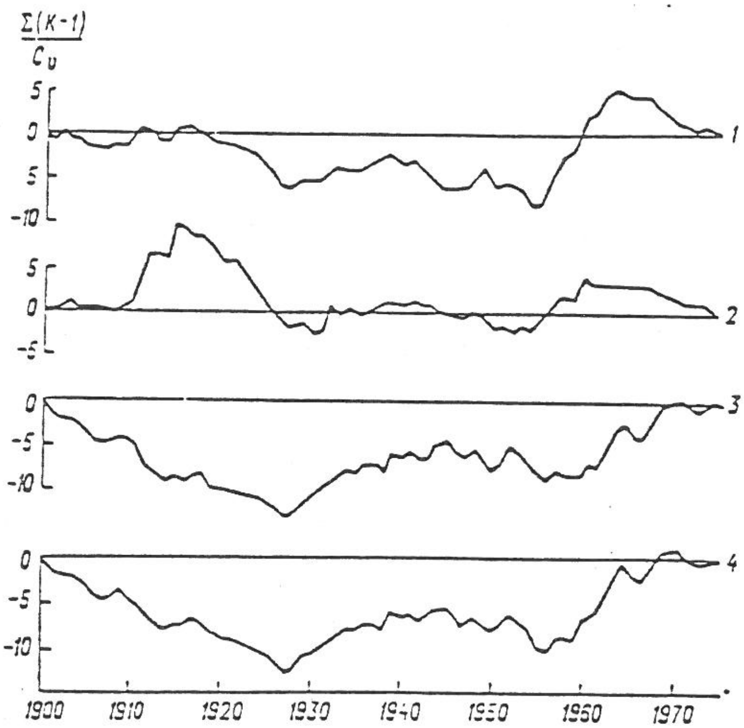


Fig. I.7 Normalized integral difference curves of modular coefficients.

1) inflow; 2) inflow from foreign countries; 3) local runoff; 4) total runoff of the Far Eastern economic region. (From Grigorkina, 1980)

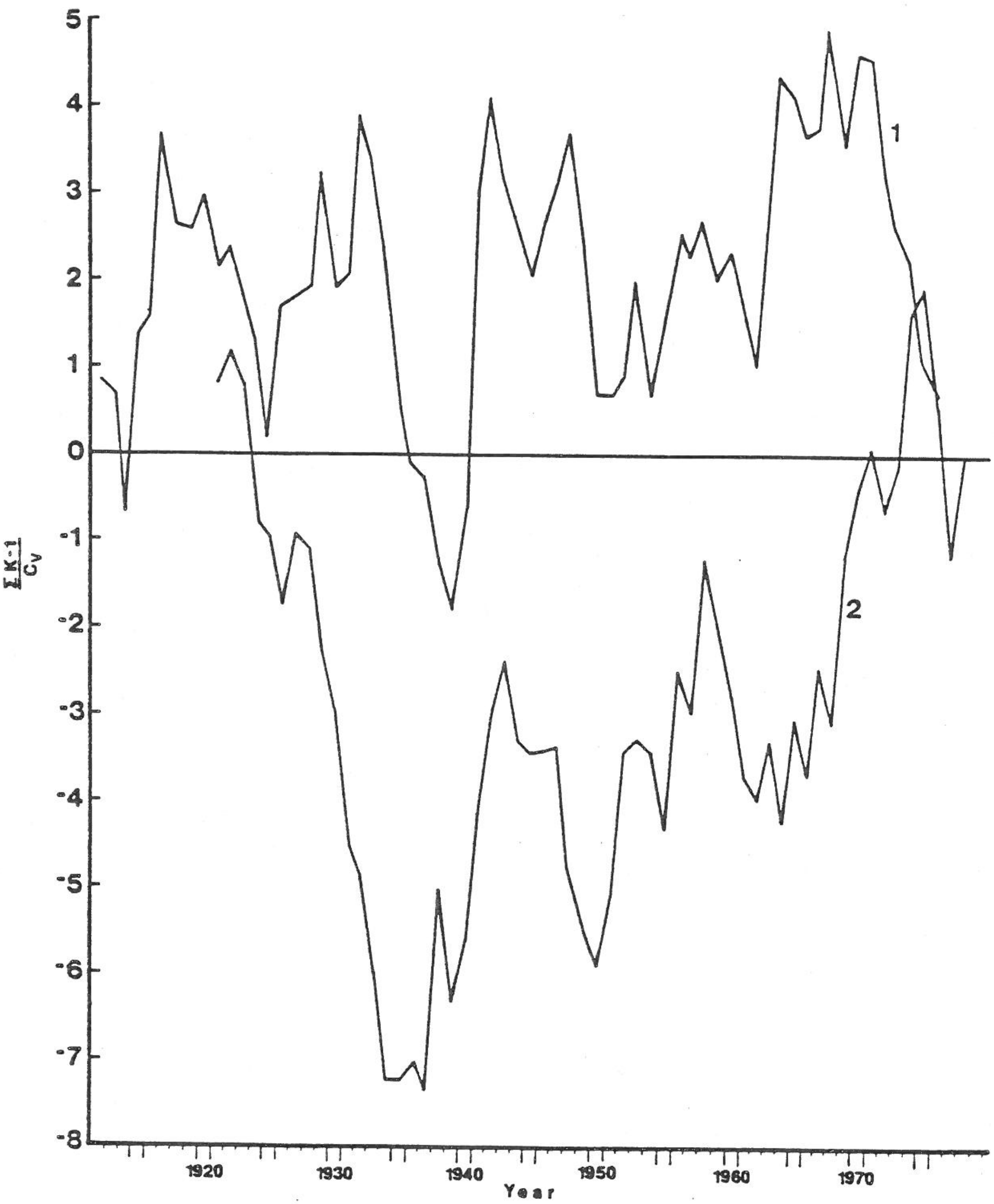


Fig.I.8 normalized integral fluctuations of modular coefficients of combined natural inflow to the (1) Sea of Azov and (2) San Francisco Bay.

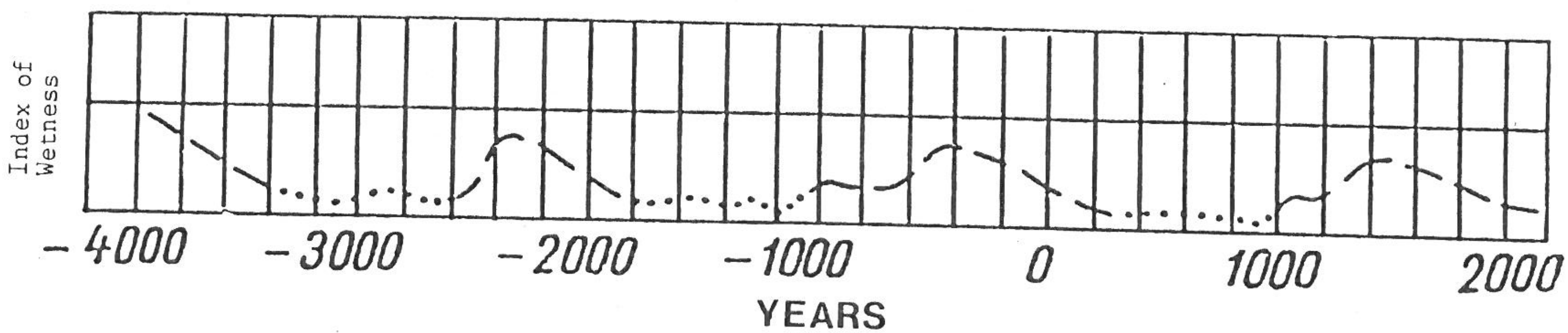


Fig. I,9 The fluctuation of wetness in Europe, Asia and North America by Shnitnikov 1957, 1968.

I.4 Definition of Historical Flow to the Delta-Estuarine Ecosystem and Water-Year Type Classifications

I.4.1 General Remarks

In numerous reports and articles describing the perennial and seasonal runoff patterns since 1921, as well as water availability to meet the needs of different water users, the Delta Outflow Index (DOI) is the major management statistic to have been created.

The DOI was developed by DWR staff and adopted by the SWRCB as the criterion of the "historical" Delta outflow fluctuations and it has become the foundation for California's water development and management decisions. Numerous regression analyses and modeling schemes have been based on it as well. The DOI has been employed for two major purposes:

1) To establish standards and criteria that are intended to provide optimal levels of runoff discharge to meet the requirements of agriculture, industry, recreation and living resources in the Delta-Suisun Bay ecosystem, and

2) To plan and implement additional water storage and conveyance facilities in the river basins and in the Delta.

As will be illustrated later, this procedure has permitted a great deal of flexibility in specifying and defining water availability as well as in setting forth standards and criteria for environmental protection because:

1. The DOI by definition describes the residual outflow to the San Francisco Bay (i.e., what is left after upstream and downstream diversions) and as such illustrates the chronological fluctuations of residual runoff (what is known in hydrological literature as controlled or regulated runoff) which strongly reflects the impact of artificial management.

2. The daily, monthly and annual values do not represent the natural runoff behavior of either the past or the present, and therefore do not reflect the origin of riverine-estuarine ecosystems or their requirements for fresh water.

3. Any conceivable water balance calculations which use the DOI automatically replace the physical sense and meaning of the behavior of natural or unimpaired runoff variables with that of artificially-created residual hydrological, biochemical and biological parameters of the estuarine system.

By definition, unimpaired runoff is the total amount of water flowing in major rivers and their tributaries based upon base flow and overland flow from the entire area of the watershed without storage facilities or conveyance systems for transporting water out of the basin.

Hence, the Delta Outflow Index should not be confused with the definition of unimpaired historical Delta outflow or other runoff characteristics such as natural river inflow to the Delta (NRI) or regulated river inflow to the Delta (RRI) (Fig. I.10).

The regulated values of runoff should be used initially as estimates of the impact of human activities throughout the watershed on seasonal and annual natural runoff fluctuations particularly when water development and future of the estuarine system, which are intimately connected with each other, are of concern.

The random or stochastic nature of natural runoff variables is analyzed (as is a well known procedure) with the help of the theory of probability, while the regulated Delta outflow parameters which consist of deterministic (i.e., man-induced) changes and stochastic elements may also be analyzed but with certain caution by the same methods of descriptive statistics, only for the purpose of comparison with the same elements of natural origin. This approach may avoid the widespread confusion and frustration particularly among those who are responsible for decision-making actions about the current and future impact of water diversions on the increase of salt pollution and possible development of irreversible changes related to the fishery and other resources of the river-Delta-San Francisco Bay ecosystem.

In the light of what has been said above, it is important to examine some of the problems related to the water-year-type classification schemes which have been used as the basis of different levels of water withdrawals and diversions in the Sacramento and San Joaquin basins for agriculture and other uses.

Since the early 1950's three different water-type classification schemes have been used by water planners and developers.

<u>First</u> The November 19, 1965 Delta Water Quality Criteria agreement and D1379 used the Bureau of Reclamation's water-type-classification system which was based on Sacramento River inflow to Shasta Reservoir.

The Bureau's classification scheme was introduced in early 1950 (P. III-g, Delta Plan, 1978). D-1379 had a similar classification of water years "in categories of natural flows available for normal, below normal, dry and critical years....based on only the inflow in Shasta Reservoir" (DWR, Peripheral Canal Project, 8, 1974, p.50).

However, in the early 1970's, the Department of Water Resources concluded that this classification system could serve water development in a very limited area of the river but it can not be used for the determination of the Delta water needs and especially not its water quality criteria because their characteristics are based on "only the inflow to Shasta Reservoir which may not be indicative of hydrologic conditions throughout the Central Valley and PARTICULARLY in the DELTA," inasmuch as during some years, when water conditions in the San Joaquin Valley "were well below normal" the same period of time could be classified as normal based on Shasta inflow (Chapter 11, 1974).

The correctness of this evaluation can be easily seen from Fig. I.11. Even casual scrutiny of the temporal and spatial runoff variables, i.e., their values and the range of annual variables, can lead to the conclusion that runoff from the upper Sacramento River has very little in common with the Sacramento-San Joaquin rivers or the Four River Index runoff.

It can be seen from the histograms (Figs. I. 12,13), that the range and frequency of occurrence of these two runoff characteristics are incomparably different. This is not surprising if one bears in mind that runoff measured at Shasta is derived from only approximately 8% of the Sacramento-San Joaquin River watershed while the combined river flow above the Delta is derived from 80% of the watershed.

It is interesting to note that despite this obvious inconsistency, the Shasta flow year-type classification was used as the environmental background during one of the most important periods of California's water development when the major water facilities were built and numerous contract obligations were adopted.

In 1974 DWR proposed a revision of the Bureau's and the Board's water-year-type classification system "used in the November 19, 1965 Delta Water Quality Criteria" and in D1379, because of its shortcomings and limited use for: a) analysis of runoff behavior and water availability studies concerning predictions, and, b) recommendations on the amount of water to be withdrawn throughout the Sacramento-San Joaquin River basin for agricultural (primarily), industrial and other needs.

Second As a result of this analysis, the DWR proposed that a modified method of water-year-type classification be used "for demonstrating operation of the Peripheral Canal and satisfaction of the Delta objectives." According to the DWR, "the modified method is based on the presence of normal unimpaired runoff to the Delta from both the Sacramento and San Joaquin River Systems," (DWR, Draft Environmental Impact Report, Peripheral Canal Project, August 1974, p. III, 50-51).

This "modified method" of runoff classification was a major step forward in comparison to the "Shasta Inflow" approach discussed above for the following reasons:

1) Its runoff is based on water from more than 75% of the Sacramento-San Joaquin watershed (the preceding, so-called 19 criteria classification, was based on runoff variables derived

from 8% of the watershed).

2) Consequently, annual and seasonal values of runoff used for this type of classification differ much less from those based on the total flow from the Sacramento-San Joaquin River watershed.

3) Their year-to-year (Fig. I.11) and even seasonal fluctuations are similar to those of the total runoff variables as well as to their order of magnitude.

However, this modified classification has one shortcoming, failure to include the significant amount of runoff from the Valley floor (more than 15% of combined river watershed) which, in combination with upstream flow, determines the total river inflow to the Delta followed by the Delta outflow to the Bay (after subtraction of the natural Delta water losses, i.e., evapotranspiration, etc.).

But, despite this shortcoming of the "modified method" (which is a typical example discussed in numerous textbooks and applied hydrology manuals), it is statistically valid for all but truncated runoff characteristics for the period of 1922-1971 which might be considered more of value than the water-year-type classification of 1965, or even the Four River Index of 1978 (basis of the D1485) if the balanced water development and preservation of the Delta-Bay ecosystem are concerned.

However, the "modified method" classification had a very short life and was replaced by the Four River Index.

<u>The Four River Index</u>. This water-year-type classification system was introduced by the DWR as a basis for setting forth runoff and salinity standards and criteria to be adopted by the State Water Resources Control Board in D-1485 in 1978.

This index is based upon the total runoff derived from the upper Sacramento River watershed and its major tributaries (see Section I.2.1.2). Hence, this system is "determined by the forecast of Sacramento Valley unimpaired runoff for the current water year (October 1 of the preceding calendar year through September 30 of the current calendar year" (Bul. 120, DWR; Final Environmental Impact Report for the Water Quality Control Plan, SWR/CB, August 1978, p. III-10 and the SWQCB reports since that time to the current year). The runoff is said to derive from 75% of the Sacramento river watershed.

Based on the data obtained during 1922-1978, the water-year-type classification was split into two sets (Fig. I.14).

This classification system, known among water planning engineers as the water management classification, possesses many "remarkable" features. The major one is its relative flexibility in meeting the contractual obligations for water delivery, and at the same time having these withdrawals adjusted to the

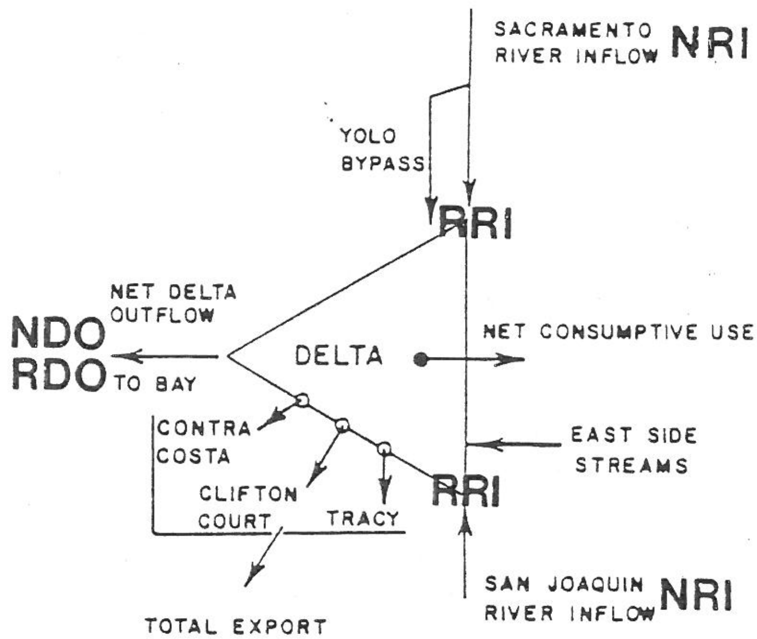


Fig.I.10 Schematic diagram of Delta water balance modified after Orlob 1977.

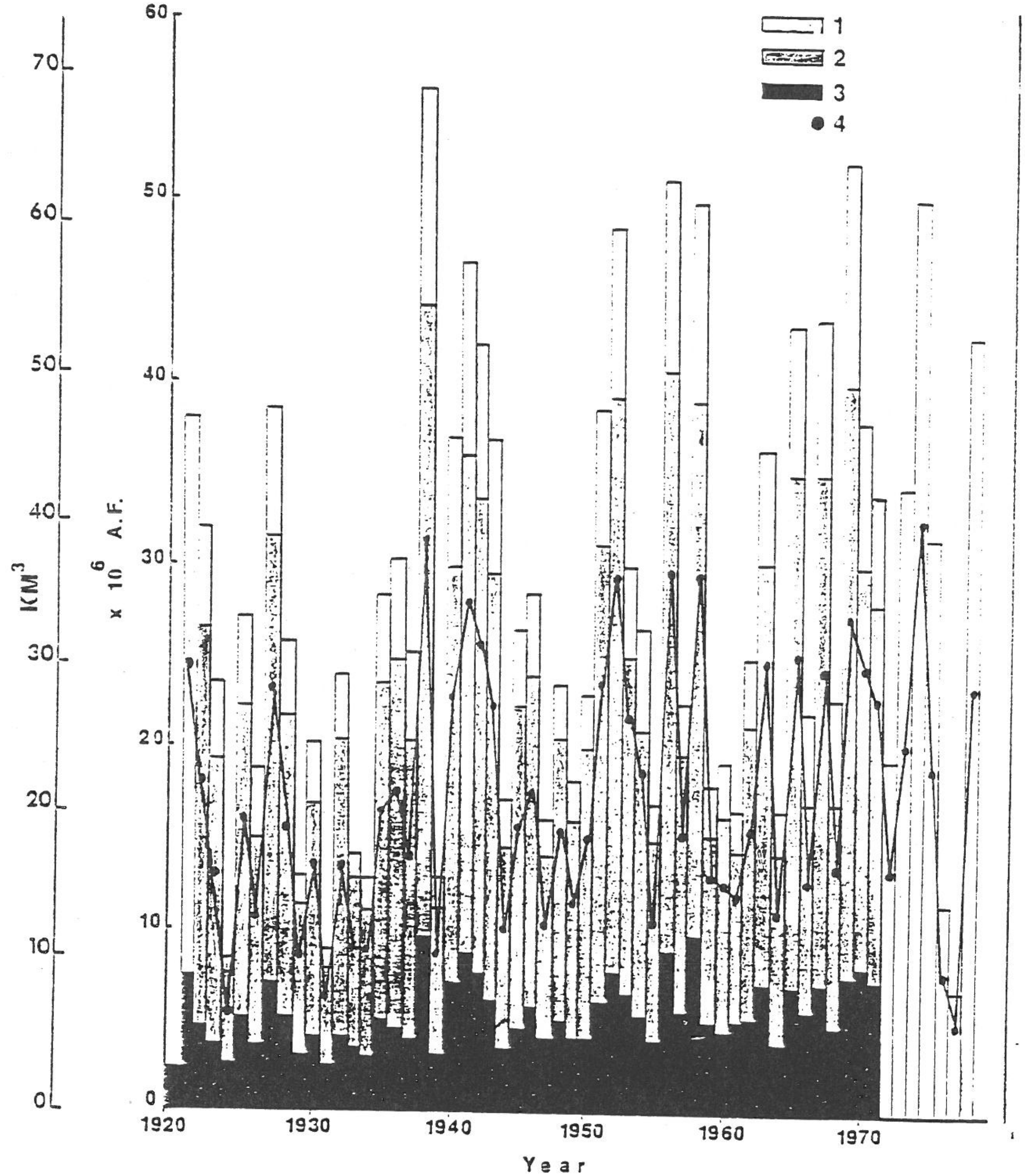


Fig.I.11 . Historical total natural river inflow to the Delta from (1) the entire watershed, (2) the foothill gauging stations, (3) to the Shasta reservoir, and (4) the four-river index.

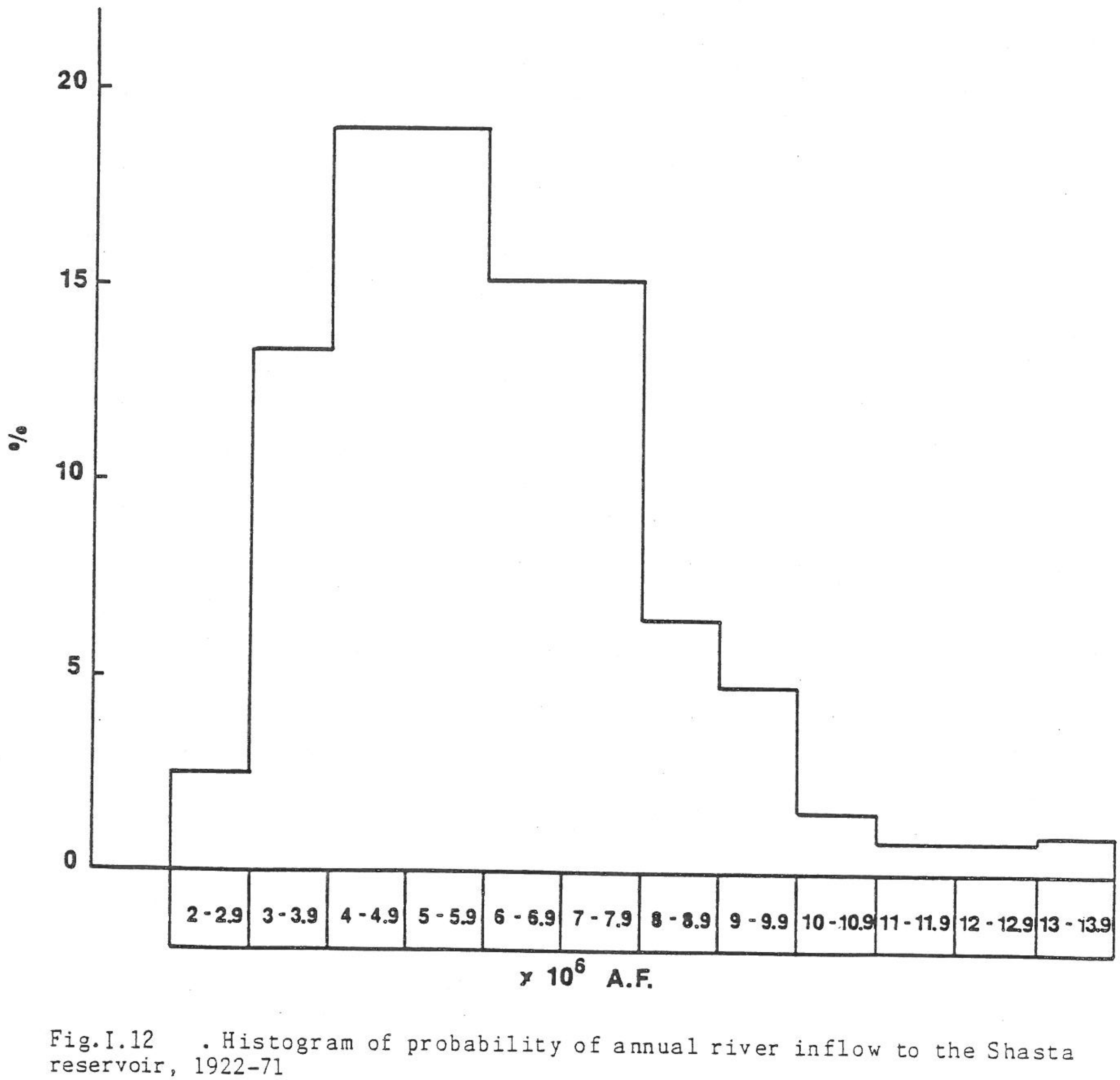


Fig.I.12 . Histogram of probability of annual river inflow to the Shasta reservoir, 1922-71

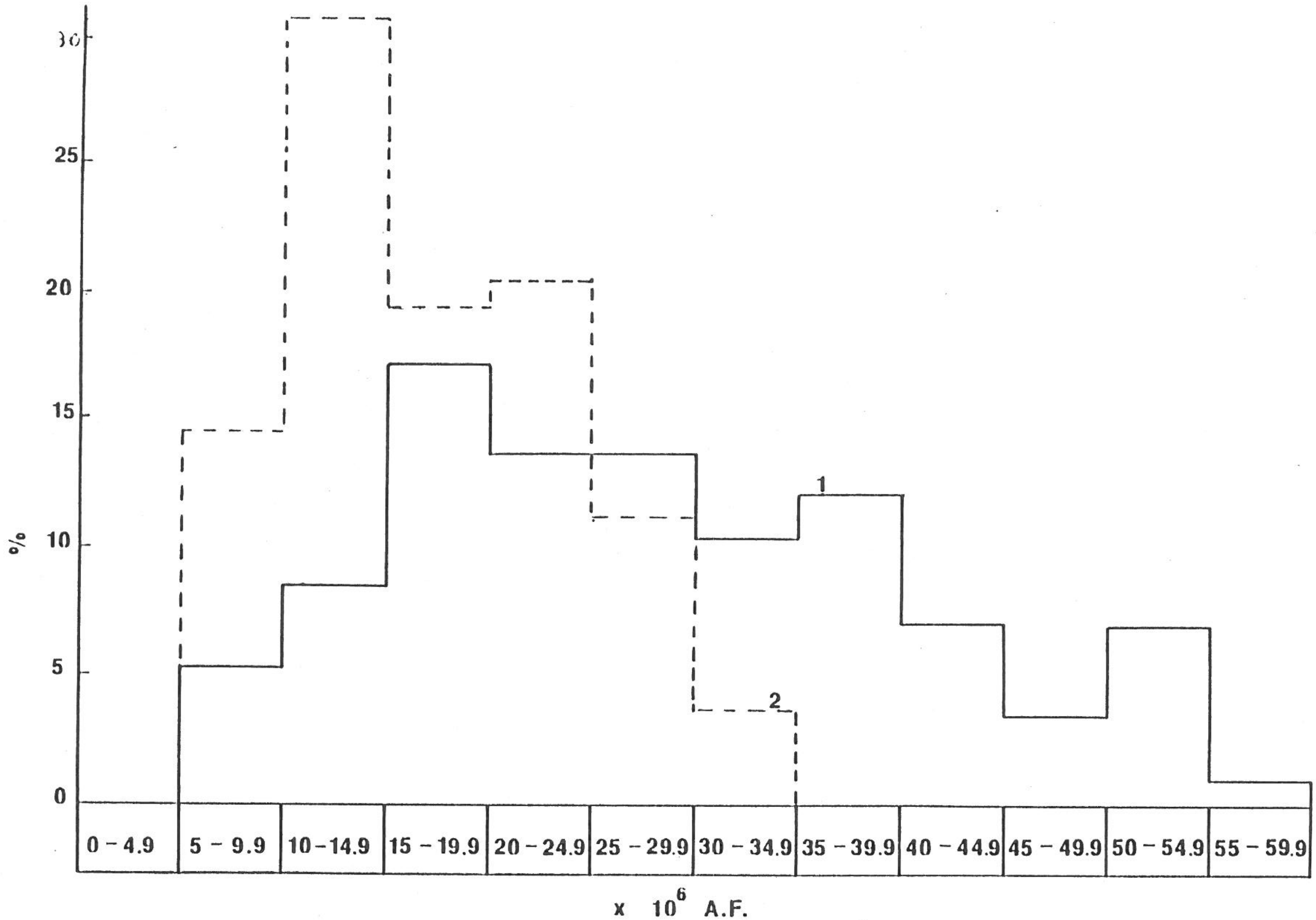
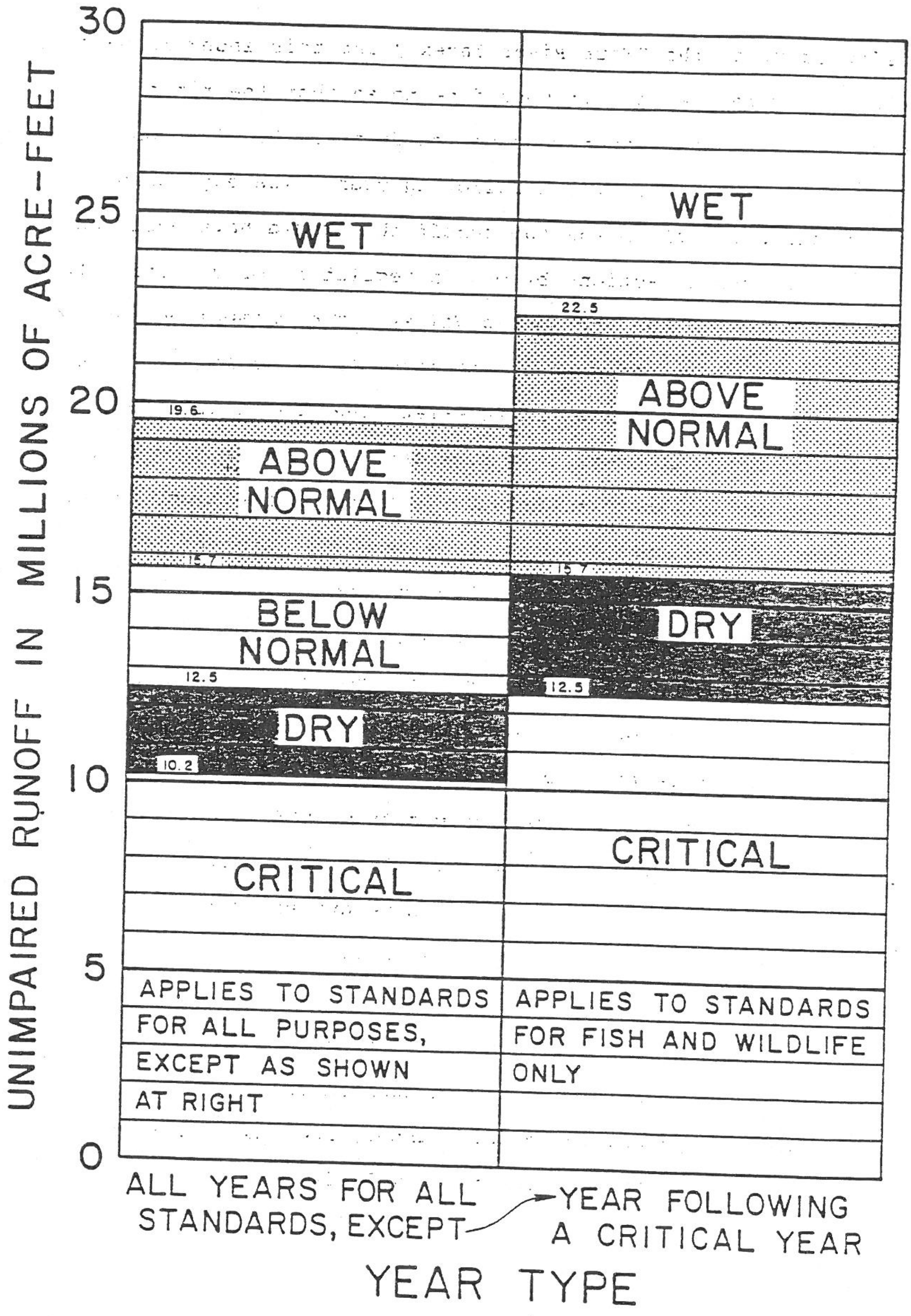


Fig. I.13 Histogram of the probability of (1) annual natural river inflow to the Delta and (2) natural runoff of the four river index, 1921-78.

Fig. I.14 . Four River Index Year Classification (taken from MWD, 1979)



alternation of years of different wetness regardless of the optimal runoff needs of the San Francisco Bay estuarine system.

Optimal runoff means the seasonal volume of discharge which will provide a dynamic equilibrium of estuarine regime characteristics within their dominant range of natural fluctuation and therefore maintain the physical and chemical conditions necessary for the survival of living resources. Had it been possible to attain these requirements, there would not have been the problems related to estuarine water quality that have developed.

However, all of these classification schemes fail to consider the needs of the Bay for definite runoff discharges, and disregard some basic laws of hydrodynamics and thermodynamics concerning the fundamentals of continuity of certain processes which affect all river-Delta-estuary-sea ecosystems.

I.4.2 Comparative Analysis of Statistical Parameters of Three Water-Year-Type Classification Systems

Data Base

The basic features of the three systems are compared as follows:

1. Total natural Sacramento-San Joaquin River inflow to the Delta from their entire watershed; period of observation, 1921-1978.

2. The Sacramento-San Joaquin upper river inflow to the Delta from 80% of the watershed (the DWR modified method, 1974; the period of observation is 1921-1971).

3. The Four River Index, i.e., upper Sacramento, American, Feather and Yuba River inflow to the Valley floor (approximately 75% of the combined watershed), from 1921 up to 1978.

Methods

These three sets of data were analyzed with two statistical models, namely, moments and grapho-analytical (three points, Chow, 1964).

As a result, the "normal" as well as the probability of exceedence and years of recurrence of different volumes of runoff, standard deviations, coefficients of variation and skewness were calculated and compared (Table I.6)

Table I.6 Statistical Parameters of Runoff for Different Parts of the Sacramento-San Joaquin Watershed (original)

Area of Origin of Runoff	Statistics			
	Q MAF	C_v	C_s	Standard Deviation MAF
1. Total Sacramento-San Joaquin River Inflow to the Delta, 1921-1978	28.3	0.52	1.0	12.5
2. Upper Sacramento-San Joaquin River Inflow to the Central Valley Floor (1921-1971)	23.3	0.48	0.80	9.6
3. The Four River Index Inflow to the Sacramento Valley Floor (1921-1978)	17.3	0.42	0.88	7.28

Q = mean for period of record;

Cv = Coefficient of variance; Cs = Coefficient of skewness

Therefore, we have the three different statistically valid "normals," (Table I.6) to describe the same process. These parameters in conjunction with C_v and C_s (as was shown earlier) provide us with a procedure for determining the probability of years of different wetness in the past and comparing their values with those observed at present, and answer, with acceptable approximation (a more detailed explanation can be found in numerous textbooks and articles on the techniques of the descriptive statistics in hydrology) what type of year or season or month we are dealing with, and how often it may be observed, and if its average is higher, equal or lower than a perennial mean (the normal). The latter occupies the middle position on a runoff frequency curve close to 50% (median) of probability of occurrence that corresponds to the recurrence of median runoff at least once every two years. Any values of runoff that are higher than the former correspond to the abnormal, wet, or wettest year, otherwise, sub-normal, dry, critical dry and drought, and each of these water-type (or wetness) years has its own probability and corresponding recurrence interval of events (Figs. I. 15,16).

<u>Discussion</u>

As can be seen from Fig. I. 17, 18, 19 and from Tables II. 7, 8 the probability curves of selected areas of runoff formation exhibit a strong similarity inasmuch as C_v and C_s are almost the

Table I.7 Comparison of the total runoff of the Sacramento-San Joaquin River to the Delta with the Four River Index runoff to the Sacramento Valley for different probabilities (1921-78)*

%		1	5	10	25	50	75	90	95	99
Years of Recurrence		100	20	10	4	2	4	10	20	100
Four River Index Runoff	Qp	38	31	27	21	16	12	9	7	5
Combined Sacramento-San Joaquin River Inflow	Qp	65	51	45	35	26	19	14	11	7

Table I.8 Comparison of the upper Sacramento-San Joaquin River inflow to the Delta (modified method) with the total river inflow to the Delta (1921-71)*

Upper Sacramento-San Joaquin River Inflow	Qp	45	40	38	30	21	16	12	9	5
Total Sacramento-San Joaquin River Inflow	Qp	59	52	47	37	26	19	14	12	7

*Note: Qp values are rounded up.

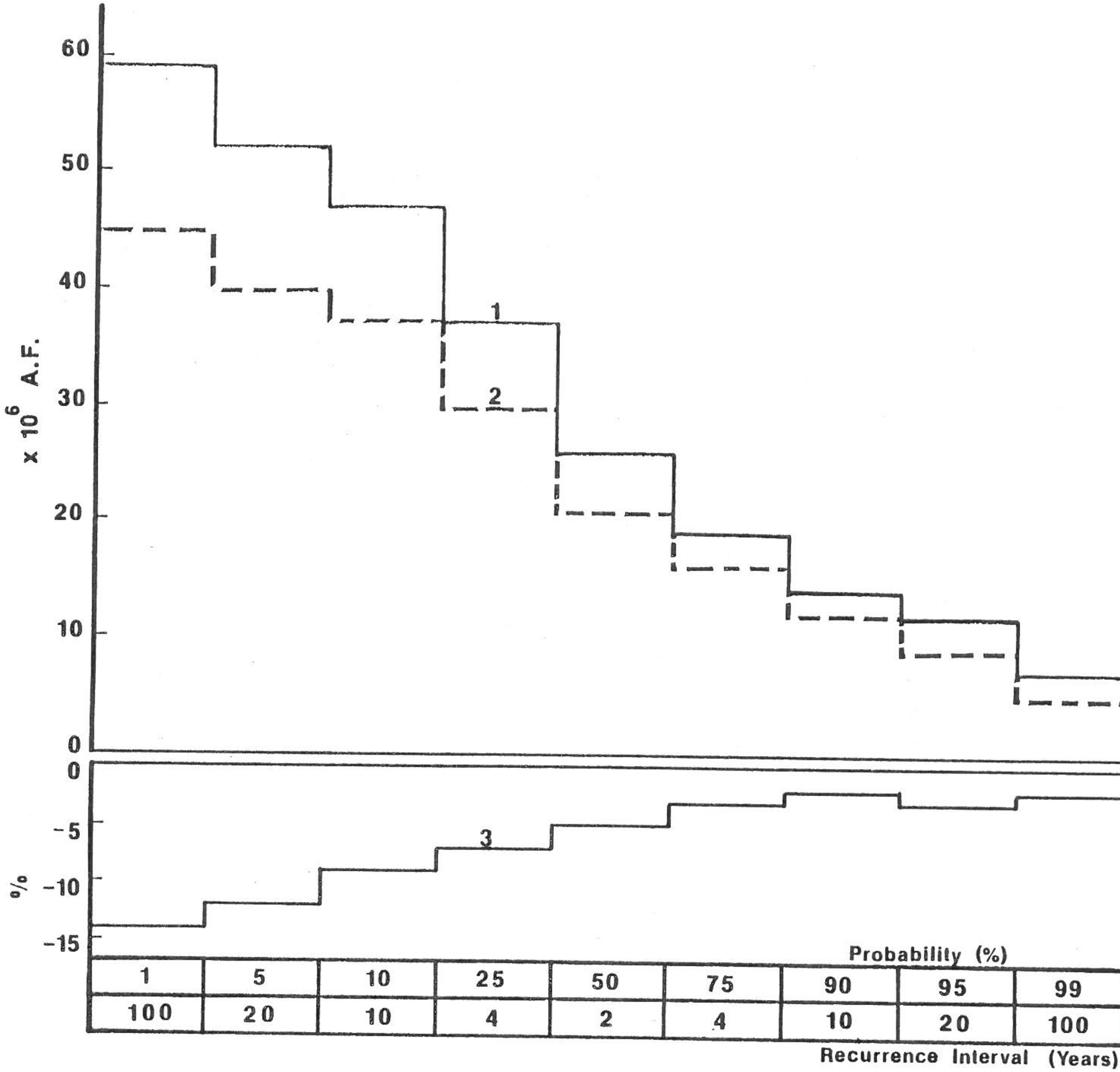
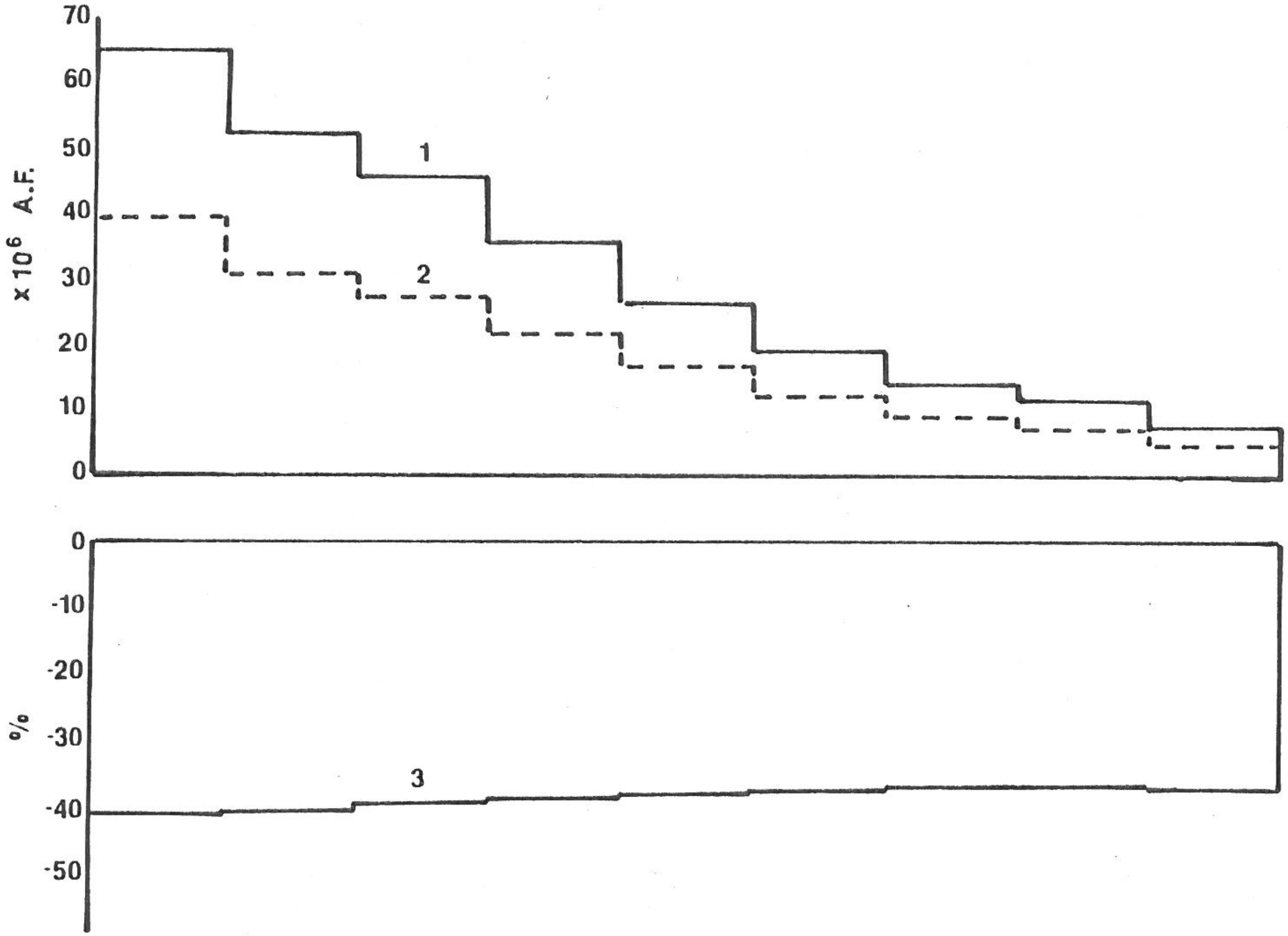


Fig. I.15 . Volume of (1) natural total annual river inflow to the Delta from the Sacramento-San Joaquin river watershed for different probabilities of runoff in comparison with (2) river inflow from the upper reaches to the Delta and (3) percentage of differences between (1) and (2) for given probabilities of flow, 1921-70.



Probability (%)	1	5	10	25	50	75	90	95	99
Recurrence Interval (Years)	100	20	10	4	2	4	10	20	100

Fig.I.16 .Volume of (1) annual combined river inflow to the Delta for different probabilities of runoff in comparison with (2) natural runoff of the four river index and (3) percentage of differences between (1) and (2) for given probabilities of flow, 1921-78.

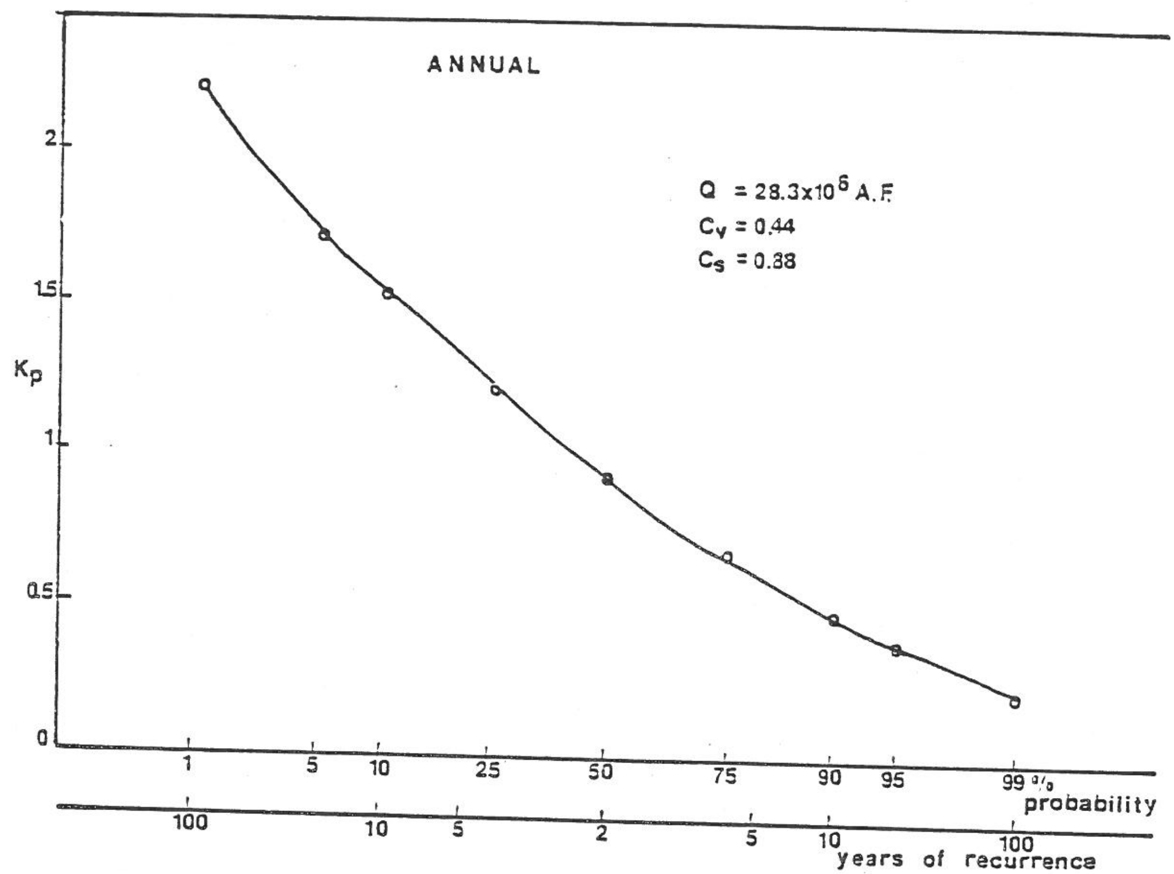


Fig.I.17.Probability Curve of Annual Natural River Inflow (1921-78).

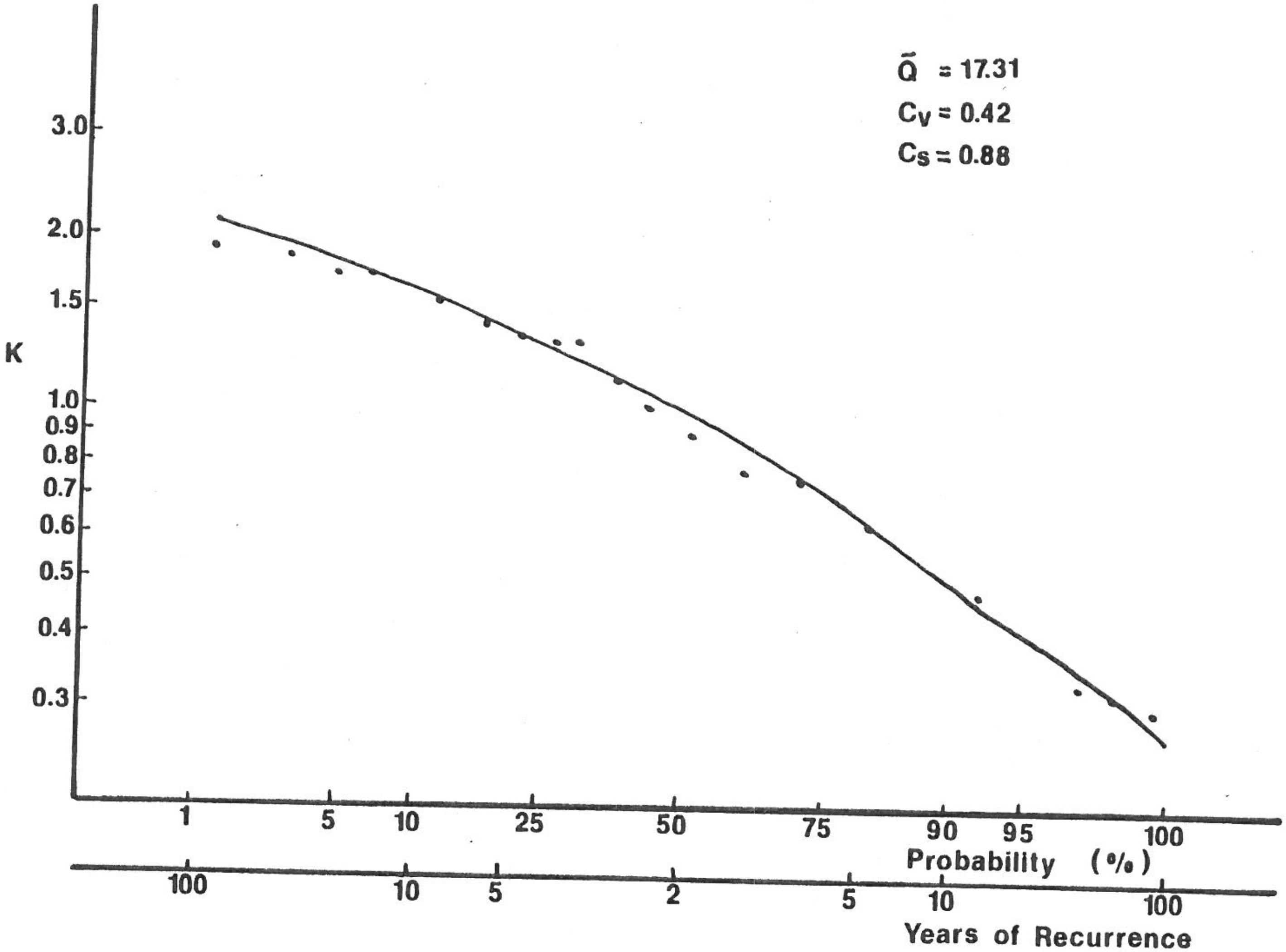


Fig.I.18 . The probability curve of the natural runoff of the four river index.

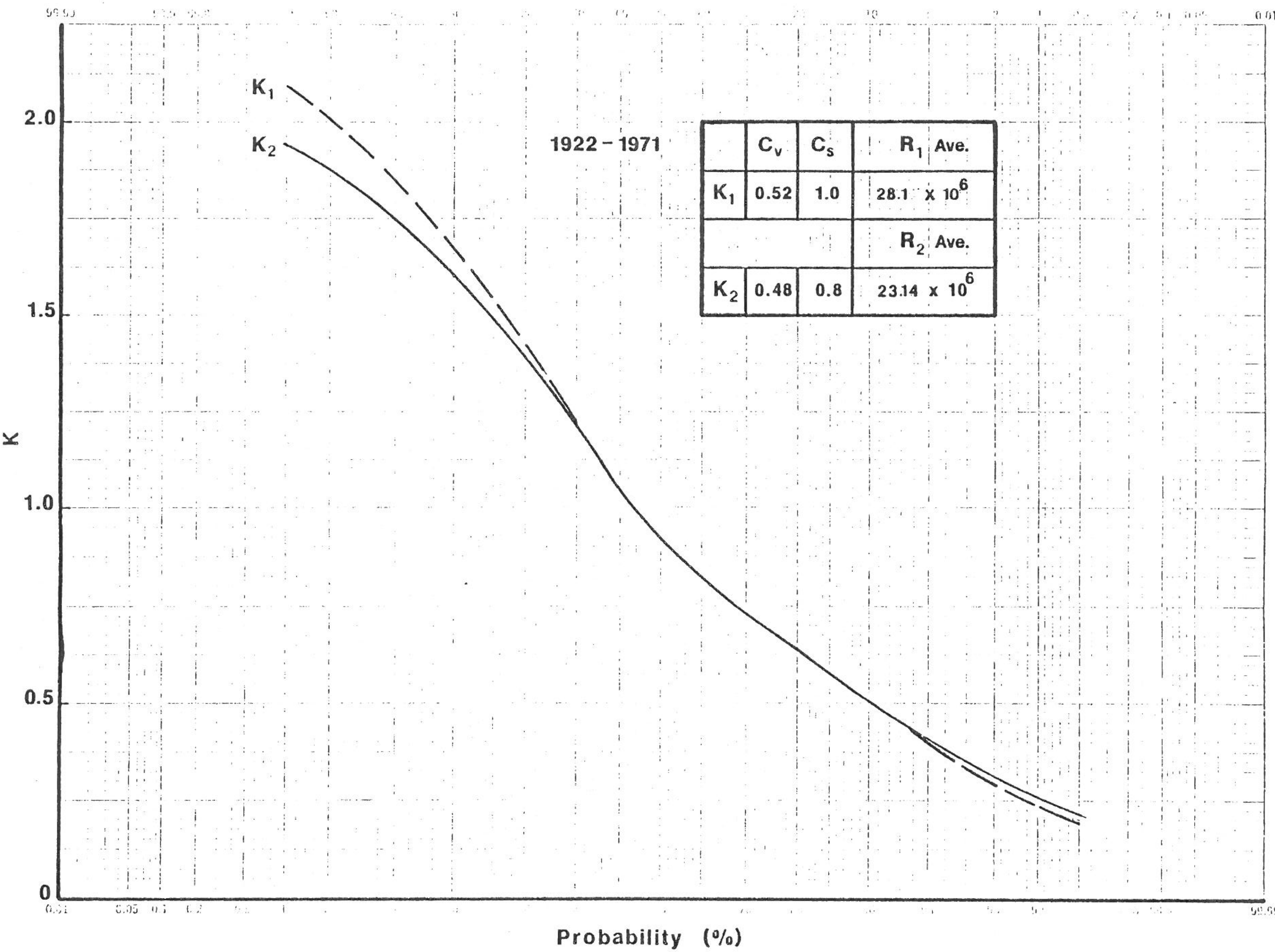


Fig. I.19 Probability of full natural inflow (K_1) and foothill gaging station's river watershed inflow (K_2) to the delta, 1922-1971 (K is the modulus value).

same. However, the absolute values of runoff for a given probability obtained from these curves differ significantly. This implies that the natural river inflow frequency curve of the upper Sacramento-San Joaquin and the Four River basin gives values of runoff for years of different wetness (the wettest, wet, abnormal, normal, sub-normal dry, critical dry and drought) considerably below the total inflow frequency curve from the entire Sacramento-San Joaquin River watershed.

I.4.2.1 Total Sacramento-San Joaquin River Inflow to the Delta versus Upper Sacramento-San Joaquin River to the Central Valley Floor

1. This runoff of 1922-1971 represents only the Rivers' flow from "the major tributaries at the foothill gauging stations..." (Letter by J. D. Vayder, Planning Branch Division of Planning, DWR, July 30, 1984), i.e., it does not include "the Valley floor and additional minor tributaries." As a result of this "omission" the annual values of upstream runoff (modified method DWR, 1974) are less than the total natural runoff (California Central Valley Natural Flow Data, April 1980, p. 27) from the watershed over to the Delta by about 1.0-12.2 MAF (1.2-15 km^3) or 10-24% of the total annual runoff. The predominant range of deviations is equal to 15-20% (Table I. 10).

2. With the exception of the years of low wetness, 1924, 1929, 1931, 1933, 1934, 1939, maximum and minimum differences in annual values between these two sets of runoff statistics were equal to 12.2 MAF (15.0 km^3 - 1938, 1969) and 2.0 MAF (2.5 km^3 - 1947), respectively.

3. These values correspond to the deviations of 52.8% and 8.7% from the normal (1922-1971).

4. And yet, the normal upstream runoff (1921-1971) adopted by the DWR when the Peripheral Canal was under discussion was equal to only 23.2 MAF (28.4 km^3, from 80% of the river watershed) while the same characteristics of the total natural runoff (100% of the river watershed) were equal to 28.1 MAF (34.8 km^3).

Therefore, the difference between the mean flow to the Delta estimated from the upper gauging stations (modified method) and the total was equal to 5.0 MAF (6.2 km^3). This value is more than the San Joaquin River inflow and constitutes 18% of the total inflow to the Delta for the period 1922-1971.

This difference (i.e., between the normals 23.2 and 28.1 MAF) leads automatically to the successive reduction of runoff values for the wet, sub-normal, dry and critical dry (drought) years.

Because each year of different wetness is calculated through multiplication of modulus Kp for a given probability, "P", by the normal runoff value, Qn, for example, for a probability of exceedance of modulus K_1, $K_{5\%}$......$K_{99\%}$......the Qp for a given probability is calculated as:

$$Q_{1\%} = K_1 * Q_N; \quad Q_{5\%} = K_{5\%} * Q_N.....K_{99\%} * Q_N$$

Therefore, if Kp is multiplied by 23.23 or 28.2 MAF, then runoff for the same probabilities of occurrence will differ (Table I.7) i.e., the higher differences between the normals of the two sets of data, the higher the differences between runoff of different probabilities.

It becomes even more obvious if one tries to compare the DWR year of wetness classification (modified method) with water-year-type classification based on a total inflow to the Delta from the entire watershed for the same probabilities (Table I.8).

The comparison of the values of the two sets of runoff variables for different probabilities of occurrence or, in other words, for years of different wetness, shows the following (Fig. I. 15):

1) Annual runoff variables of the 1, 5, 10 (wettest); 25 (wet); 50 (median, close to normal wetness); 75 (sub-normal wetness), 90 (dry); 95 (critical dry) and 99% (drought) probabilities of the total river inflow to the Delta higher of those of upper Sacramento-San Joaquin River inflow (Figs. I.15, 16). The range of these differences for above normal and sub-normal years of wetness are approximately equal to 14-17 and 2-5 MAF, respectively.

It is not difficult to see that these differences are too significant not to be taken into serious consideration if a water year type is related to recommendations on water available for withdrawals as well as to what water-year-type the impaired runoff corresponds to, etc., are in question.

For example, if the total river inflow year-type-classification is used for annual runoff evaluation, then the majority of the years of the DWR's "modified" method" classified as wet, above normal, sub-normal and dry will be shifted to the subsequent low category of wetness.

Table I. 9 provides support to this statement. For example, the number of wet and sub-normal years ("modified method") were reduced twice when their natural values were compared with the runoff of the corresponding wetness, according to the total runoff classification.

Table I.9 Comparison of the Modified Method and the Combined Sacramento-San Joaquin River Inflow Water-Year-Type Classification

Water Year Type*	Modified Method	Number of Events	Total Year Inflow Classification	Number of Events
Wet Years (Greater than 125%)	29.03	15	35.14	7
Abnormal		4		8
Normal Year	23.23	2	28.20	1
Sub-normal		11		5
Below Normal (Less than 80%)	18.58	4	22.56	9
Dry (Less than 70%)	16.26	8	19.74	7
Critically Dry (Less than 57%)	13.24	6	16.00	11
Drought (Less than 30%)	7.00		8.46	2

*Water-Year-Type designations are in compliance with the Department of Resources Bulletins 23-62 and 130-70; Average based on 1922-1971 period 23.229 MAF.

At the same time, the number of years designated in the "modified method" as below normal (or it is better to say, sub-normal) and critical dry years increased more than twice, according to the total inflow classification.

Even more serious inconsistencies in evaluation water-year-type can be found if the values of annual natural and regulated total river inflow to the Delta is compared with the Four-River Index wetness classification which is the background of the planning of water development and decision-making of D1485.

One of the reasons for this is that the Four-River Index runoff to the Sacramento Valley in historical retrospective represents only part, in spite of its essential magnitude, of the Sacramento-San Joaquin River watershed. Therefore, its values are lower than they would have been if the total flow had been taken into consideration for the classification under discussion.

Table I.10 Comparison of Different Year-Type Classification of Runoff, 4-River Index, Upstream and Total Watershed

Water Year	4-River Index Runoff Qi x1000 AF*	Q80 Runoff 80% of Watershed x1000 AF**	Qnri 100% of Watershed x1000***	Differences		% Deviation	
				Qnri-Qi	Qnri-Q80	Qnri-Q80 / Qnri	Qnri-Qi / Qnri
1921	23,801		38,682				
22	17,981	26,713	32,693	14,712	5,980	18.3	45.0
23	13,206	19,512	23,594	10,388	4,082	17.3	44.0
24	5,736	7,433	8,202	2,466	769	9.4	30.0
25	15,993	22,300	26,718	10,725	4,418	16.5	40.0
26	11,765	15,331	18,495	6,730	3,164	17.2	36.4
27	23,834	31,591	38,442	14,608	6,851	17.8	38.0
28	16,762	21,835	26,241	9,479	4,405	16.8	36.1
29	8,400	11,382	12,895	4,495	1,513	11.7	34.8
1930	13,518	17,189	20,304	6,786	3,215	15.8	33.4
31	6,096	7,898	8,756	2,660	858	9.8	30.4
32	13,116	20,442	24,021	10,905	3,579	14.9	45.4
33	8,938	12,776	14,142	5,204	1,336	9.4	36.8
34	8,630	11,150	12,852	4,222	1,702	13.2	32.8
35	16,587	23,694	28,341	11,754	4,647	16.4	41.5
36	17,351	24,855	30,325	12,974	5,470	18.0	42.8
37	13,331	20,442	25,118	11,787	4,676	18.6	38.9
38	31,826	44,367	56,529	24,703	12,162	21.5	43.7
39	8,180	11,382	12,754	4,574	1,372	10.8	35.9
1940	22,434	29,965	36,990	14,556	7,025	19.0	39.3
41	27,079	35,773	46,590	19,511	10,817	23.2	41.9
42	25,236	33,682	42,009	16,773	8,327	19.8	39.9
43	21,125	29,501	36,437	15,312	6,936	19.0	42.0
44	10,433	14,867	17,105	6,672	2,238	13.1	39.0
45	15,063	22,300	26,533	11,470	4,233	16.0	43.2
46	17,621	23,926	28,662	11,041	4,736	16.5	38.5
47	10,388	14,170	16,209	5,821	2,039	12.6	35.9
48	15,754	20,674	23,708	7,954	3,034	12.8	33.5
49	11,970	16,260	19,087	7,117	2,827	14.8	37.3
1950	14,442	19,745	23,161	8,719	3,416	13.6	37.6
51	22,947	31,359	38,611	15,664	7,252	23.1	40.6
52	28,600	39,257	48,775	20,175	9,518	24.2	41.4
53	20,086	25,087	30,104	10,018	5,017	16.7	33.3
54	17,428	20,906	26,530	9,102	5,624	21.2	34.3
55	10,983	14,867	17,165	6,182	2,298	13.4	36.0
56	29,887	40,883	51,046	21,159	10,163	19.9	41.4
57	14,889	19,745	22,686	7,797	2,941	13.0	34.4
58	29,710	39,025	50,064	20,354	11,039	22.0	40.6
59	12,049	15,331	17,945	5,896	2,614	14.6	32.8

Table I.10 cont.

1960	13,057	16,493	19,131	6,074	2,638	13.8	31.7
61	11,972	14,402	16,626	4,654	2,224	13.4	28.0
62	15,115	21,371	25,125	10,010	3,754	14.9	39.8
63	22,993	30,198	36,550	13,557	6,352	17.4	53.9
64	10,921	14,408	16,652	5,731	2,244	13.5	34.4
65	25,663	35,076	43,125	17,462	8,049	18.7	40.5
66	12,950	17,422	20,704	7,754	3,282	15.8	37.4
67	24,059	35,076	43,537	19,478	8,461	19.4	44.7
68	13,640	16,957	20,311	6,671	3,354	16.5	32.8
69	26,980	39,954	52,137	25,157	12,183	23.4	48.2
1970	24,058	30,197	37,956	13,898	7,759	20.4	36.6
71	22,572	28,107	34,088	11,516	5,981	17.5	33.8
72	13,426	-	19,591	6,165	-	-	31.5
73	20,047	-	34,662	14,615	-	-	42.2
74	32,495	-	50,238	17,743	-	-	35.3
75	19,222	-	31,732	12,510	-	-	39.4
76	8,266	-	11,606	3,340	-	-	28.8
77	5,131	-	6,756	1,625	-	-	24.0
78	23,807	-	48,846	25,039	-	-	51.3
Mean 1922-1971	17,225,000	23,145,460	28,115,620		4,970,120	17.7	

Note: *Data from Municipal Water District of Southern California, 1979 Report No. 935

**Data from "Draft Environmental Impact Report, Peripheral Canal Project," August, 1974, p. 111-51, (Bull. 23-62 and 130-70 with average based on 1920-1970 period; runoff = 23,229,000 acre feet).

***Data from "California Central Valley Natural Flow Data," April, 1980. Department of Water Resources, Planning Division.

I.4.2.2 <u>Total Sacramento-San Joaquin River Inflow to the Delta versus the Four River Index</u> (hydrological basis of D1475).

The Four River Index describes total flow behavior only for the four major rivers of the Sacramento River watershed; all other middle and minor tributaries of the upper Sacramento-San Joaquin River basin (the basis of DWR's "modified method" of 1974) as well as runoff from the Sacramento Valley floor, have been excluded from consideration.

The comparison of these two sets of data and their statistics for different probabilities reveals the following (Fig. I.16):

1) There are considerably greater differences between their runoff values (with the exception of the 1976 dry and 1977 drought years) in comparison with the first sets of runoff fluctuations (Table I.10)

2) In 64% of the observations for the 58 years, the total natural runoff considerably exceeded the Four River total (Table I.11).

Table I.11 Number of years and ranges of exceedance of the total Sacramento-San Joaquin River inflow to the Delta over the Four River Index (1922-1978)

Range MAF	Number of Years	% of Total Years
1-5	8	13.8
5.1-10	19	32.8
10.1-15	18	31.0
15.1-20	7	12.1
20.1-25	4	6.9
25.1-26	2	3.4
		100.0

It should be emphasized that the largest differences in the runoff of 1969 and 1978 (Table I.10) were almost equal to the unimpaired normal Delta outflow to the Bay (27.3 MAF) as calculated for the same period of observation, and more than 30% of differences constitute half of the normal natural river inflow.

Even in the case of the drought (1977), the difference between the NRI and Four River Index was equal to 1.62 MAF which is slightly higher than the volume of the Delta itself.

3) In sum, it must be emphasized that for all major categories of wetness (Fig. I.14) the negative deviations of the Four River Runoff from the NRI is equal to 40% on the average (Fig. I.16). This means that any of the years of different wetness obtained from the Four River Index runoff probability of occurrence will correspond to years of much lower wetness if these data are compared for the same probabilities of runoff but obtained on the basis of its total natural (or monthly) annual values (i.e., the NRI).

For example, the absolute values of this difference vary between 10-27 MAF (wet and above-normal, i.e., 1, 5, 10, 25% of probability of exceedence) and 3-15 MAF (75, 90, 95 and 99%) and 10 MAF for 50% of probability of exceedence.

To clarify our point, it is interesting to trace how these differences may contribute to the designation of wetness of any year. This, in turn, is important for those concerned with water availability for diversions and at the same time safeguarding the Delta-Bay water needs.

The normal Four River Index mean runoff is 17.2 MAF (from 75% of the Sacramento River watershed). This implies that all years which have natural runoff higher than that (roughly 125% of the normal which corresponds to 21.5 MAF) are considered as wet years (Table I.12) and their number comprises more than one third of the total years under discussion (or 36.2%).

However, when values of runoff of all wet years of the DWR's Four River Index (denoted as the first classification) are compared with values of runoff for the same probabilities of wet years of a total river inflow classification (denoted as the second classification), then only the runoff of 1938, 1952, 1956, 1958, and 1974 (the period 1921-1978) can be considered above normal but not as wet years (125% of 28.3 corresponds to 35.4 MAF) as far as Delta-Bay water quality and biological conditions are concerned.

Using the same approach, it is possible to demonstrate that the majority of below normal (50-74% probability of occurrence) and sub-normal (75% of normal) of the first classification corresponds to below sub-normal and critical dry years if the total river inflow classification is used. But the limits of runoff below sub-normal and critical dry years in this case are much higher and their range is equal to 14.2-21.1 MAF and 7-14 MAF, respectively (Table I.12).

Therefore, the statistical model which incorporated the Four River Index as a basis for the water-year-type classification is shown to be inadequate in assessing statistically valid values of the annual unimpaired runoff entering the Delta-estuarine system.

These enormous differences strongly suggest the cautious use of this classification as the basis for decisions on water diversions during the year.

For example, the comparison of the value of regulated total Sacramento-San Joaquin River inflow to the Delta with the data on flow of different probabilities obtained from the frequency curve for the Four-River Index and for the NRI of the Sacramento-San Joaquin River shows the following:

First. The values of regulated river inflow when compared with the probability of occurrence of runoff of the Four-River Index yields a higher number of years in the wet categories than using the probability of occurrence of the total natural river inflow. (Table I.12).

Second. As a result of the above, even under highly regulated conditions in years like 1962, 1968 and 1978 when the amount of diverted water (NRI-RRI) was equal to 9.0, 7.0 and 17.0 MAF, respectively (which correspond to 36, 34 and 35% diversion of the NRI), according to the Four-River Index, the RRI of these years may be classified as mean wet (21-27 MAF) for 1978, and below normal (16-17.2 MAF) for 1962 and 1968.

However, classification of the same years, according to the ranges of wetness of the total natural Sacramento-San Joaquin River inflow, will place them into categories of below normal (26-28.3 MAF) for 1978 and critical dry (14-19 MAF) for 1962 and 1978.

Third. It must be emphasized that when the Four-River Index is used to categorize the wetness of each year, according to the residual values of the RRI to the Delta, it may lead to the conclusion that there are no shortages of water for the Delta-Bay ecosystem inasmuch as the majority of the RRI corresponds to the Four River Index wetness characterized as years of abnormal or high wetness.

For example, for the years 1959, 1961, 1964, 1972, 1979 and 1981, the RRI to the Delta corresponds to median and sub-normal category of the Four-River Index classification. This may lead to the erroneous conclusion that the riverine-estuarine system has an adequate freshwater supply which can be used to provide additional water diversions without any negative effect to the system. However, for the total Sacramento-San Joaquin River inflow system, they fall into the category of dry and critical dry years (Table I.12).

It should be noted that this range of probability of runoff, i.e., ranging between normal and dry years, is the category of greatest interest to water developers the world over for both short and long-term water supply planning (but not for seasonal flood control) because statistical information on water supply for probabilities 50-95% or even 97-99% is a crucial one for semi-arid zones. (The runoff values which correspond to these probabilities of occurrence are such that any essential changes in annual and monthly flow due to climatological factors and superimposed water diversions may automatically transform a normal year into a sub-normal, dry, critical dry and even drought year.)

At the same time, the knowledge of the variability of flow (years of different wetness) is of paramount importance to permit the environmental specialist to predict possible ecological changes in water quality, sanitary conditions, residence time, tolerance level of hydrophysical changes, etc. on the estuarine environment which should be incorporated into any type of physical or biological modeling of the riverine-estuarine system.

Fourth. If water planners rely upon water-year-type classification based on the total natural inflow to the Delta and Bay, then it becomes obvious that for the majority of cases there is no excess water supply. However, under the water allocation system based on the Four-River Index, the Delta-Bay system has been subjected to significantly greater diversions over prolonged periods of time (since the beginning of CVP and SWP operation).

Similarly, under the total basin classification system, years of lower than sub-normal wetness are considered relatively rare events. However, the San Francisco Bay ecosystem continues to be subjected to nearly continuous conditions of sub-normal and even lower than sub-normal wetness.

In conclusion, during the last three decades, water planning, construction of water facilities and intensified withdrawals have been based partially or entirely on three different water-year-type classification systems:

1. The Sacramento River inflow to Shasta Reservoir, accounting for 8% of the total (Bureau of Reclamation, 1965);

2. The Sacramento-San Joaquin upper river runoff, comprising 80% of the total (DWR modified method, 1974), and

3. The Four-River Index, corresponding to 67% of the total runoff to the Delta-San Francisco Bay (D1485, DWR; SWRCB, 1978).

The use of these different classification systems raises the following two questions:

1. What ecological principles and hydrological procedures are utilized to develop estuarine basin water-year-type classification systems in the San Francisco Bay system and elsewhere?

2. From the standpoint of both balanced water development and preservation of natural resources of the Delta-Bay ecosystem, which classification system should be employed to guide the balanced management of the Delta-Bay ecosystem: The Four-River

Index or total Sacramento-San Joaquin River runoff?

In response to these questions, the choice of water-year-type classification should not be a matter of arbitrary decisions based on the competing interests and their single-purpose requirements.

The choice of runoff classification should be based on the careful analysis of historic flow patterns derived from 100% of the river watershed. It is this total flow that makes this estuary an estuary. The spatial and temporal distribution of physical and chemical characteristics, diversity of organisms, productivity, etc. are all determined by this flow.

The past, present and future of any estuarine regime depend upon the cumulative interaction between the total freshwater discharges and the total brackish and salty water entering from the adjacent coastal zone, but not on the arbitrary manipulation of their values (Ketchum, 1983; Bowden, 1967; Officer, 1976; Pritchard, 1967; Fischer, 1979)

In this case, the acceptable levels of water withdrawals as well as the establishment of statistically-valid ecological criteria for the riverine-estuarine system, will be based on the genesis of the estuary.

Hence, the water-year-type classification is only of value for consideration of the impact of human activities on the estuary if the integral flow from the entire watershed will be taken into account.

In this report, we have used the year-type classification based on the total natural river inflow/Delta outflow for the analysis of changes of runoff variables which took place because of upstream and Delta and total water diversions.

Table I.12 Comparison of the Four River Index and the Combined Sacramento-San Joaquin River Inflow Water-Year-Type Classifications

Probability of Exceedance	Years of Recurrence	Runoff of the Four-River Index MAF	Number of Events and Years	Total Sacramento-San Joaquin River Inflow	Number of Events and Years
0.5-0.8	Historical Wet		5 (1956, 1958, 1969, 1974, 1982)		1 (1983)
1	100	38		65	
	Critical Wet		5 (1965, 1967, 1970) 1980, 1984)		
5	20	31		51	1 (1982)
	Very Wet		2 (1963, 1973)		
10	10	27		45	
	Mean Wet		4 (1971, 1973, 1975, 1978)		5 (1956, 1958, 1969, 1974, 1984)
25	4	21		35	
	Above Normal				5 (1963, 1965, 1967, 1970, 1980)
Normal		17.2		28.3	1 (1973)
50	2	16	5 (1957, 1962, 1966, 1968, 1979) (median)	26	2 (1971, 1978)
	Sub-Normal		7 (1959, 1960, 1961, 1964, 1972, 1976, 1981)		1 (1975)
75	4	12		19	
	Dry				7 (1957, 1959, 1962, 1966, 1968, 1972, 1979)
90	10	9		14	
	Critical Dry				5 (1960, 1961, 1964, 1976, 1981)
95	20	7		11	
	Drought		1 (1977)		
99	100	5		7	1 (1977)

PART II

COMPARATIVE ANALYSIS OF NATURAL AND REGULATED RUNOFF CHARACTERISTICS OF THE SACRAMENTO-SAN JOAQUIN RIVER DELTA SYSTEM

General Remarks

Our analysis of annual runoff fluctuations, mainly for the period 1921-78 during which three distinct cycles of wetness were established, used the following scheme:

1. The description of general characteristics of unimpaired and impaired annual runoff fluctuations (runoff statistics and category of wetness);

2. Perennial variability of regulated runoff before and after CVP and SWP operations, including annual upstream and Delta diversions;

3. Probability of occurrence of impaired runoff values that would be observed under unimpaired river inflow and Delta outflow conditions (NRI, NDO);

4. Annual and monthly water deficit for the period 1921-83 with major emphasis on the period 1956-78.

This information allows us to answer, in a general manner, the following questions:

1. Were the limitations of natural water supply considered in establishing California water development plans?

2. Is there sufficient water to justify increasing water diversions and enlarging the capacity of conveyance facilities to transfer more water from the Delta to any water users?

These are only the first of many questions regarding factors that affect the hydrologic, oceanographic and biologic characteristics of the ecosystem.

II.1 Annual Variability of Natural and Regulated Runoff Discharges to the Delta-San Francisco Bay System

II.1.1 Runoff Statistics

The natural runoff (NRI and NDO) forming in the Sacramento-San Joaquin River watershed averages 28.3 and 27.7 MAF (or 34.9and 34.2 Km^3, respectively) over a 58-year period (Table II. 1).

The year-to-year fluctuations of regulated seasonal runoff repeat the same patterns as those observed with natural runoff, but their values as well as their probability of occurrence and other statistical parameters, are much different (Fig. II. 1, 2, Table II.1, Appendix 1-7).

Table II. 1 Statistics of the natural and regulated Sacramento-San Joaquin River perennial inflow/Delta outflow

Period	Range Q MAF	Q MAF	Cv	Cs	Standard Deviation MAF
		Natural River Inflow (NRI)			
1921-1978	6.75-56.53	28.30	0.44	0.39	12.50
		Regulated River Inflow (RRI)			
1921-1978	5.57-55.76	22.12	0.51	0.99	11.34
		Natural Delta Outflow (NDO)			
1921-1978	5.81-56.26	27.18	0.45	0.90	12.23
		Regulated Delta Outflow (RDO)			
1922-1982	2.53-52.97	20.41	0.54	0.95	11.02

The means of the annual natural and regulated RUNOFF varied considerably from year to year (Figs. II, 1, 2).

The maximum and minimum volumes of annual runoff corresponded to the quite wide range of percentage of their normal (Qn) (Table II. 2):

Table II. 2 Maximum and minimum volumes of runoff (million acre-feet)

Ratio	Q NRI	Q RRI	Q NDO	Q RDO
Qmax of 100% Qn River	199.8	197.0	207.0	194.9
Qmin of 100% Qn Delta	23.8	19.7	21.4	9.3

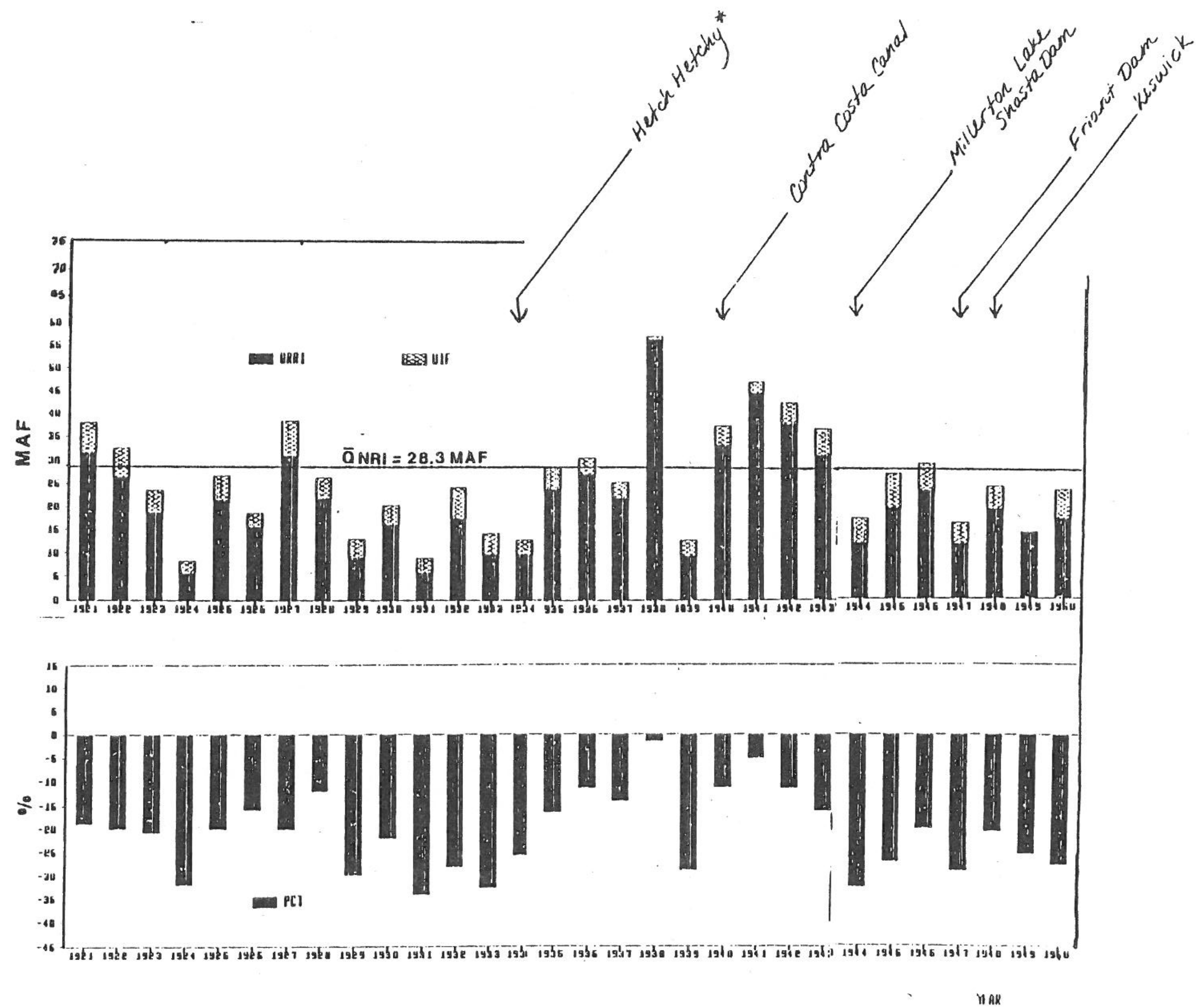


Fig II.1a The Chronological Fluctuations of Natural and Regulated River Inflow to the Delta, and Percentage of Upstream Water Diversions from the Sacramento-San Joaquin Rivers Watershed (1921-83). (QRRI = Mean Annual Regulated River Inflow; DIF = Difference Between Natural and Regulated Mean Annual River Inflow in Million Acre Feet; PCT = Percentage of Mean 1921-78 Natural River Inflow; * year of completion of facility)

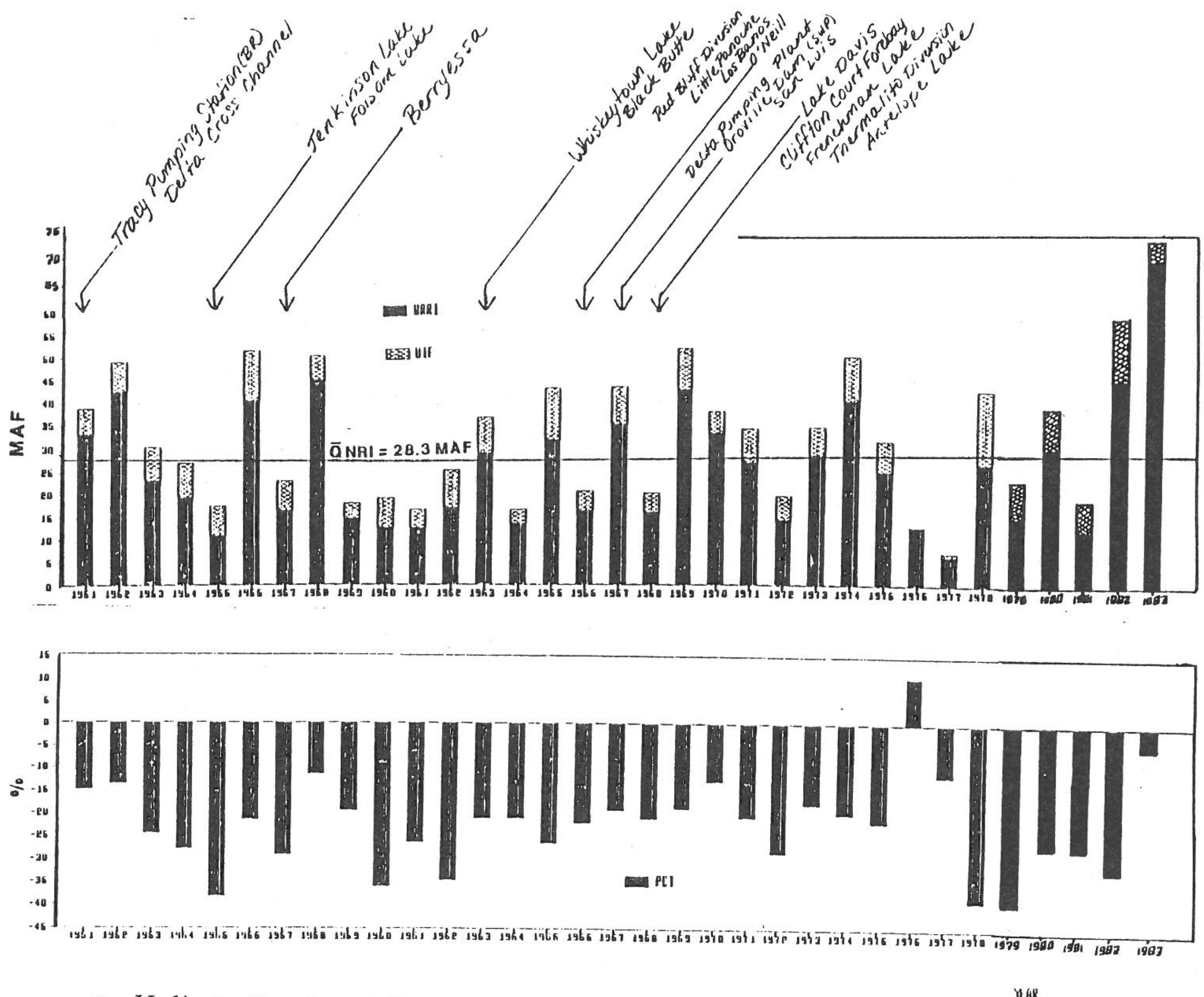


Fig.II.1b The Chronological Fluctuations of Natural and Regulated River Inflow to the Delta, and Percentage of Upstream Water Diversions from the Sacramento-San Joaquin Rivers Watershed (1921-83). (QRRI = Mean Annual Regulated River Inflow; DIF = Difference Between Natural and Regulated Mean Annual River Inflow in Million Acre Feet; PCT = Percentage of Mean 1921-78 Natural River Inflow; * year of completion of facility)

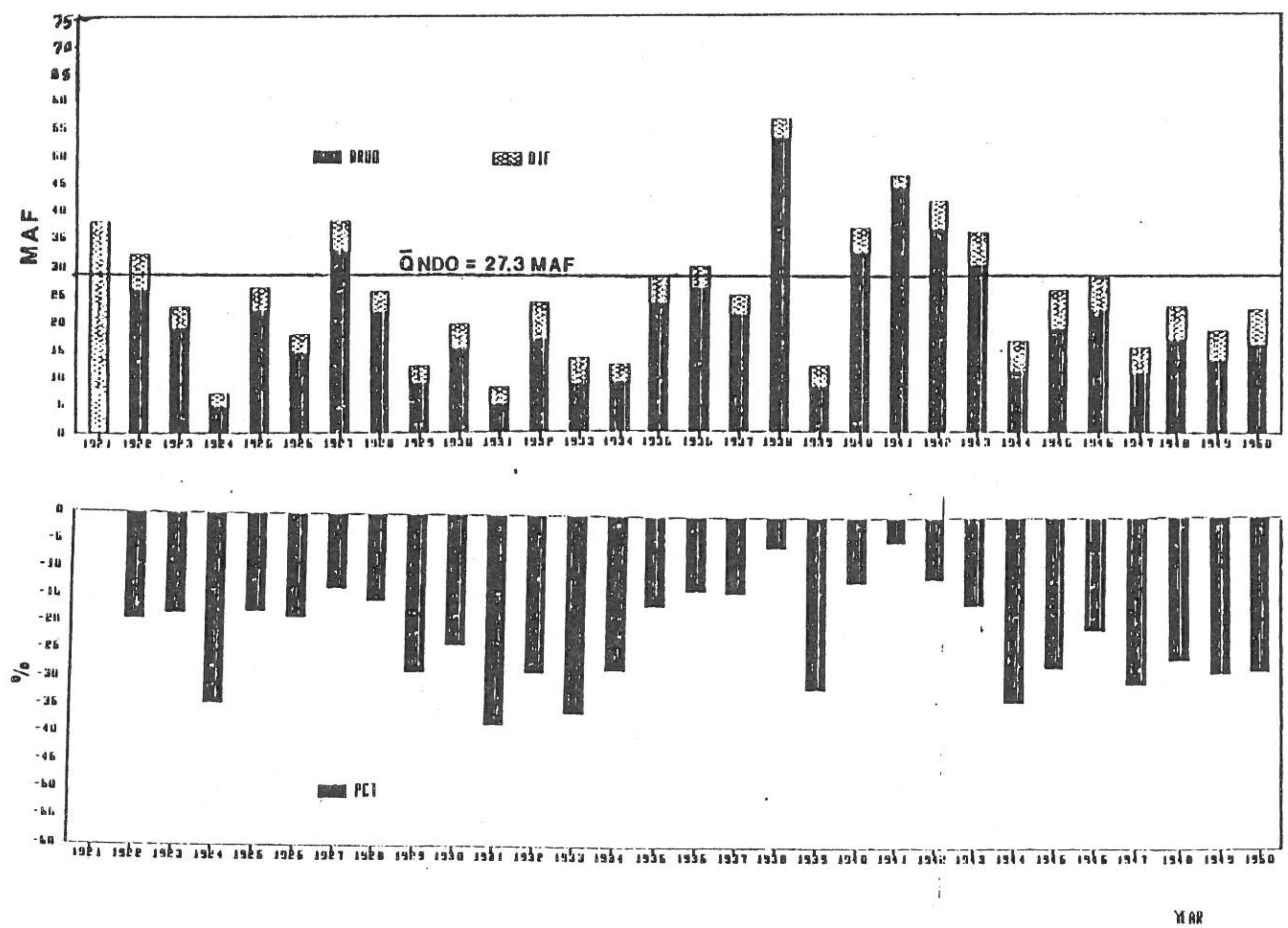


Fig. II.2a The Chronological Fluctuations of Natural and Regulated Delta Outflow to the San Francisco Bay, and Percentage of Combined Upstream and Downstream Water Diversions from the Sacramento-San Joaquin Rivers Watershed (1921-83). (QRDO = Mean Annual Regulated Delta Outflow. DIF = Difference Between Natural and Regulated Mean Annual Delta Outflow in Million Acre Feet; PCT = Percentage of Mean 1921-78 Natural Delta Outflow.)

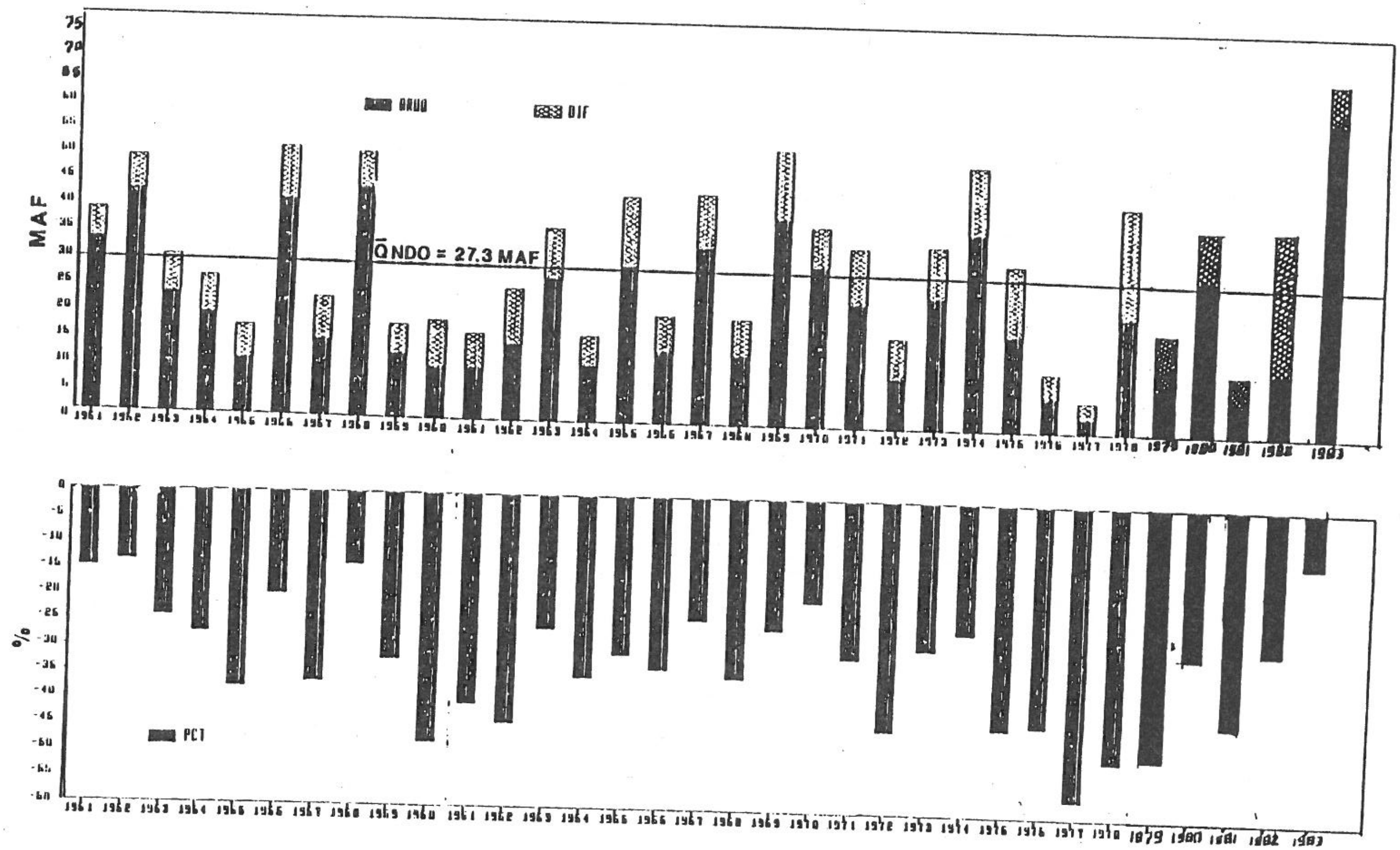


Fig. II.2b The Chronological Fluctuations of Natural and Regulated Delta Outflow to the San Francisco Bay, and Percentage of Combined Upstream and Downstream Water Diversions from the Sacramento-San Joaquin Rivers Watershed (1921-83). (QRDO = Mean Annual Regulated Delta Outflow. DIF = Difference Between Natural and Regulated Mean Annual Delta Outflow in Million Acre Feet; PCT = Percentage of Mean 1921-78 Natural Delta Outflow.)

However, the mean perennial RRI (22.12 MAF) and RDO (20.41 MAF) correspond only to 78.4 and 75.1% of their normal values, respectively (Table II. 1).

The ratio between maximum and minimum annual NRI and NDO is equal to 8.4 and 9.7 times over, respectively; while the equivalent ratio for RRI and RDO is equal to 10.0 and 20.9, respectively.

The differences between these two sets of ratios (e.g., natural and regulated runoff) especially for the RDO might be attributed to the fact that water diversions have the highest impact on the net annual runoff to the Delta-Bay system when the natural runoff is characterized by its low or lowest values (e.g., dry or critical dry year of wetness).

It should be emphasized that the same regularities are typical for seasonal ratio between upstream and downstream characteristics of natural and regulated runoff (as will be discussed later).

In general, water withdrawals from the Sacramento-San Joaquin Rivers system have not changed (Figs. II. 1, 2) the trend of the annual fluctuations of runoff since their amplitude is still governed by natural causes (rain, snowmelt). In the majority of cases, as mentioned earlier, periods of 3-6 consecutive years of low wetness are followed by 1-2 years of high wetness, and only two periods were observed between 1912 (Table II. 4) and 1978 (Fig. II. 1, 2) with three consecutive years (1914-16) and four consecutive years (1940-43) of high wetness. These years of the pre-project conditions were influenced to a lesser extent by the water diversions than any of the high wetness years of the post-project conditions (since 1944).

As a result of water diversions, the years of natural low wetness, like 1924, 1931 and 1977, are characterized by the lowest regulated annual runoff, and at the same time, the peaks of the highest would-be natural runoff were truncated by regulations in about 10 to 30%. The amplitude of natural flow is less than the amplitude of the regulated river inflow and Delta outflow. The regulated river inflow and Delta outflow fluctuations are similar in time, but their level of diversions is very different.

II.1.2. Dynamics of Annual Wetness (Water-Year-Type)

The comparison of years of different wetness of natural and regulated annual RUNOFF with the normal river inflow on the one hand, and Delta outflow on the other, for the period 1922-1982 shows the following peculiarities (Table II. 3).

Table II. 3 The number of years of different wetness in relation to "normal" runoff - Annual

Runoff Character-istics	Wettest and Wet Years	Years	Sub-normal and Dry Years	Years	Critical Dry Years	Years
Qnri	1921, 1927, 1938, 1940-43, 1951, 1952, 1956, 1958, 1963, 1965, 1967, 1969-70, 1974, 1978, 1982	18	1925, 1930, 1944, 1947, 1949, 1955, 1959, 1961, 1964, 1968, 1972	11	1924, 1929, 1931, 1933, 1934, 1939, 1976, 1977	8
Qrri	1938, 1941-42, 1952, 1956, 1958, 1969, 1974, 1982	9	1926, 1930, 1932, 1945, 1948, 1949, 1950, 1954, 1957, 1959, 1962, 1966, 1968, 1979	14	1924, 1929, 1931, 1933, 1934, 1939, 1944, 1947, 1955, 1960, 1961, 1964, 1972, 1976, 1977, 1981	16
Qndo	1921, 1927 1938, 1941-43 1951, 1952, 1956, 1958, 1963, 1965, 1967, 1969-70, 1974, 1978, 1982	18	1926, 1930, 1944, 1947, 1949, 1955, 1959-61, 1964, 1968, 1972	11	1924, 1929, 1931, 1933 1934, 1939 1976, 1977	8
Qrdo	1938, 1941, 1942, 1952, 1956, 1958, 1969, 1974 1982	9	1923, 1926, 1930, 1932, 1945, 1948, 1950, 1954, 1957, 1962, 1975	11	1924, 1929, 1931, 1933, 1934, 1939, 1944, 1947, 1949, 1955, 1959, 1960, 1961, 1964, 1966, 1968, 1972, 1976, 1977, 1979, 1981	21

Note: 1. Wettest and wet years - the Qnri and Qrri and Qndo and Qrdo of any year are 25% or more above "normal" (28.3 and 27.2 MAF, respectively)

2. Sub-normal and dry years of wetness - when the same runoff parameters are 25% or more below "normal."

3. Critical dry years of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

Table II. 4 Upstream Diversions of the Sacramento and San Joaquin Rivers, 1912-1929

Year	Natural Sacramento River Annual Inflow (acre feet)	Upstream Gross Diversions MAF	Percentage of Diversions	San Joaquin Natural River Inflow (acre feet)	Upstream Diversions MAF	%
1911-1912	12,829,400	1.100	8.6	3,868,850	2.135	55.3
1913	15,150,000	1.091	7.2	3,173,900	2.128	67.1
14	36,443,000	1.103	3.0	11,631,550	2.515	21.7
15	30,480,800	1.154	3.8	8,607,900	2.364	27.4
16	30,037,000	1.430	4.8	11,953,000	2.546	21.3
17	20,757,600	1.563	7.5	8,816,950	2.743	31.1
18	12,687,400	1.902	15.0	5,860,546	2.600	44.4
19	18,828,100	2.314	12.3	5,315,600	2.344	44.0
20	10,447,300	2.274	21.7	4,651,000	2.274	48.8
21	29,355,300	2.222	7.6	7,634,750	2.651	34.7
22	21,374,200	2.196	10.3	10,195,000	2.570	25.2
23	16,271,500	2.141	13.2	7,724,400	2.916	37.8
24	6,222,600	2.177	35.0	2,447,550	1.831	74.8
25	20,110,100	2.105	10.5	7,044,850	2.725	38.8
26	15,142,600	2.479	16.4	4,858,600	2.684	55.1
27	29,467,900	2.634	8.9	8,375,350	3.157	37.7
28	20,551,700	2.495	12.1	6,462,600	2.872	44.4
29	9,600,700	2.422	24.7	4,321,000	2.752	63.6
1889-1929	24,800,000					
1909-1929	20,592,000					
1919-1929	17,919,700					
1924-1929	19,027,300					

1. Sacramento River Diverted Inflow to the Delta, Department of Public Works, V.27, 1931

2. San Joaquin River Inflow, the same source (with addition of diversion, returning water and consumptive use, performed by M. Rozengurt)

1. The number of the wettest and wet, sub-normal and dry, and critical dry years of wetness of the Qnri and Qndo are equal. This implies that under natural conditions, the water losses sustained by the Delta due to evapotranspiration do not affect noticeably enough the values of the natural Delta outflow to the Bay regardless of the water year type classification.

2. However, the number of the wettest and wet, sub-normal and dry and critical dry years of the Qrri differ significantly in comparison with the Qnri, namely: the number of years of a high wetness of regulated inflow decreased to half while the number of sub-normal and critical dry years increased as much as 1.3 and 2 times.

3. Almost the same ratios characterize Qrdo vs. Qndo, namely: the number of wet years of the RDO decreased to half; the number of critical dry years increased as much as 1.6 times; while the number of sub-normal and dry years of wetness stayed equal.

It is important to emphasize that the above-mentioned differences must not be considered as the result of purely arithmetic manipulations, but as the consequence of man's activities superimposed upon natural alterations of years of different wetness (or water supply from the entire river watershed). In light of this statement, we attempt to analyze some major features of "collaboration" between Sacramento-San Joaquin annual natural runoff fluctuations and diversions.

First. Under natural conditions, unimpaired annual runoff during the 58-year period fluctuated within the predominant range of 24.5-34.5 MAF (Fig. II. 3) (approximately 56% of the total number of observations). As can be seen, the median of 26.0 MAF of this range is very close to the normal (see Fig. I. 17). There are relatively even alterations of several consecutive years of different wetness which had predominant duration of 2-6 years (Figs. II. 1, 2). During this period, it was not a rare event to witness 2-4 years of sub-normal flow followed by 1-2 years of wet or close to the "normal" runoff. On the average (as will be seen later from the 5-year running means evaluation), the water supply to the Delta-Bay ecosystem (e.g., NRI and NDO) deviated within +25-30% of the "normal" (except in 1929-34 when consecutive sub-normal and dry years resulted in a severe water deficit). During these would-be natural conditions the above normal years accounted for 30%, and critical dry years 13.1% of the total of the period from 1921-1978.

The probability of occurrence of the natural wettest (56.5 MAF; 1937-38) and driest (6.8 MAF; 1976-77) hydrological years accounted for 2.5 and 98.4%, respectively (or not less than once per 40 and 63 years).

In the majority of years, natural river inflow/Delta outflow of the range 34.5-24.5 MAF corresponds to the probability of occurrence 30-54% (or not less than once per 3.3-2.4 years,

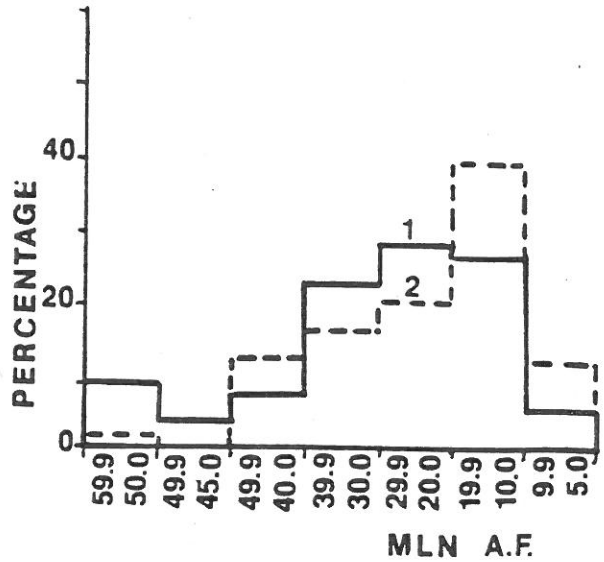


Fig.II.3a . Annual Histogram of Occurrence of (1) Natural (1921-78) and (2) Regulated (1921-82) River Inflow to the Delta.

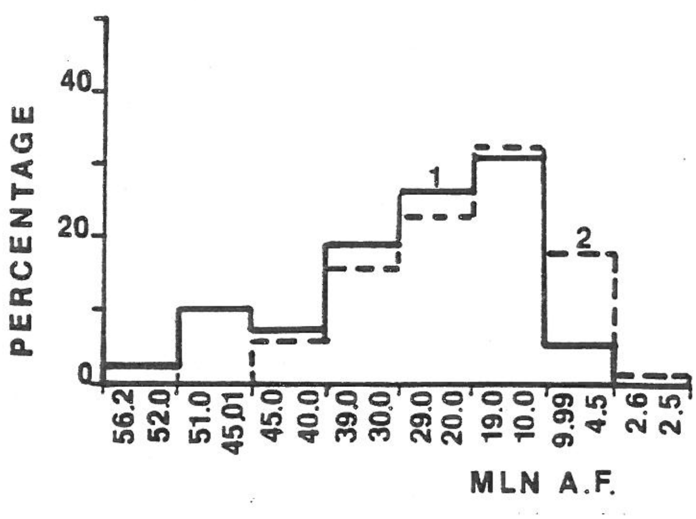


Fig.II.3b . Annual Histogram of Occurrence of (1) Natural (1921-78) and (2) Regulated (1922-82) Delta Outflow to the Bay.

Fig. I.17). These natural conditions would have prevailed if water management needs for water had not prevailed over the river's natural water supply.

Second. However, since the beginning of the twentieth century, water development has become the vital feature of the economic growth and welfare of California.

During the initial period of 1912-29, for which most of the data are available, the annual diversions from the upper parts of the Sacramento and San Joaquin Rivers accounted for 1.1-2.6 MAF and 1.8-3.2 MAF respectively (Table II. 4) (Department of Public Works, 1931). The range of diversions in percentage of the mean for the 18-year period for the Sacramento River was 3% (1914) to 35% (1924), and for the San Joaquin River was 38% (1927) and 75% (1924).

From this example, it can be seen why the use of percentage values of diversions without the corresponding absolute volume of water withdrawal, may lead to erroneous conclusions about the possible impact of the diversions on the water supply to the system. It is also important to note that almost the same amount of water withdrawn at years of different wetness may represent quite different percentages of diversions. For example, in the wet year of 1921, 2.2 MAF (7.6%) were diverted from the Sacramento River, almost the same amount as for the driest year of 1924, corresponding to 35%. The San Joaquin River diversions of 1912, 1916 and 1926 illustrate the same peculiarities in manipulation of percentage of water withdrawals and their absolute volumes, i.e., the percentage of diverted water in 1916 was equal to 21.3%, while for the two other years almost the same volumes correspond to 55.1 and 55.3% (Table II. 4).

The same amount of water diverted from annual or seasonal runoff for years of different wetness will have a different impact on the ecological conditions of the Delta-San Francisco Bay ecosystem due to the fact that the residual inflow discharged to the system after diversions in above normal, and especially in wet years, will be equal or slightly less than the normal runoff, while diversions performed during natural sub-normal or dry years shift residual runoff (RRI and RDO) to the critical dry or drought years. Hence, the residual runoff of 1924 for both rivers can be considered as a typical example, namely, the diversion which took place during this critical dry year left a residual inflow which can be characterized as a drought.

It is important to emphasize that since 1919 for the Sacramento, and since 1912 for the San Joaquin River until 1929, almost the same amount of water has been withdrawn annually regardless of the wetness of the year. In practice, beginning in the late 1920's, San Joaquin River inflow to the Delta was reduced to a small proportion of its unregulated flow and Sacramento River RUNOFF provided the major contribution of water supply to the Delta.

It is also important to note that the first significant decline of commercial fish catch during the late 1920's was preceded by ten to fifteen years of this diversion practice.

Third. In the following 49-year period (1930-78), the intensity of water development increased markedly (Figs. II. 1, 2), and starting with the operation of Shasta Dam in 1944 and the many subsequent facilities of the Central Valley Project (CVP) and State Water Project (SWP), between 1944 and 1978 the two types of water diversions have become inseparable parts of water regulation practice in the Sacramento-San Joaquin River watershed, namely:

1) Upstream, which include multi-purpose water accumulation in reservoirs behind dams (flood control, power plant operations, maintenance or navigational depths, and local industrial, municipal and agricultural intakes);

2) Downstream water diversions (Delta diversions), the primary function of which is to provide water supply for the irrigation of the southern part of the Central Valley and Delta agriculture through the Delta and out of the Delta conveyance system. The Sacramento has become the major source of flow to a portion of the mouth of the San Joaquin River through the construction of different types of water conveyance facilities.

It should be noted that before the project operations, the cumulative capacity of different types of small storage facilities in the Sacramento-San Joaquin Rivers watershed was equal to approximately 4-5 MAF; after the projects' completion, this value reached 15-18 MAF (or 55-66% of a total combined NRI). Such water accumulation requires partial recharging of the reservoirs practically each year. In addition, many water losses are sustained by the Delta system due to conveyance of 2-5 and more MAF per year from areas of origin in the north to the regions of major consumption in the south. Therefore, the Delta has experienced the combined pressure of up and downstream water diversions, and the remaining regulated Delta outflow represents the final residual modified runoff to the San Francisco Bay.

II.1.3 Impact of Water Diversions on Annual Natural Runoff Fluctuations

The percentages of upstream and downstream diversions (as well as their absolute values) are different (Fig. II. 4 and Tables II. 5-10). As has been said, there are two periods of water regulations: 1) pre-project and 2) post-project, which describe two different stages of water development. That is why it would be logical, here as well as in the later discussion, to underline their major differences, whose origin lies in the increase in water withdrawals from the first to the second period as much as 3-5 times.

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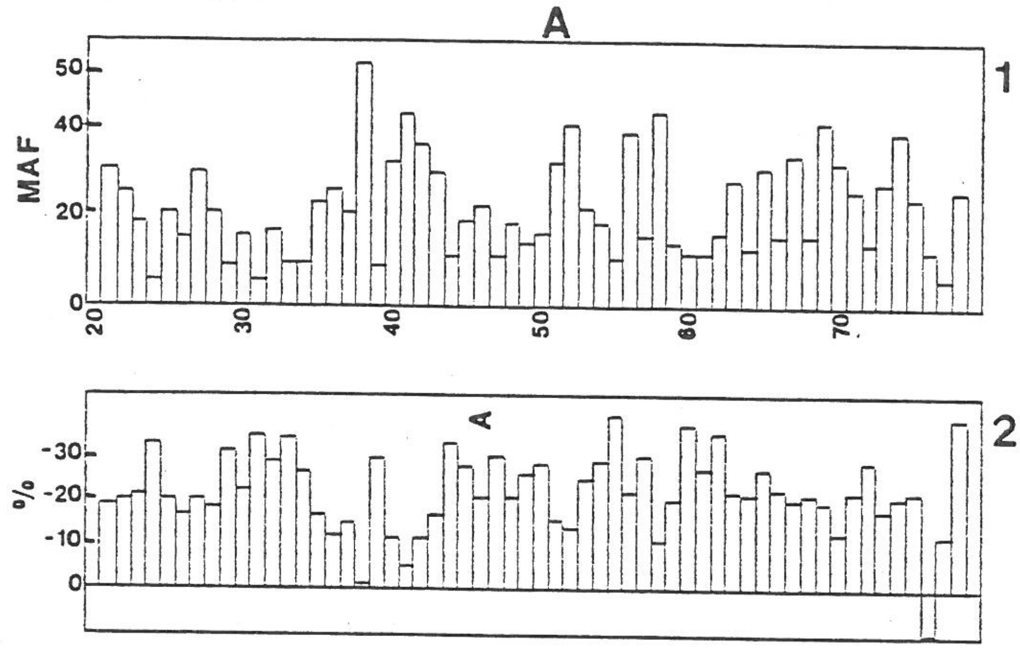

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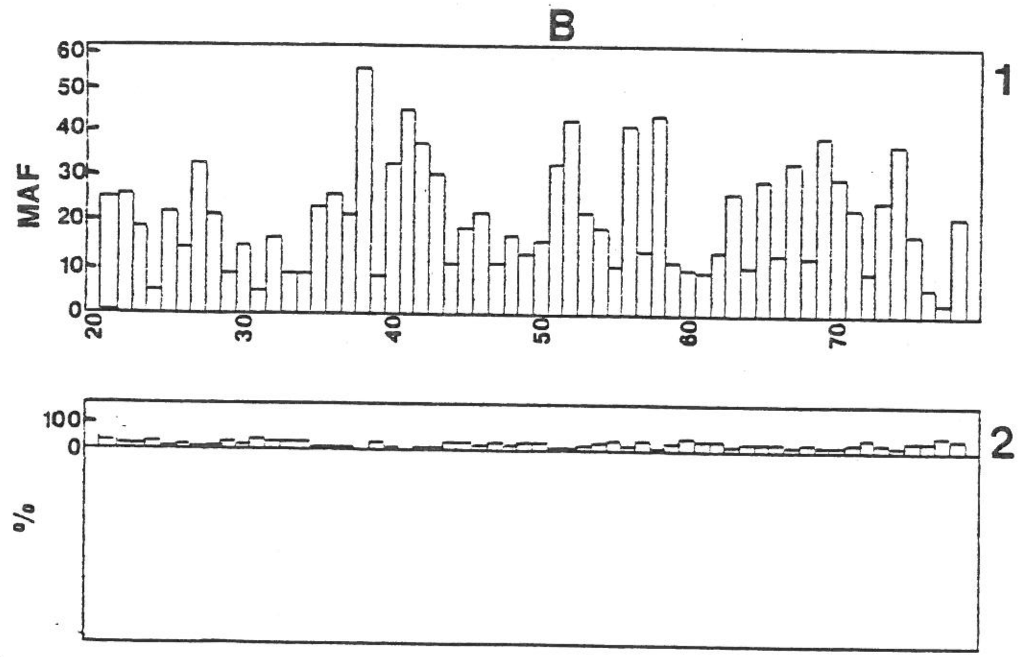

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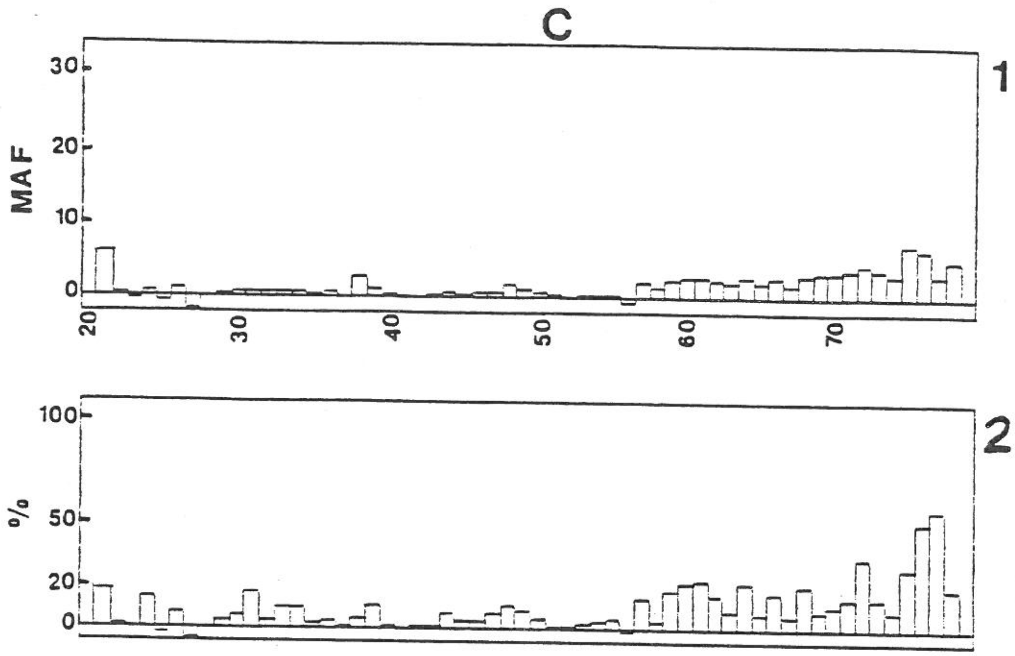

Fig. II.4 . (A,B,C)

A-1. Annual Chronological Fluctuations of Regulated River Inflow (Qrri) to the Delta

-2. Percentage of Upstream Diversions

B-1. Annual Chronological Fluctuations of Regulated Delta Outflow (Qrdo) to the San Francisco Bay

-2. Percentage of Downstream Diversions

C-1. Annual Chronological Values of Inner Delta Diversions (Qrri-Qrdo)

-2. Inner Delta Diversions in Percentage of Regulated River Inflow.

Table II.5 The monthly and annual volumes of upstream diversions from 1956 to 1983 (in thousand acre feet)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Annual
1956	-33	53	5304	-889	-257	-60	1883	2348	1727	977	155	-271	-11017
1957	-179	-348	-279	72	2065	230	1449	2307	1426	242	-131	-268	-6612
1958	-240	-282	374	726	1023	196	-163	2894	1547	672	-88	-465	-5498
1959	-395	-392	-316	843	447	472	1667	1280	665	-89	-334	-83	-3587
1960	-77	-68	7	300	1548	1690	1670	1662	869	-94	-208	-208	-6911
1961	-95	86	400	192	327	554	1322	1622	691	-123	-268	-202	-4411
1962	-33	128	412	367	1804	213	2607	2106	1719	298	-272	-394	-8706
1963	558	-245	223	930	723	977	1331	2341	1449	456	-120	-528	-7754
1964	-380	470	-509	282	-94	349	1405	1859	1020	-98	-358	-484	-3516
1965	-249	178	5118	-232	-362	582	2599	2075	1712	594	-33	-517	-11491
1966	-627	256	-466	-10	172	1350	2478	1915	405	-184	-354	-291	-4585
1967	-242	440	325	1401	-1437	1816	916	2852	2337	1254	-52	-723	-8676
1968	-644	-473	-254	646	1879	506	1537	1543	496	-200	-285	-400	-4279
1969	-234	134	772	3495	-1315	-822	2639	4377	1925	759	-479	-904	-9892
1970	-629	-547	1448	2818	-2186	580	1175	2111	1290	-2	-430	-732	-4727
1971	-460	972	-494	-31	266	2530	1493	2759	1917	3	-759	-978	-7258
1972	-579	-274	-7	237	671	2345	1995	1839	787	-332	-558	-573	-5559
1973	-425	43	444	-94	16	-41	2216	4162	140	-170	-516	-642	-6166
1974	-481	1952	73	574	-804	5790	-209	3260	1856	77	-818	-1132	-10055
1975	-912	-895	-845	-203	959	2137	1311	4008	2729	121	-622	-806	-6859
1976	-480	-598	-916	-396	270	539	692	857	-63	-352	-350	-367	+1153
1977	-131	85	-138	-109	40	195	402	519	386	-140	-129	-4	-803
1978	96	126	1563	4005	1445	1777	2050	2716	2988	848	-443	-455	-16146
1979	-550	-361	-384	208	650	1456	1998	1804	1063	-327	-579	-574	-5172
1980	-213	-9	231	2086	1475	-1358	1774	2584	1788	552	-394	-623	-6753
1981	-467	-397	-122	1978	596	1372	1453	1375	363	-530	382	-458	-1986
1982	-2	3030	1883	-775	2130	1297	2527	2731	1640	396	-716	-961	-12173
1983	-239	192	-254	885	-276	-881	387	2567	3509	826	-571	-1259	-3189

Table II.6 The monthly and annual inner Delta seasonal water losses from 1956 to 1984* (in thousand acre-feet)

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Annual
1956	108	48	-687	-398	-244	-37	-135	46	104	210	189	152	-644
57	147	109	90	-23	-53	80	183	161	386	499	455	283	2291
58	153	125	2	-176	-401	-224	-271	26	237	458	443	288	1456
59	221	136	73	-77	-140	161	285	306	408	521	463	175	2710
60	222	145	69	-46	-84	133	232	292	428	528	477	295	2781
61	241	2	78	-44	46	103	255	304	439	564	499	295	2879
62	230	42	64	42	-322	24	263	325	421	534	486	304	2662
63	33	139	35	-82	-68	10	-50	268	401	527	492	348	2349
64	221	8	93	-47	128	150	289	341	392	554	509	324	2988
65	215	56	-167	-130	83	141	55	321	420	548	478	304	2298
66	252	-3	-43	-34	12	191	273	336	440	545	517	310	2855
67	244	-98	-6	-80	-166	138	58	406	308	240	378	300	1933
68	238	110	88	-18	-58	308	418	498	-1296	588	548	490	3386
69	480	290	128	100	-490	430	210	440	350	494	566	182	3635
70	200	110	100	340	-274	280	360	412	508	592	526	334	3657
71	250	-152	148	252	54	330	312	404	558	672	654	372	3814
72	350	226	110	192	176	508	434	536	684	576	604	452	4840
73	412	16	274	72	-526	160	308	556	652	732	714	472	4058
74	364	170	270	326	80	-1862	300	624	734	900	826	444	3259
75	354	196	204	345	795	1334	710	649	532	644	862	683	7431
76	704	638	614	540	456	582	384	488	448	526	656	656	6683
77	348	144	281	402	218	252	188	242	271	325	331	248	3426
78	162	192	248	291	421	190	144	267	679	766	777	565	5282
79	430	327	464	16	-37	218	424	529	600	790	870	708	5339
80	505	357	325	171	237	253	356	410	577	656	799	614	5260
81	523	479	457	305	389	170	511	425	463	701	806	561	5790
82	382	201	325	24	432	385	426	518	448	502	731	347	4721
83	359	215	406	437	405	-4	219	265	521	588	674	360	4445
84	237	-147	7	155	306	444	538	514	599	849	817	459	4769

*Note: Calculated as the difference between regulated river inflow and regulated Delta outflow (RRI-RDO)

Table II.7 The monthly and annual volumes of total upstream and downstream diversions, 1956-1983 (x 1000 AF)*

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Annual
1956	75	101	4617	-1287	-501	-97	1748	2394	1831	1187	344	-119	10293
57	-32	-239	-189	49	2012	310	1632	2468	1812	741	324	15	8903
58	-87	-157	376	550	622	-28	0434	2920	1784	1130	355	-177	6854
59	-174	-256	-243	766	307	633	1952	1586	1073	432	129	92	6297
60	145	77	76	254	1464	1823	1902	1954	1297	434	269	87	9782
61	146	88	478	148	373	657	1577	1926	1130	441	231	93	7288
62	197	170	476	409	1482	237	2870	2431	2140	832	214	-90	11368
63	591	-106	258	848	655	987	1281	2614	1850	983	372	-180	10153
64	-159	478	-416	235	34	499	1694	2200	1412	456	151	-160	6424
65	-34	234	4951	-362	-279	723	2654	2396	2132	1142	445	-213	13798
66	-375	253	-509	-44	184	1541	2751	2251	845	361	163	19	7440
67	2	342	319	1321	-1603	1954	974	3258	2645	1494	326	-423	10609
68	-406	-363	-166	628	1821	814	1955	2041	-800	388	263	90	6265
69	246	424	900	3595	-1805	-392	2849	4817	2275	1253	87	-722	13527
70	-429	-437	1548	3158	-2460	860	1535	2523	1798	590	96	-398	8384
71	-210	820	-346	221	320	2860	1805	3163	2475	675	-105	-606	11072
72	-229	-48	103	429	847	2853	2429	2375	1471	244	46	-121	10399
73	-13	59	718	-22	-510	119	2524	4718	2052	562	198	-170	10235
74	-117	2122	343	900	-724	3928	91	3884	2590	977	8	-688	13314
75	-558	-699	-641	142	1754	3471	2021	4657	3261	765	240	-123	14290
76	224	40	-302	144	726	1121	1076	1345	385	174	306	289	5528
77	217	229	143	293	258	447	590	761	657	185	202	244	4226
78	258	318	1811	4296	1876	1967	2194	2983	3667	1614	334	110	21428
79	-26	-121	-15	162	550	1556	2322	4210	1531	330	164	18	10511
80	199	226	487	2190	1685	1203	2027	2879	2245	1078	250	-120	12013
81	-46	-11	256	916	902	1458	1855	1676	687	34	60	-11	7676
82	286	3164	2134	-798	2483	1743	2857	3121	1968	769	-112	-721	16891
83	24	347	75	1308	123	-850	-257	2713	3905	1280	-26	-1008	7634

*NOTE: Calculated as NDO-RDO. The negative values denote gainings.

Table II.8 The monthly and annual percentage of water diverted upstream of the Delta, 1956-1983*

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Annual
1956	-8.0	7.5	41.8	-8.3	-4.7	-1.5	45.3	38.6	43.5	56.8	20.5	-46.4	21.5
57	-24.4	-50.2	-40.3	7.4	60.8	5.4	51.9	51.0	51.7	27.4	-24.7	-49.4	29.1
58	-23.0	-28.2	18.6	21.8	9.3	2.8	-1.8	36.7	32.1	36.0	-9.7	-70.9	10.9
59	-66.3	-63.4	-47.5	30.8	12.6	19.9	64.1	62.7	56.5	-15.3	-78.4	-13.4	19.9
60	-16.6	-15.7	1.3	27.7	36.1	43.2	57.7	61.2	56.1	-16.6	-50.4	-53.0	36.1
61	-22.3	10.0	24.2	17.5	12.3	23.3	55.9	65.8	50.7	-22.9	-59.2	-50.7	26.5
62	-7.7	19.4	28.5	34.3	32.0	6.6	57.9	59.5	61.8	29.8	-54.6	-99.4	34.6
63	16.9	-28.3	9.3	40.6	11.8	34.8	18.0	39.9	48.1	34.3	-18.1	-97.4	21.2
64	-56.7	22.9	-49.8	13.4	-7.5	26.6	63.1	66.6	58.6	-15.2	-84.8	-132.2	21.1
65	-56.4	15.2	43.9	-2.8	-12.6	24.0	42.8	47.1	54.8	39.7	-3.5	-96.9	26.6
66	-119.8	14.2	-33.6	-.3	8.0	44.2	63.8	67.0	39.9	-33.0	-81.1	-71.1	22.1
67	-60.8	26.6	8.2	27.6	-44.0	34.2	16.6	37.0	36.9	42.7	-5.7	-127.5	19.9
68	-108.0	-75.4	-24.2	29.6	38.8	15.8	60.5	63.1	40.7	-32.7	-49.5	-88.8	21.0
69	-40.6	12.7	31.6	31.1	-17.4	-16.0	37.7	50.4	38.0	37.2	-57.6	-154.2	18.9
70	-84.8	-71.6	33.7	19.5	-53.6	13.9	53.5	66.5	59.4	-.2	-75.4	-153.1	12.4
71	-76.6	39.1	-10.5	-.7	11.2	53.2	37.2	57.9	51.1	0.2	-111.4	-168.0	21.2
72	-94.7	-34.8	-.4	13.8	31.0	59.4	69.1	68.1	47.4	-52.8	-126.2	-108.7	28.3
73	-61.1	2.6	18.9	-1.5	0.2	-.8	57.9	76.6	56.2	-20.0	-91.4	-126.3	17.7
74	-65.9	34.1	1.4	6.2	-28.8	68.6	-3.1	60.1	51.3	4.9	-104.6	-195.8	20.0
75	-155.1	-126.9	-80.8	-16.2	22.3	32.7	34.6	63.9	59.8	8.7	-86.6	-131.2	21.6
76	-46.1	-59.0	-101.3	-53.2	23.6	34.5	45.1	53.6	-9.8	-80.3	-64.8	-79.2	-9.9
77	-29.1	19.1	-34.3	-19.4	7.5	30.7	52.0	51.4	47.8	-36.8	-36.7	-.9	11.8
78	24.8	22.6	66.9	47.8	29.1	24.5	35.1	48.8	71.0	45.6	-64.4	-54.4	37.6
79	53.8	36.9	38.7	-11.0	-25.6	-56.9	-155.4	-133.1	-116.0	29.2	53.4	56.9	38.2
80	21.6	0.8	15.4	-28.0	-20.3	21.4	-86.0	-182.4	-122.3	-41.1	37.1	58.8	23.6
81	47.8	45.3	10.0	-138.1	-38.1	-76.3	-120.7	-139.3	49.3	51.6	38.2	54.5	23.7
82	0.2	-1.3	-34.6	12.9	-39.7	-24.4	-28.8	-67.0	76.4	-25.7	45.0	50.8	29.4
83	13.5	-7.5	4.3	-15.1	2.8	5.3	5.3	-40.8	-72.9	-25.1	26.1	56.1	6.0

*NOTE: Calculated as $\frac{NRI-RRI}{RRI} \cdot 100$. The negative values denote gainings.

Table II.9 The monthly and annual percentage of inner Delta diversions, 1956-1984*

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Annual
1956	24.4	7.3	-9.3	-3.4	-4.2	-.9	-5.9	1.2	4.6	28.2	31.5	17.7	-1.6
57	16.1	10.4	9.2	-2.5	-3.9	2.0	13.6	7.2	29.0	77.9	68.9	34.9	14.2
58	11.9	9.7	0.1	-6.7	-4.0	-3.3	-3.0	0.5	7.2	38.4	44.7	25.7	3.2
59	22.3	13.4	7.4	-4.0	-4.5	8.5	30.6	40.2	80.0	77.7	60.9	25.0	18.8
60	41.1	29.0	13.2	-5.8	-3.0	5.9	19.0	27.8	62.9	80.0	76.9	49.1	22.7
61	46.3	0.2	6.2	-4.8	1.9	5.6	24.5	36.1	65.5	85.4	69.3	49.1	23.5
62	50.0	7.9	6.2	6.0	-8.4	0.8	13.9	22.7	39.7	76.2	63.1	38.4	16.2
63	1.2	12.5	1.6	-6.0	-1.2	0.5	-.8	7.5	25.7	60.5	63.0	32.5	8.1
64	21.0	0.5	6.0	-2.5	9.5	15.6	35.2	36.6	54.4	74.8	65.2	38.1	22.7
65	31.1	5.6	-2.5	-1.5	2.5	7.6	1.5	13.7	29.7	60.8	49.2	28.9	7.2
66	21.9	-.1	-2.3	-1.2	0.6	11.2	19.5	35.7	72.1	73.6	65.4	44.2	17.7
67	38.1	-8.0	-.1	-2.1	-3.5	3.9	1.2	8.3	7.7	14.2	39.3	23.2	5.5
68	19.1	10.0	6.7	-1.1	-1.9	11.4	41.8	55.3	-180.0	72.5	63.7	57.6	21.1
69	59.2	31.5	7.6	1.2	-5.5	7.2	9.8	10.2	11.1	38.5	43.2	12.2	8.6
70	14.5	8.3	3.5	2.9	-4.3	7.8	35.2	38.8	57.7	65.0	52.6	27.6	11.0
71	23.5	-10.0	2.8	6.1	2.5	14.8	12.3	20.2	30.4	48.6	45.4	23.8	14.2
72	29.4	21.3	7.0	13.0	11.8	31.7	48.7	62.3	78.6	60.0	60.4	41.0	34.4
73	36.7	1.0	14.4	1.1	-9.3	3.4	19.1	43.7	59.8	71.7	66.1	41.0	14.2
74	30.0	4.5	5.5	3.8	2.2	-70.2	4.4	28.8	41.7	61.2	51.6	25.9	8.1
75	23.6	12.2	10.7	23.7	23.8	30.3	28.7	28.7	29.0	51.1	64.3	48.0	29.8
76	46.3	39.6	33.7	47.3	52.4	57.0	45.7	65.9	64.0	66.5	73.7	79.0	52.3
77	60.0	40.0	52.0	60.0	44.4	57.2	50.8	49.3	64.5	62.5	68.9	59.0	57.5
78	55.8	44.6	32.2	6.6	11.8	3.4	3.7	9.4	55.6	75.8	68.7	43.7	19.7
79	42.1	33.5	46.2	0.8	1.4	8.5	32.9	39.0	65.4	70.5	80.2	70.2	31.8
80	51.2	33.0	21.7	2.3	3.3	3.9	17.2	24.2	39.5	48.8	75.3	51.0	15.7
81	53.6	54.7	37.3	21.3	24.8	9.5	42.4	43.0	62.9	68.2	80.6	66.8	42.4
82	54.3	8.6	5.9	0.4	8.0	7.2	4.8	12.7	20.9	32.6	46.9	18.3	10.4
83	20.2	8.4	6.9	7.4	4.0	-0.2	3.0	4.2	10.8	17.9	30.8	16.1	6.4
84	10.7	-3.5	0	2.4	11.3	17.1	38.0	42.7	55.2	57.4	61.6	36.1	13.4

*NOTE: Calculated as $\frac{RRI-RDO}{RRI} \cdot 100$. The negative values denote gainings.

Table II.10 The monthly and annual percentage of total diversions, 1956-1983*

Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Annual
1956	-6.3	14.3	38.2	-8.8	-8.8	-3.6	41.8	38.4	44.0	64.6	22.9	-57.6	19.7
57	-14.0	-44.3	-32.1	10.4	60.4	7.7	57.8	54.2	63.8	78.9	33.2	-36.1	37.0
58	-13.3	-20.3	21.5	21.3	8.6	1.9	-4.1	36.2	35.0	55.6	19.9	-67.7	13.6
59	-53.4	-52.5	-36.8	31.0	12.0	25.7	74.3	76.2	90.0	59.5	-45.5	3.4	32.0
60	12.1	7.3	15.8	24.9	35.6	46.6	64.9	70.8	80.7	62.7	24.7	-33.1	48.2
61	14.4	19.0	28.6	20.7	14.1	28.3	65.6	77.1	81.0	70.3	4.7	-26.0	40.9
62	29.8	31.7	33.5	39.0	29.9	7.5	63.0	67.6	75.6	78.8	-2.8	-108.5	43.7
63	19.9	-16.8	11.9	39.9	11.7	37.1	17.9	43.4	59.4	69.1	34.2	-87.0	26.7
64	-34.7	25.9	-44.4	14.7	0.3	41.2	75.0	77.9	79.7	56.6	-32.1	-159.1	35.6
65	-18.4	22.8	43.3	-3.2	-9.8	29.7	43.6	53.0	66.6	72.5	32.4	-101.6	31.0
66	-111.7	18.4	-27.3	0.4	10.0	49.9	70.2	77.9	80.3	43.9	-27.5	-57.8	33.3
67	-33.3	26.6	10.5	30.4	-49.5	38.1	18.1	41.3	40.7	47.0	15.1	-144.4	23.9
68	-100.8	-59.6	-14.0	33.0	38.2	26.4	76.2	82.6	-89.1	44.0	17.8	-25.4	35.2
69	32.3	42.2	39.1	33.9	-20.1	-7.6	40.1	54.9	43.3	56.9	-22.1	-206.3	25.4
70	-69.5	-60.2	38.0	23.4	-59.6	20.9	68.5	78.7	81.6	54.2	-36.2	-176.3	20.8
71	-56.3	37.7	-3.6	5.7	12.8	60.3	43.9	65.8	64.6	39.4	-71.2	-182.8	31.2
72	-63.1	-8.5	13.5	25.2	39.3	72.0	83.8	87.4	87.7	7.4	-80.0	-67.0	50.7
73	-1.7	11.8	31.9	4.5	-5.5	3.9	65.0	86.5	81.3	54.7	-7.0	-94.2	29.0
74	-20.8	38.4	9.0	10.5	-26.3	47.0	0.9	70.9	70.5	57.8	-38.2	-205.0	25.7
75	-118.2	-107.3	-52.7	11.8	42.7	54.1	52.6	73.7	70.5	47.5	5.7	-63.4	43.8
76	20.7	0.0	-37.0	17.5	42.7	71.6	68.7	82.8	48.7	-17.3	32.9	45.7	42.8
77	35.7	48.6	36.2	53.1	49.0	70.7	73.5	73.6	77.4	-16.7	-15.5	38.1	56.4
78	55.8	58.9	78.6	53.1	39.0	28.8	37.3	52.6	36.6	85.1	24.0	-6.7	49.7
79	-71.0	22.9	-2.8	79.4	17.6	40.4	72.9	83.6	82.8	50.0	43.4	5.6	47.9
80	29.3	26.8	29.4	23.2	19.4	24.6	54.3	69.1	71.7	61.0	51.7	-25.6	29.9
81	-11.3	-2.8	25.0	44.8	43.4	47.3	72.8	74.9	71.6	9.4	23.6	-4.1	49.7
82	47.1	59.7	29.5	15.3	33.5	26.1	25.5	46.7	53.7	42.6	-15.7	-87.7	29.5
83	1.7	13.0	1.4	19.4	1.3	-5.3	-3.8	31.0	47.6	32.2	-1.8	-116.4	10.6

*NOTE: Calculated as $\frac{NDO-RDO}{NDO} \cdot 100$. The negative values denote gainings.

II.1.3.1 Pre-Project Period (1921-1943) RRI, Regulated River Inflow

The predominant range of upstream diversions in percentage was 15-25%, with a maximum of 34% which corresponds to 2.96 MAF (1931 - critical dry year), while the highest volume of 7.5 MAF was diverted in 1927, (but only 20% of the mean natural inflow) following 1926, a year of sub-normal wetness of 18.5 MAF. The minimum upstream diversion of 0.8 MAF which corresponds to 1.3% of the NRI of 1938, the wettest year. The predominant range of volumes of upstream diversions was 3.5-4.5 MAF (Fig. II. 4A).

Pre-Project Period

RDO - Regulated Delta Outflow

The predominant range of total diversions and withdrawals in percentage was 15-25% (Fig. II. 4B), with a maximum of 39% (1931) corresponding to 3.37 MAF, and minimum of 5.1% (1941-wet year). However, the maximum volume of the total Delta diversions was 7.4 MAF (32% of the mean of 1932) and minimum 2.4 MAF (only 5.1% of the mean of 1941). The predominant volumes of total diversions ranged between 4.5-5.5 MAF.

The maximum of Delta diversions of 2.6 MAF was documented in 1938. At the same time, several increases in water supply to the Delta were observed, (presumably due to local releases) the highest of which, 1.8 MAF, took place in 1927. The predominant volume of inner Delta diversions ranged between 0.3-0.8 MAF (Fig. II. 4C).

In sum, the total water regulation of this period (upstream, i.e., above the Delta, downstream, i.e., Central Valley floor, and inner Delta) may be characterized as moderate with the exception of the critical dry period of 1929-34.

The typical feature of the pre-project period was that upstream water withdrawals in many instances were 5-15 times higher than the inner Delta diversions. This implies that water development in the Central Valley became the major factor, even before the CVP and SWP operation, in the progressive decline in to the Delta.

The outstanding hydrological features of this period were the historic natural droughts of 1924 and 1931, which were exacerbated by massive upstream and downstream diversions of 2.6-2.96 MAF, which constitute 32 and 34% of the average annual NRI, respectively, or in sum with the Delta consumptive use (including diversions) of 0.82 and 0.97 MAF, the total decline of the NDO corresponds to 50 and 53% of its average of 6.9 and 7.5 MAF, respectively.

In addition, due to total diversions, the annual NDO of three years, 1933, 1934 and 1939, was transformed from the category of sub-normal and dry years into RDO of the drought years category.

In reports describing the period of the 1920's and early 1930's, the increased salt intrusion into the Delta and salinization of the water body of the western Delta were considered in relation to water diversions (Dept. of Public Works, 1931). It was predicted that continuation of such practices would result in inevitable losses in water quality, decreased water supply for different water users, and threats to the entire Delta ecosystem (Department of Public Works, 1928).

II.1.3.2 Post-Project Period (1944-1983)

RRI, Regulated River Inflow

This period is characterized by the increase in absolute and relative values of annual water diversions resulting from intensified construction and subsequent operation of water storage and conveyance facilities. During this period, the Central Valley and State Water Projects began and approached completion by 1955 and 1973, respectively. The predominant range of upstream diversions of 5-7 MAF (Table II. 6) was as much as 1.4-1.5 times higher than the upstream diversions of the preceding period of 1921-1943.

In relative values, the predominant range of upstream diversions increased to 25-35% (Figs II. 4A), maximum of 38% (1978) and minimum of 12% (1977) (Table II. 8). The .cp3 corresponding volumes of water diverted in these years were 16.2 MAF and 0.8 MAF.

Such an unprecedented increase of upstream diversion in 1978 may be explained because the two previous years were critical dry and drought, therefore, the water storage reserves were exhausted. In addition, during years when new dams or water facilities were put into operation like 1956, 1962 and 1965 (Fig. II. 1), which had high flows but were preceded by years of sub-normal wetness, the upstream diversion was very high, 11.0, 8.7 and 11.5 MAF, respectively, which represented 21.5, 34.6 and 26.6% of their natural river inflow to the Delta. It should be noted that the high values of upstream diversion ranging from 11-16.2 MAF constitute 39-57% of the normal combined river inflow to the Delta, and that these values do not include Delta diversions which coincidentally may be, as will be seen later, very high.

Post-Project Period (1944-1983)

RDO, Regulated Delta Outflow

The predominant range of total annual water diversions (Fig. II. 4B) was increased to 30-40% for this period (Table II. 10), with a maximum of 56.4% (1977, drought year) and minimum of 13.6%

(1952-abnormal (wet) year). In absolute values, predominant range of diversions was 6-12 MAF.

Therefore, the post-period range of the total annual diversions increased in comparison with the pre-project period as much as 1.3-1.8 times. Moreover, during 15 out of 28 years, the total diversions were higher than permissible entitlement for water of 9.0-9.2 MAF for both the CVP and SWP by as much as 1.2-1.8 times (Table II. 7, excluding 1978).

The distinct feature of Delta diversion of this period is the scale and capacity of many installations in order to pump out water from the Delta. The gradual implementation of numerous water conveyance facilities in and out of the Delta (Cross-Delta Canal, Delta Pumping Plant, SWP, capacity of 6,200 cfs; Bureau of Reclamation's Tracy Pumping Plant, capacity of 4,600 cfs, and many small, local pumping facilities) to provide water for mainly agricultural needs in the San Joaquin River Valley as well as in the Delta resulted in an unprecedented growth of the Delta diversions. For example, the predominant range of Delta diversion 0.5-0.8 MAF (1944-1955) was replaced by 2.0-3.0 MAF between 1957-1968 and 3.5-6.0 MAF in 1969-1984.

Therefore, since the late 1950's and up to 1984 the Delta diversions increased several times and reached the scale which was an order of magnitude higher than those occurring during the pre-project period of water development.

More to the point, in some years the annual volume of conveyed waters was more than 1.5 times higher than would-be normal San Joaquin River runoff. For example, in 1975 (a wet year) annual Delta diversions attained the highest value on record, i.e., 7.4 MAF (30% from RRI). This volume is 5.8 times higher than Delta volume itself. In addition, there have been many other times during the last 15 years when volumes of annual Delta diversions were 2-4 times higher than the Delta volume.

This water development is said (in numerous publications and reports) to be responsible for salt intrusion and salinization of the Delta water. There are no doubts that this assumption is adequate. Besides, the more water will be siphoned off from the Delta the more likely substantial salinization of the Delta will occur (Lauff, 1967; Officer, 1976).

(The cause of brackish or salt water penetration to the Delta of any rivers is explained on the one hand by reduction of runoff and on the other hand by development of strong entrainment drag-along effect of artificial flow inside the Delta, which suck in intermediate brackish water to the surface in direction of flow that results in salinization of Delta waters.)

We would like to stress that in the case of 1975, the sum of the upstream of 6.9 MAF (22% from NRI) and Delta diversion of 7.4 MAF managed to shift the natural category of this year from wet to the lower than subnormal (44% from NDO). This is a typical example of the role of diversion on wetness of the year.

The greatest volume of water diversions for the entire 58-year period, 21.4 MAF, took place in 1978 (fortunately a wet year which was preceded by two successive very dry years, 1976 - critical dry, and 1977 - drought). This water was used to recharge depleted reservoirs and satisfy other demands for water.

It is interesting to notice that this historic withdrawal, unseen for the entire period of water development (Fig. II. 4B), whose volume almost equaled the would-be natural sub-normal annual Delta discharges to the Bay, represented only 50% of the mean NDO of that year. Meanwhile, the total water withdrawals in the 1977-drought year were equal to only 4.2 MAF, but 76% of the NDO. There is speculation that this drought (1977) and the preceding critical dry year, exacerbated by diversions, especially inner Delta (6.7 MAF or 50.3% of the RRI of 1976), may have played a dramatic role in the almost steady decline in the striped bass population and catch and other biological species for the following six years which had not been documented before this event.

It is important to emphasize that the RDO for 1976 and 1977 of 6.5 and 2.5 MAF, respectively, corresponded to the probability of exceedance of the would-be normal Delta outflow to the Bay of 99% (once in 100 years) and as to 1977, it was beyond the limit of the theoretical frequency curve of the NDO (Table II. 11). In other words, it may have a recurrence interval of at least once per several hundred years. Meanwhile, the value of would-be natural Delta outflow for these years corresponded approximately to a recurrence of one time in 23-25 years (1976) and one time in 100 years (1977), which by themselves are very rare events (Table II. 11).

Hence, the diversion in critical dry years not only exacerbates the water deficit in the Delta-Bay ecosystem, but also results in shifting of years of critical wetness to the category of drought.

Evidently, for years of wetness like 1976 and 1977, the upstream water storages are not capable of providing a level of emergency discharges capable of mitigating the detrimental influence of the natural deficit in water supply on the environment of the riverine-estuarine system.

It is important to emphasize again that as a rule, the sub-normal and critical years of wetness are characterized by having the highest proportion of their flows diverted for out-of-basin uses, although the amount of water transferred for different users may be much less than the amount of water withdrawn for years of normal or above normal wetness. However, when the needs of agricultural and other users are high following several consecutive sub-normal or dry years, e.g., 1977, even a low proportion of water diverted may have a major impact on the regime characteristics of the Bay, especially in the Delta-Suisun

Bay because:

1) The residual flow, which would correspond to the natural outflow conditions of 97-99% of probability or a recurrence interval of not less than once in 33 or even in 100 years, is too little to repel salt intrusion or to prevent salinity increases in the system which have been observed several times since the 1920's;

2) The value of residual flow is nearly equal to the losses sustained by the system due to differences between precipitation and evaporation over the San Francisco Bay, and

3) This reduced volume of residual flow is comparable to the volume of the Delta and therefore cannot provide adequate flushing and circulation for the Delta and the Bay.

<u>Summary.</u>

Gradual substantial annual increases of upstream, downstream and total diversions during post-project period (1944-1983) in comparison with the pre-project period (1921-43) have resulted in significant modification of the Sacramento-San Joaquin river water supply to the Delta-Bay estuarine system:

1. The number of subnormal, dry and critical dry years of RRI and RDO increased 1.3-2 times, while the number of wet and normal years in comparison with NRI and NDO decreased by half.

2. As a result, the San Francisco Bay ecosystem has experienced a chronic deficit in water supply, particularly for years of normal and subnormal and critical natural water supply.

3. The predominant range of annual upstream Delta and total water diversion since the 1960's (up to 1983) was 20-30%, 20-45% and 35-52%, respectively.

4. The predominant range of absolute values of upstream, Delta and total diversions was 6-12, 4-6 and 9-13 MAF, respectively.

5. As a general rule, the highest percentage of diversions before and after CVP and SWP completion occurred in years of subnormal and critical dry categories of wetness.

6. The highest volume water was diverted in wet and normal years following years of subnormal or low wetness.

7. In general, the persistent increases in annual upstream, downstream and total water diversions from the Sacramento-San Joaquin river system (which are many times higher, that those documented for the pre-project period) support the assumption that the entitlement of different water users has been the factor governing the management of this system. It is our contention

that in order to maintain the health of the Delta-Bay system, decisions regarding water diversions should be based on the natural limits of the water resources and wetness of the year (for a series of years) based upon data on past and present flow regimes.

II.2 Seasonal Variability of Natural and Regulated Runoff Discharges to the Delta-San Francisco Bay System

The major features of temporal variations of runoff patterns for the pre- and post-project periods can be described and summarized through comparison of the natural and regulated flow values for typical years, like wet, normal, dry and critical dry years.

To make a comparison between impaired and unimpaired values of runoff for each month of the year of the period 1922-1983 easily understandable and uniform, we used the following scheme:

1. The mean value of runoff for each month relates to the statistical parameters of runoff to have their values designated to corresponding years of wetness.

2. The dynamics of runoff withdrawals are analyzed for each month separately and their residual (regulated) values for pre- and post-project conditions are compared with statistical characteristics of the would-be natural total Sacramento-San Joaquin River inflow to the Delta and Delta outflow to the Bay for the same month.

3. The latter comparisons allow us to obtain the statistical meaning (probability of occurrence) of the observed regulated flow characteristics and therefore to emphasize the possibility of their recurrence as if they were part of the natural (unimpaired) runoff.

4. A special section is devoted to the estimation of the cumulative losses or gains sustained by the system because of upstream and downstream water diversions and withdrawals (the word "losses" describes qualitatively as well as quantitatively the amount of water which was taken out of the system for any reasonable needs) for each month and year for the period 1922-1983.

II.2.1 Monthly Runoff Distribution

Unimpaired river flow is at its highest from January through May, while minimum flows occur in August through October (Fig. II. 5), reflecting seasonal rainfall and snowmelt (usually reaching peak level during April-May) patterns. The observed seasonal average trend in flow patterns may deviate slightly from the predominant intra-annual distribution if abnormal wet and dry years occur.

In general, surface water supply to the riverbed is the result of the complex interaction of different climatological and geomorphological factors of the entire watershed, i.e., from the highest mountain elevation to floodplain characteristics. Therefore, when large-scale modification of the river drainage network takes place (storage facilities, dams, water conveyance systems, etc.) it is logical to expect inevitable changes to occur in the environment of the river and adjacent basin. The first and most conspicuous changes are those affecting the hydrology of the river watershed, i.e., intensity of seasonal fluctuations (amplitudes), their duration and values, etc.

About 53%* of runoff occurs in spring (March through June, although in some classifications, March is considered the last month of winter), 36% in winter (December, January, February), 4% in the summer (July, August) and 7% in autumn (September, October, November).

The average duration of flooding is four months (usually February, March, April and May), although during years of low wetness this period may be two months shorter.

The intra-annual amplitude of NRI/NDO (Tables II. 12, 13, Figs. II. 5, 6) is very high and has almost the same range of 0.2-14.7 MAF**, therefore, the ratio between these values is 73.5 times.

The maximum amplitudes of runoff are typical for January (0.6-14.7 MAF). The monthly maximum value of runoff during January is the highest in comparison with the observed maximum for the spring.

The minimum natural amplitudes are typical for August and September and also have the lowest monthly values of runoff.

The upstream and downstream runoff regulation has truncated the highest values of seasonal runoff and therefore reduced the monthly amplitude (Tables II. 12, 13) with the exception of August, September, October). As a result, the intra-annual variables of regulated river inflow/Delta outflow are characterized by much lower values of mean monthly maximum and mean monthly minimum runoff during the spring (Figs. II. 5, 6).

The mean values of RRI for the spring are 72% for April, and for May and June, only 54 and 55% of their corresponding normal for the periods in question (Table II. 12).

The mean value of RDO for April is 70%, but for May and June only 51 and 48%, respectively.

This significant mean reduction of runoff, which was higher for some years during the spring (as we see later) is attributable to post-project water development.

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*These percentages are based on means of various parameters for the entire 1921-78 period.August, September and October).

**From here on all runoff values in the text are rounded up.

Table II.11 Variables of a theoretical curve of probability of exceedance of mean monthly and annual Natural Delta Outflow

Probability of exceeding	1	5	10	25	50	75	90	95	99
Years of recurrence	100	20	10	4	2	4	10	20	100
October	1.39	1.00	0.84	0.61	0.44	0.34	0.29	0.27	0.26
November	5.96	3.68	2.70	1.55	0.80	0.45	0.36	0.34	0.31
December	12.22	7.66	5.75	3.30	1.61	0.80	0.48	0.41	0.38
January	14.90	9.81	7.58	4.71	2.55	1.34	0.85	0.71	0.60
February	10.98	8.19	6.90	5.04	3.45	2.21	1.44	1.08	0.62
March	10.54	7.94	6.77	5.10	3.50	2.30	1.56	1.17	0.74
April	9.06	7.42	6.60	5.25	3.94	2.75	1.80	1.27	0.33
May	9.42	7.64	6.72	5.35	3.98	2.74	1.78	1.37	0.79
June	6.98	5.22	4.41	3.29	2.23	1.43	0.95	0.68	0.35
July	2.57	1.87	1.55	1.10	0.72	0.43	0.26	0.18	0.09
August	0.86	0.65	0.56	0.42	0.29	0.19	0.13	0.10	0.05
September	0.65	0.52	0.46	0.37	0.28	0.21	0.16	0.14	0.10
Annual	63.38	49.93	43.56	34.14	25.33	18.26	13.10	10.65	6.88

Table II.12 Mean monthly values of the Sacramento-San Joaquin natural and regulated runoff (MAF), 1921-1978

Month	Qnri	Qrri	Qndo	Qrdo
October	0.58	0.76	0.46	0.56
November	1.14	1.06	1.25	0.97
December	2.44	2.09	2.52	2.03
January	3.35	3.14	3.54	3.14
February	3.84	3.63	3.92	3.53
March	3.85	3.26	3.89	3.25
April	4.14	3.00	4.10	2.85
May	4.26	2.32	4.15	2.11
June	2.65	1.45	2.51	1.20
July	1.04	0.69	0.83	0.35
August	0.54	0.61	0.32	0.24
September	0.45	0.71	0.30	0.45

Table II.13 Monthly range of mean natural and regulated runoff of the Sacramento-San Joaquin River system (in million acre feet), 1921-1978

Month	Qnri	Qrri	Qndo	Qrdo
October	0.32- 3.29	0.29- 2.73	0.22- 3.37	0.13- 2.70
November	0.34- 6.04	0.36- 4.16	0.29- 6.15	0.22- 4.32
December	0.40-12.67	0.52- 7.97	0.26-13.03	0.26- 8.30
January	0.56-14.44	0.62-11.62	0.58-14.73	0.27-11.90
February	0.53-10.92	0.49-10.40	0.53-11.23	0.27-10.3
March	0.63-11.08	0.44-11.60	0.64-11.25	0.19-11.92
April	0.77- 8.80	0.37- 8.96	0.69- 8.86	0.18- 9.23
May	1.01- 8.79	0.29- 7.34	0.94- 8.67	0.23- 6.92
June	0.47- 6.31	0.11- 4.96	0.33- 6.19	0.00- 4.80
July	0.32- 2.93	0.00- 1.68	0.11- 2.72	0.00- 1.44
August	0.28- 0.94	0.04- 1.60	0.06- 0.73	0.00- 0.82
September	0.27- 0.83	0.18- 1.89	0.11- 0.68	0.03- 1.54

Note: 1. Qrdo for the period of 1922-1982.

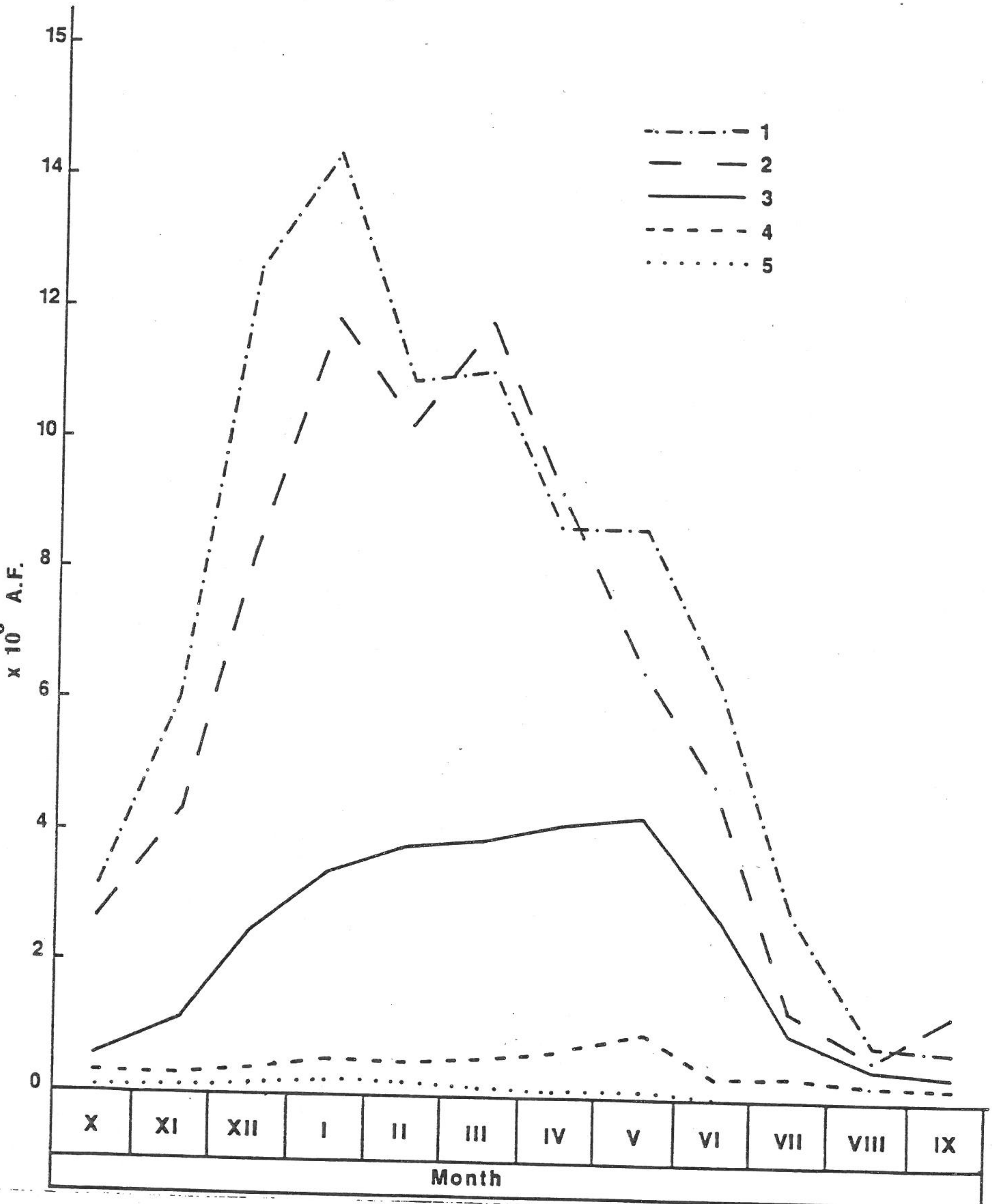


Fig. II.5 Seasonal extreme and average runoff fluctuation in flow to the Delta from the Sacramento-San Joaquin River watershed: (1) monthly maximum value of natural river inflow to the Delta, 1921-1978; (2) monthly maximum value of regulated Delta outflow, 1922-1978; (3) mean monthly full natural runoff to the Delta, 1921-1978; (4) monthly minimum value of natural river inflow to the Delta, 1922-1978; (5) monthly minimum value of regulated Delta outflow, 1922-1978.

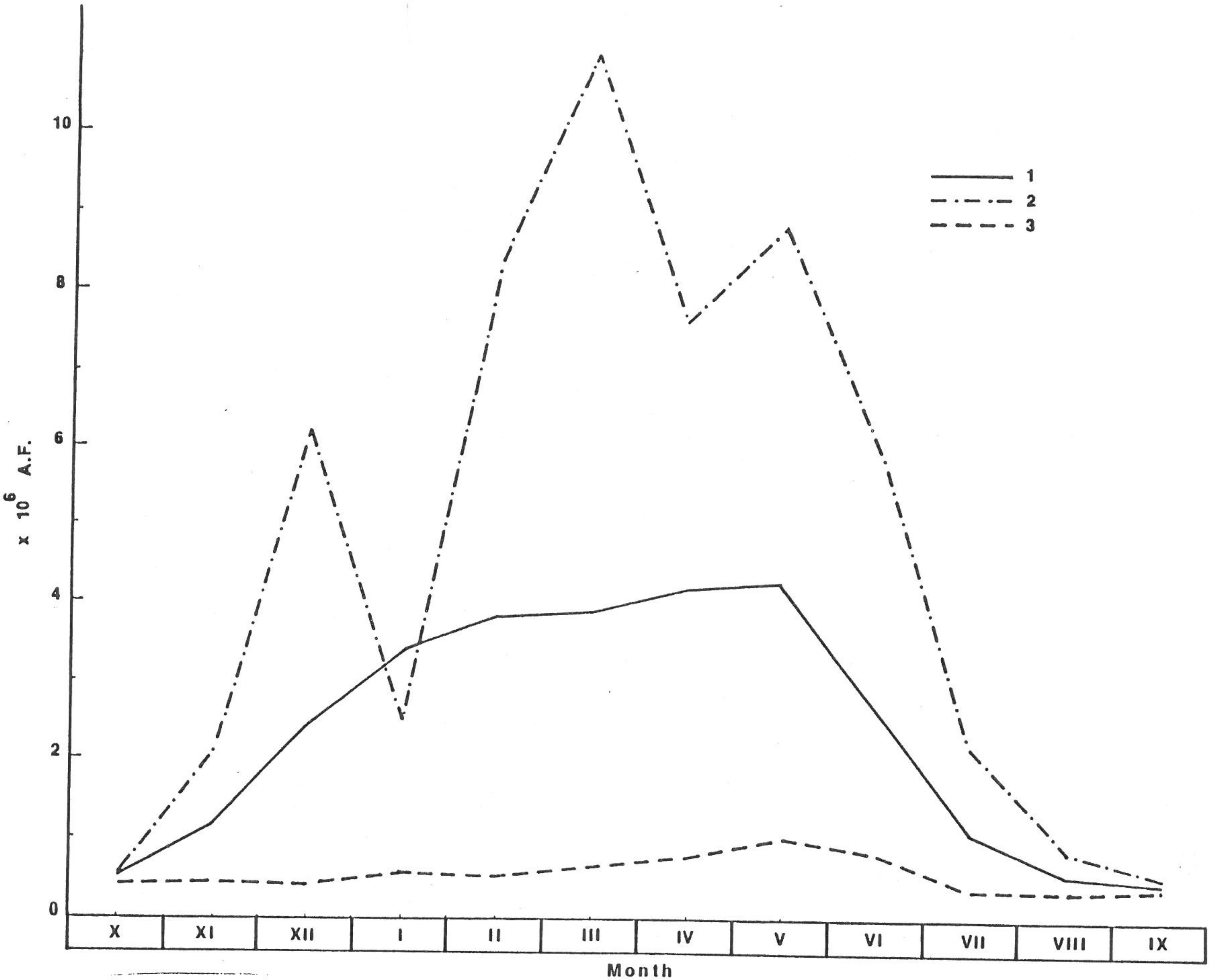


Fig.II.6 . Monthly fluctuations of natural inflow to the Delta for the (1) average (1921-78), (2) wettest (1938), and (3) driest (1977) years.

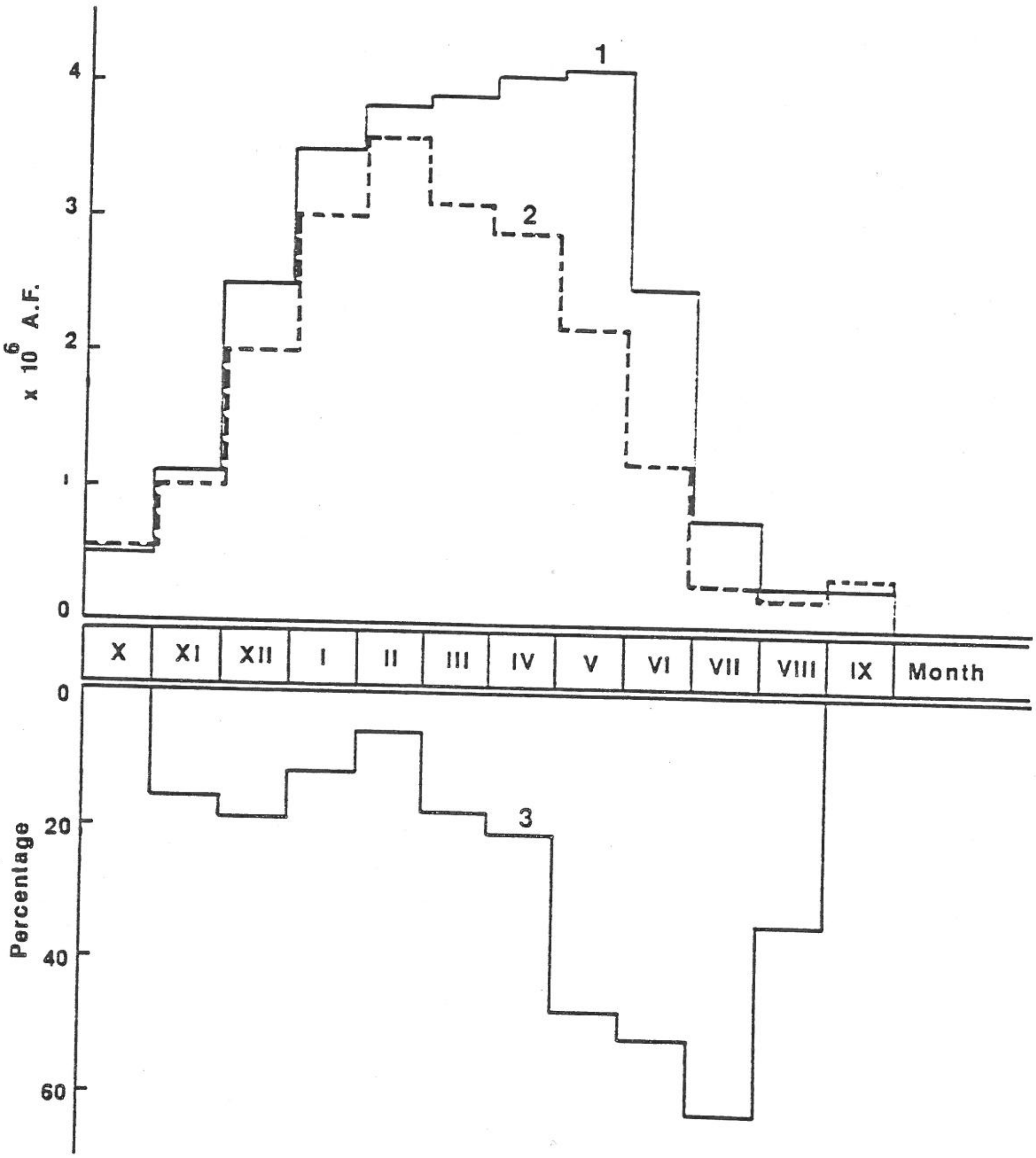


Fig. III.7 Mean seasonal fluctuation of (1) natural and (2) regulated Delta outflow and (3) Delta diversion, 1921-1978 (expressed as a percentage of natural Delta outflow).

It is interesting to note that almost the same percentage of reduction of the natural spring runoff (vital for sustaining the diversity of estuarine living and non-living resources) has taken place in many other areas of the Northern Hemisphere (Baydin, 1980).

It should be emphasized that there have been sharp increases in values of mean monthly RRI and RDO during late summer and fall since the 1960's which can be considered as a result of returning water discharges from the agricultural drainage network as well as from, presumably, storage releases to reduce the concentration of chemical pollutants.

For example, the maximum RRI increased over maximum NRI of 70% and 128% in August and September, respectively, while maximum RDO increased over NDO 12% and 126%, respectively.

The impact of water development on intra-annual runoff fluctuation may be seen from several examples of years of different wetness before and after project operations

II.2.2 Seasonal Dynamics of Wetness under Natural and Regulated Runoff

Winter

This season is of paramount importance in terms of providing water supply for the river-Delta-estuary ecosystem for the rest of the hydrological year. The runoff from this period (including March) constitutes more than 50% of the total for the year, with the highest range of runoff fluctuations between 2 and 14 MAF, but under relatively normal conditions the runoff may be distributed almost evenly between December and February. Hence, when significant withdrawals take place during these months (20-40% of NDO), particularly to recharge the storage facilities, the impact of this action on the Delta-Bay environment in combination with the diversions of 40-85% of incoming spring runoff may exacerbate the water deficit in months to come.

Tables II. 14-17 illustrate the modification of runoff resulting in the transformation of years of high wetness into sub-normal or even critical dry, as we will see for some months of the hydrological year. For winter, there are several common and diverse features related to the changes in frequency of occurrence in number of years of different wetness for the period 1921-78 due to upstream withdrawals.

First, water regulation had almost no effect on the number of sub-normal and dry months of December and January. In addition, the number of wet months of January remained almost the same.

Table II.14 The number of years of different wetness in relation to "normal" monthly runoff - December

Runoff Character- istics	Wettest and Wet Years	Years	Sub-normal and Dry Years	Years	Critical Dry Years	Years
Qnri	1921, 1923, 1938, 1941, 1942, 1946, 1951, 1952, 1956, 1965, 1967, 1970, 1971, 1974	14	1922, 1928, 1934, 1947 1955, 1961, 1962, 1966, 1972	9	1924, 1925, 1926 1929, 1931, 1933, 1935, 1936, 1937, 1939, 1940, 1944, 1948, 1949, 1950, 1954, 1957, 1959, 1960, 1964, 1968, 1972, 1975, 1976, 1977	25
Qrri	1938, 1946, 1951, 1956, 1960, 1971, 1974	7	1932, 1943, 1947, 1955, 1958, 1963, 1964, 1966, 1973, 1975, 1976	11	1924, 1925, 1926, 1928, 1929, 1931, 1933, 1934, 1935, 1936, 1937, 1939, 1940, 1944, 1947, 1949, 1950, 1954, 1957, 1959, 1960, 1961, 1962, 1969, 1972, 1977, 1978	27
Qndo	1923, 1924, 1938, 1941, 1942, 1946, 1951, 1952, 1956, 1965, 1967, 1970, 1971, 1974	14	1922, 1925, 1928, 1934, 1944, 1945, 1947, 1955, 1961, 1962, 1966, 1972	12	1924, 1929, 1931, 1933, 1936, 1937, 1939, 1940, 1944, 1948, 1949, 1950, 1954, 1957, 1959, 1960, 1964, 1968, 1975, 1976, 1977	21
Qrdo	1938, 1941, 1942, 1946, 1951, 1956, 1965, 1967, 1961, 1974	10	1922, 1928, 1932, 1943, 1945, 1947, 1964, 1969, 1972, 1973, 1975	11	1924, 1926, 1929, 1931, 1933, 1934, 1935, 1936, 1937, 1939, 1940, 1944, 1948, 1950, 1954, 1957, 1959, 1960, 1961, 1962, 1968, 1976, 1977, 1978	24

Note:

1. Wettest and wet years - the Qnri and Qrri and Qndo and Qrdo of any year are 25% or more above "normal" (2.44 and 2.52 MAF, respectively)
2. Sub-normal and dry years of wetness - when the same runoff parameters are 25% or more below "normal."
3. Critical dry years of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

Table II.15 The number of years of different wetness in relation to "normal" monthly runoff - January

Runoff Character-istics	Wettest and Wet Years	Years	Sub-normal and Dry Years	Years	Critical Dry Years	Years
Qnri	1921, 1936, 1940-43, 1951, 1952, 1953, 1956, 1965, 1967, 1969-70, 1973, 1974, 1978	16	1923, 1928, 1930, 1932, 1934, 1945, 1948, 1950, 1955, 1963, 1964, 1968, 1972,	13	1922, 1924, 1926, 1929, 1931, 1933, 1937, 1939, 1944, 1945, 1947, 1949, 1957, 1960, 1961, 1962, 1972, 1975, 1976, 1977	20
Qrri	1941, 1942 1943, 1946, 1951, 1952, 1953, 1956, 1965, 1969, 1970, 1973, 1974	13	1927, 1930, 1932, 1934, 1935, 1949, 1954, 1958, 1959, 1966	10	1924, 1926, 1928, 1929, 1931, 1933, 1937, 1939, 1944, 1945, 1946, 1949, 1955, 1957, 1960, 1964, 1968, 1972, 1975, 1977	20
Qndo	1921, 1936, 1940, 1941-43, 1951, 1952, 1953, 1965, 1967, 1969-70, 1973, 1974, 1978	16	1923, 1928, 1930, 1932, 1934, 1938, 1948, 1950, 1955, 1963, 1964, 1968	12	1922, 1924, 1925, 1926, 1929, 1931, 1933, 1937, 1939, 1944, 1945, 1947, 1949, 1957, 1960, 1961, 1962, 1972, 1975, 1976, 1977	21
Qrdo	1941, 1942, 1943, 1946, 1949, 1951, 1952, 1953, 1956, 1965, 1969, 1970, 1973, 1974	14	1922, 1928, 1930, 1932, 1934, 1950, 1954, 1955, 1959, 1964	10	1924, 1925, 1926, 1929, 1931, 1933, 1937, 1939, 1944, 1945, 1947, 1948, 1949, 1957, 1960, 1961, 1962, 1963, 1968, 1972, 1975, 1976, 1977	23

Note:

1. Wettest and wet years - the Qnri and Qrri and Qndo and Qrdo of any year are 25% or more above "normal" (3.35 and 3.54 MAF, respectively)
2. Sub-normal and dry years of wetness - when the same runoff parameters are 25% or more below "normal."
3. Critical dry years of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

Table II.16 The number of years of different wetness in relation to "normal" monthly runoff - February

Runoff Characteristics	Wettest and Wet Years	Years	Sub-normal and Dry Years	Years	Critical Dry Years	Years
Qnri	1925, 1927, 1936, 1938, 1940, 1941, 1942, 1945, 1952, 1956, 1958, 1962, 1963, 1968, 1969, 1973, 1978	17	1928, 1930, 1932, 1934, 1935, 1944, 1947, 1953, 1955, 1961, 1971, 1972, 1974	13	1923, 1924, 1929, 1931, 1933, 1939, 1946, 1948, 1949, 1955, 1964, 1976, 1977	13
Qrri	1925, 1927, 1936, 1938, 1940, 1941-42, 1951, 1952, 1956, 1957, 1963, 1969, 1970, 1973	15	1928, 1932, 1950, 1959, 1960, 1961, 1965, 1968, 1975	9	1924, 1929, 1930, 1931, 1933, 1934, 1935, 1939, 1944, 1946, 1947, 1948, 1949, 1953, 1955, 1957, 1964, 1966, 1971, 1972, 1976, 1977	22
Qndo	1925, 1927, 1936, 1938, 1940, 1941, 1942, 1945, 1952, 1956, 1962, 1963, 1969, 1973, 1978	15	1928, 1930, 1932, 1934, 1935, 1944, 1961, 1966, 1971, 1972, 1974	11	1923, 1924, 1929, 1931, 1933, 1939, 1946, 1948, 1949, 1955, 1964, 1976, 1977	13
Qrdo	1925, 1927, 1936, 1938, 1940, 1941, 1952, 1956, 1958, 1963, 1969, 1970, 1973	13	1928, 1932, 1950, 1960, 1961, 1968, 1975, 1978	8	1923, 1924, 1929, 1930, 1931, 1933, 1934, 1935, 1939, 1946, 1947, 1948, 1949, 1955, 1957, 1964, 1966, 1971, 1972, 1976, 1977	21

Note:

1. Wettest and wet years - the Qnri and Qrri and Qndo and Qrdo of any year are 25% or more above "normal" (3.84 and 3.89 MAF, respectively)
2. Sub-normal and dry years of wetness - when the same runoff parameters are 25% or more below "normal."
3. Critical dry years of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

Table II.17 The number of years of different wetness in relation to "normal" monthly runoff - March

Runoff Characteristics	Wettest and Wet Years	Years	Sub-normal and Dry Years	Years	Critical Dry Years	Years
Qnri	1921, 1928, 1938, 1940, 1941, 1943, 1952, 1958, 1967, 1969, 1974, 1975, 1978	13	1925, 1926, 1933, 1934, 1939, 1944, 1945, 1946, 1948, 1953, 1959, 1961, 1963, 1965	14	1923, 1924, 1929, 1931, 1955, 1964, 1976, 1977	8
Qrri	1938, 1940, 1941, 1943, 1958, 1969	6	1925, 1932, 1935, 1942, 1944, 1945, 1946, 1947, 1948, 1953,	10	1924, 1926, 1929, 1931, 1933, 1934, 1939, 1948, 1953, 1955, 1959, 1961, 1963, 1964, 1965, 1966, 1972, 1976, 1977	19
Qndo	1921, 1927, 1928, 1937, 1938, 1940, 1941, 1943, 1952, 1958, 1967, 1969, 1974, 1975, 1978	15	1925, 1926, 1933, 1934, 1939, 1944, 1946, 1948, 1953, 1959, 1961, 1963, 1965	13	1923, 1924, 1929, 1931, 1955, 1964, 1976, 1977	8
Qrdo	1927, 1938, 1940, 1941, 1943, 1952, 1958, 1969, 1978	9	1925, 1932, 1944, 1945, 1946, 1947, 1950, 1960, 1962, 1968, 1975	11	1923, 1924, 1926, 1929, 1931, 1933, 1934, 1941, 1948, 1953, 1955, 1961, 1963, 1964, 1965, 1966, 1971, 1972, 1976, 1977	20

Note:

1. Wettest and wet years - the Qnri and Qrri and Qndo and Qrdo of any year are 25% or more above "normal" (3.85 and 3.89 MAF, respectively)
2. Sub-normal and dry years of wetness - when the same runoff parameters are 25% or more below "normal."
3. Critical dry years of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

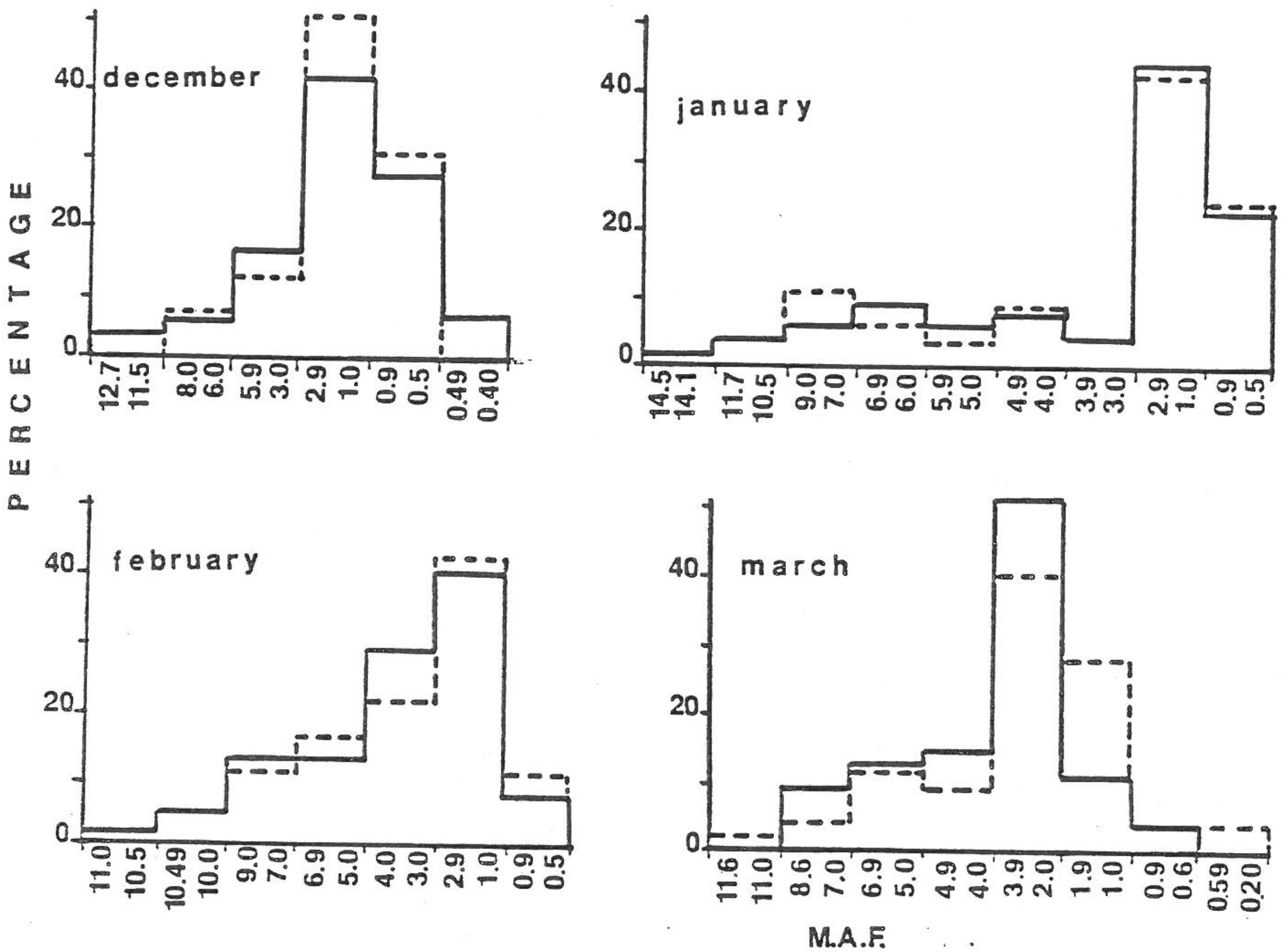


Fig. II.8 Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1921-82) River Inflow to the Delta for the Winter Months.

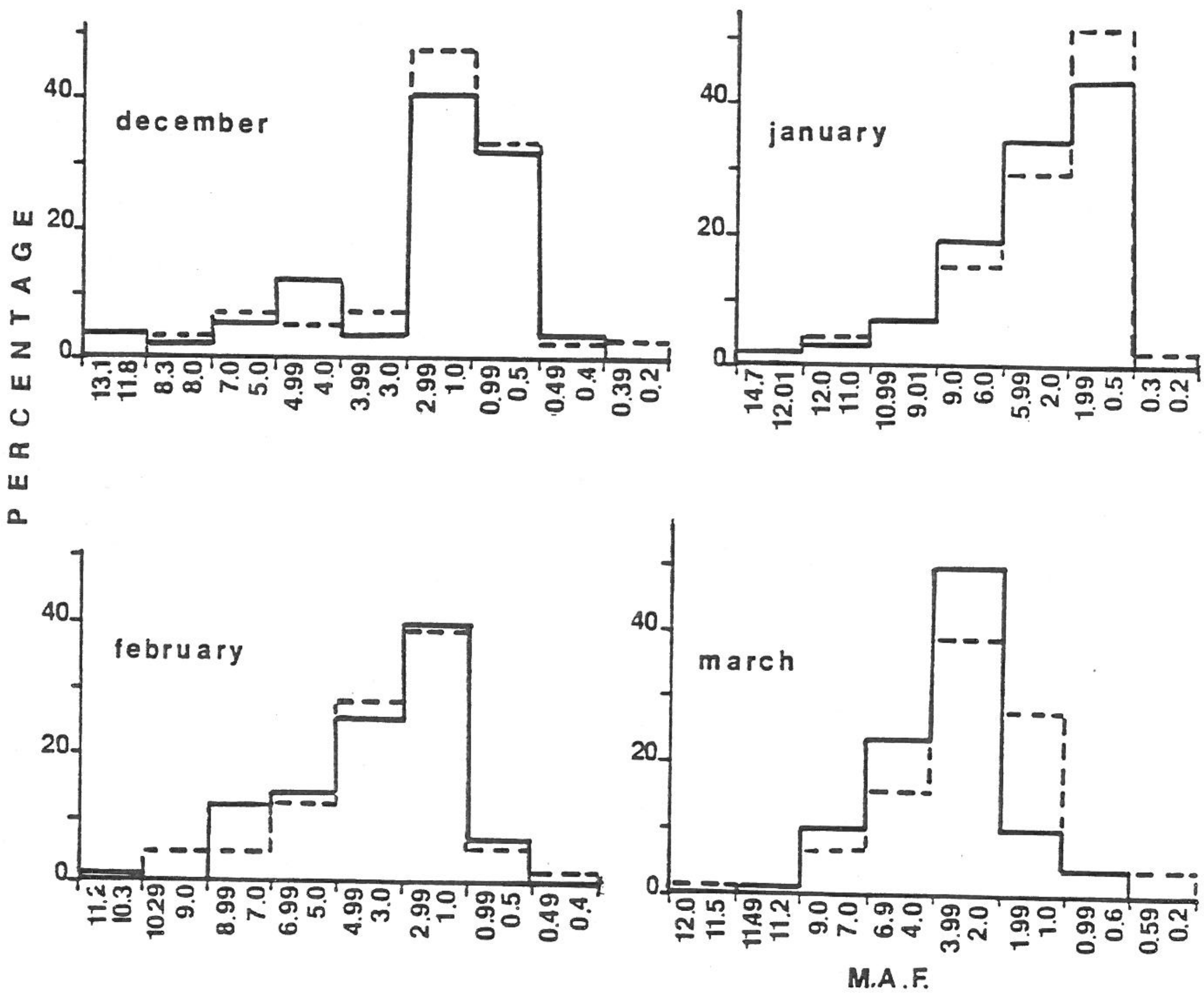


Fig. II.9. Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1922-82) Delta Outflow the Bay for the Winter Months.

Second, however, the number of wet months of December and especially March under natural and regulated conditions are quite different. The number of years of this category for RRI and RDO for December and March was reduced up to two times.

At the same time, the number of critical dry months of February and especially March for RRI increased more than two times, and therefore these last two months of winter (which are characterized by relatively high precipitation, the lack of evapotranspiration and the beginning of snowmelt) were subjected to conditions of flow formation which were much less favorable in terms of water supply to the estuarine system, particularly when considered in conjunction with the subsequent precipitous reduction of spring runoff.

These changes are graphically depicted in the histograms of monthly natural and regulated flow distribution (Figs. II. 8, 9).

The persistent features of these figures are:

1. The reduction of frequency of occurrence of the highest runoff;

2. Truncation of the highest values of runoff that were typical for the natural runoff distribution; and

3. The shift of the frequencies from the scale of high ranges (NRI and NDO) to very low ranges of river inflow/Delta outflow (RRI and RDO).

Overall, the frequency of occurrence of RRI and RDO within the ranges corresponding to sub-normal conditions of wetness, increased more than 1.5 times. This implies that the system received less fresh water than would be needed to flush out natural and anthropogenic wastes and salt (which may have accumulated from the previous year or years, particularly of sub-normal wetness).

SPRING

1. Under natural conditions, the distribution of months of different wetness for NRI and NDO are approximately the same (Tables II. 18-20).

2. With water regulation, the number of the wettest, wet and sub-normal years were reduced, but the number of springs with dry and critical dry RRI and RDO increased in such proportion as to suggest that we are dealing, in effect, with a new river system. This means that not only have the numbers of spring months in each category of wetness changed dramatically since project operations began, but also that the absolute values of spring residual runoff remaining after upstream and downstream diversions reached a point almost never observed in the

historical past.

3. The most significant changes in the number of occurrences was for wet and critical dry years. For example, the number of wettest and wet months of April (Table II. 18) was reduced as much as 1.7-2.5 times under regulated conditions (i.e., RRI and RDO versus NRI and NDO), but for May and June the reduction in the numbers of wet and wettest months is 5.3-8 times and 3.6-5.7 times, respectively (Tables II. 19, 20).

At the same time, there were no significant changes in the number of sub-normal and dry years.

However, the number of critical dry months of April, May and June increased as much as 5.2-5.4, 3.5-3.7, and 2.2-2.4 times, respectively.

These ratios demonstrate that since the water diversions were intensified, which coincided in some years with the natural low wetness discussed earlier, the system has experienced a water supply deficit.

This shift in hydrological regime of the rivers from predominantly above normal and normal months to sub-normal and critical dry months for would-be natural runoff is well illustrated in Figs. II. 10, 11.

These figures show that this type of monthly shift predominantly natural runoff surplus ranges to regulated runoff ranges, can be characterized as conditions of deficit.

It is important to stress that this runoff redistribution is typical for many rivers located in semi-arid zones of the Northern Hemisphere which are under water regulation. It should also be emphasized that the impact of water supply redistribution and reduction has a similar pronounced effect on living and non-living resources of estuarine and coastal zone systems regardless of where they are. This is especially true for many rivers, like the Sacramento-San Joaquin, whose late winter-spring runoff usually accounts for 40-65% of their annual mean runoff, and therefore, an essential part of it is used for surface and ground water storage recharges, conveyance to other areas and local consumption.

It is interesting to note that as a rule, 30-85% of the natural spring runoff is diverted each year in many areas of the globe, despite the fact that spring runoff is the most vital part of any riverine-estuarine environment. It brings to the system more than 60% of the annual sediment load, more than 70% of organic and inorganic matter, provides for oxygen enrichment and flushing of the natural and man-induced wastes, and is entirely responsible for the estuarine salinity regime of the subsequent months of the year. As such, the spring runoff defines the productivity of the estuary and its adjacent coastal zone. Hence, if there is no such runoff, it is logical to expect that

Table II.18 The number of years of different wetness in relation to "normal" monthly runoff - April

Runoff Character-istics	Wettest and Wet Years	Years	Sub-normal and Dry Years	Years	Critical Dry Years	Years
Qnri	1927, 1935, 1938, 1940-43, 1952, 1954, 1958, 1963, 1965, 1967, 1969, 1974, 1978	15	1930, 1939 1944, 1947 1955, 1957 1959, 1960, 1961, 1964, 1968, 1970, 1972	13	1924, 1929, 1931, 1934 1976	5
Qrri	1935, 1938, 1940, 1941, 1952, 1958, 1963, 1974, 1982	9	1945, 1946, 1950, 1956 1971, 1975	6	1924, 1929, 1930, 1931, 1932, 1933, 1934, 1939, 1944, 1947, 1949, 1951, 1953, 1955, 1957, 1959, 1960, 1961, 1962, 1964, 1966, 1968, 1970, 1972, 1973, 1976, 1977	27
Qndo	1927, 1935 1938, 1941-43 1940, 1948 1952, 1954 1958, 1963, 1965, 1967, 1969, 1974, 1978	17	1930, 1933, 1939, 1944, 1944, 1947, 1955, 1957, 1959-61, 1964, 1968, 1970, 1972	14	1924, 1929 1931, 1934, 1976	5
Qrdo	1935, 1938, 1940, 1941, 1952, 1958, 1964, 1974	8	1945, 1946, 1950, 1956, 1971	5	1924, 1929, 1930, 1931, 1933, 1934, 1939, 1944, 1947, 1949, 1951, 1953, 1955, 1956, 1958, 1962, 1964, 1965, 1966, 1968, 1970, 1972, 1973, 1975, 1976, 1977	26

Note:

1. Wettest and wet years - the Qnri and Qrri and Qndo and Qrdo of any year are 25% or more above "normal" (4.14 and 4.10 MAF, respectively.)
2. Sub-normal and dry years of wetness - when the same runoff parameters are 25% or more below "normal."
3. Critical dry years of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

Table II.19 The number of years of different wetness in relation to "normal" monthly runoff - May

Runoff Characteristics	Wettest and Wet Years	Years	Sub-normal and Dry Years	Years	Critical Dry Years	Years
Qnri	1922, 1935, 1937, 1938, 1941, 1942, 1943, 1952, 1956, 1958, 1963, 1967, 1969, 1973, 1974, 1975, 1978	17	1926, 1929, 1930, 1933, 1947, 1960, 1961, 1964, 1966, 1968, 1970, 1972	12	1924, 1931, 1934, 1939, 1959, 1976, 1977	7
Qrri	1938, 1952	2	1928, 1932, 1942, 1943, 1945, 1946, 1950, 1951, 1953, 1965, 1975, 1978	12	1924, 1927, 1929, 1930, 1931, 1933, 1934, 1939, 1944, 1947, 1950, 1954, 1955, 1959, 1960, 1961, 1962, 1964, 1966, 1968, 1971, 1972, 1976, 1977	24
Qndo	1922, 1937, 1938, 1941, 1942, 1948, 1952, 1956, 1958, 1963, 1967, 1969, 1973, 1974, 1975, 1978	16	1926, 1929, 1930, 1933, 1947, 1960, 1961, 1964, 1966, 1968, 1970, 1972	12	1924, 1931, 1934, 1939, 1959, 1976, 1977	7
Qrdo	1922, 1938, 1952	3	1924, 1928, 1932, 1936, 1940, 1943, 1945, 1946, 1950, 1951, 1953, 1954, 1957, 1965, 1978	15	1924, 1926, 1929, 1931, 1933, 1934, 1939, 1944, 1947, 1949, 1955, 1959, 1960, 1961, 1962, 1964, 1966, 1968, 1970, 1971, 1972, 1973, 1974, 1975, 1976, 1977	26

Note:
1. Wettest and wet years - the Qnri and Qrri and Qndo and Qrdo of any year are 25% or more above "normal" (4.26 and 4.15 MAF, respectively.)
2. Sub-normal and dry years of wetness - when the same runoff parameters are 25% or more below "normal."
3. Critical dry years of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

Table II.20 The number of years of different wetness in relation to "normal" monthly runoff - June

Runoff Characteristics	Wettest and Wet Years	Years	Sub-normal and Dry Years	Years	Critical Dry Years	Years
Qnri	1921, 1927, 1932, 1935, 1938, 1941, 1942, 1948, 1952, 1953, 1956, 1958, 1969, 1971, 1974, 1975, 1978	17	1929, 1930, 1946, 1947, 1949, 1951, 1954, 1960 1961, 1964, 1972	11	1924, 1926, 1928, 1931, 1833, 1934, 1939, 1947, 1959, 1966, 1968, 1976, 1977	13
Qrri	1938, 1952, 1966	3	1932, 1936, 1937, 1940, 1943, 1945, 1950, 1953, 1963, 1965, 1971, 1974, 1975	13	1926, 1928, 1929, 1930, 1931, 1933, 1934, 1939, 1944, 1946, 1947, 1949, 1951, 1954, 1955, 1957, 1959, 1960, 1961, 1962, 1963, 1964, 1965, 1966, 1970, 1972, 1973, 1974, 1976, 1977, 1978	31
Qndo	1921, 1922, 1927, 1932, 1935, 1938, 1941, 1942, 1948, 1952, 1953, 1956, 1958, 1967, 1971, 1974, 1975, 1978	18	1928, 1929, 1930, 1944, 1946, 1949, 1951, 1954, 1960, 1964, 1972	11	1924, 1926, 1928, 1931, 1934, 1939, 1947, 1959, 1960, 1961, 1966, 1968, 1976, 1977	14
Qrdo	1922, 1938, 1942, 1952, 1967	5	1923, 1925, 1936, 1937, 1940, 1943, 1945, 1950, 1963, 1971, 1975	11	1926, 1928, 1929, 1930, 1931, 1933, 1934, 1939, 1944, 1946, 1947, 1949, 1951, 1954, 1955, 1957, 1959, 1960, 1961, 1962, 1963, 1964, 1965, 1966, 1970, 1972, 1973, 1974, 1976, 1977, 1978	31

Note:

1. Wettest and wet years - the Qnri and Qrri and Qndo and Qrdo of any year are 25% or more above "normal" (2.65 and 2.51 MAF, respectively.)
2. Sub-normal and dry years of wetness - when the same runoff parameters are 25% or more below "normal."
3. Critical dry years of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

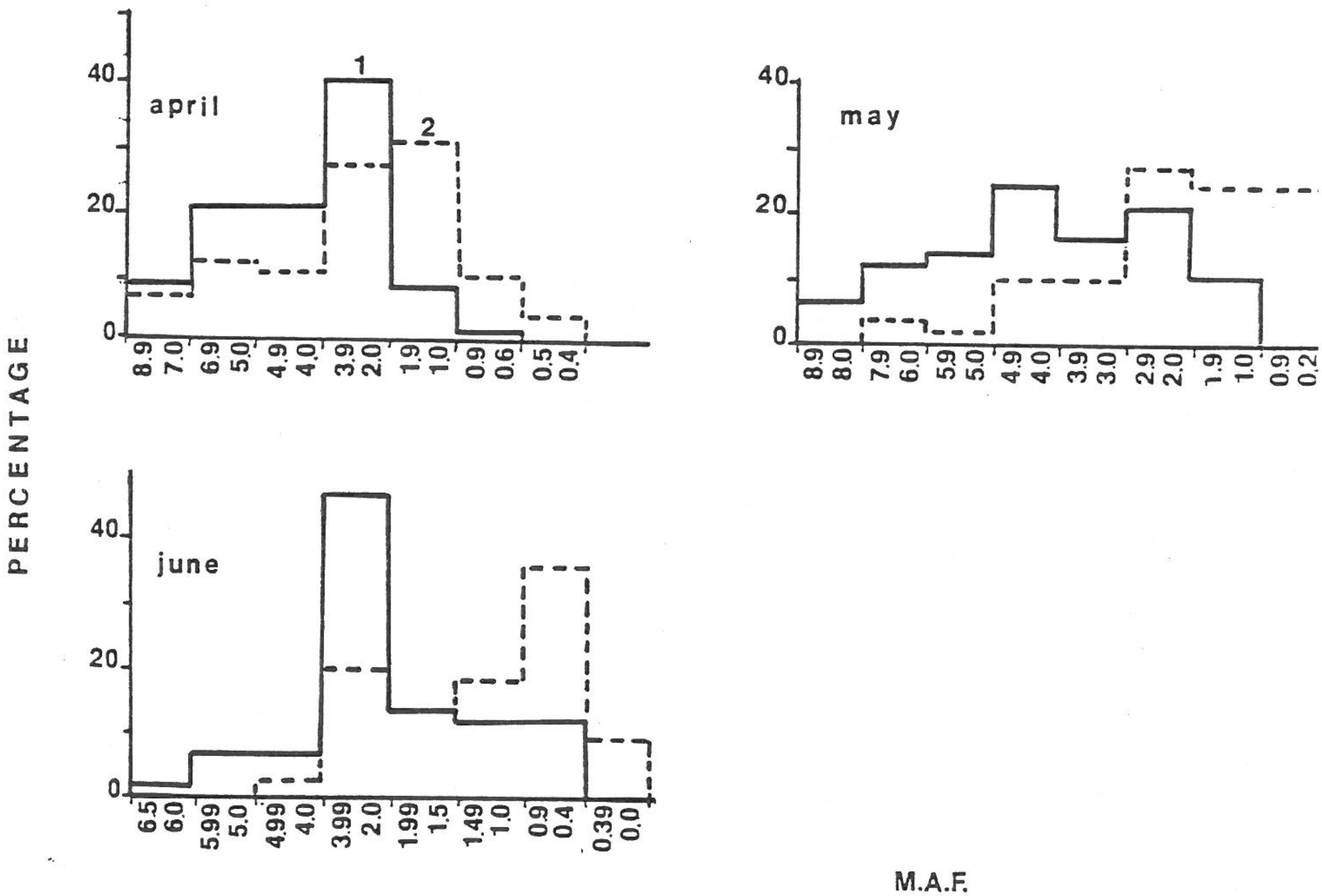


Fig.II.10 . Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1921-82) River Inflow to the Delta for the Spring Months.

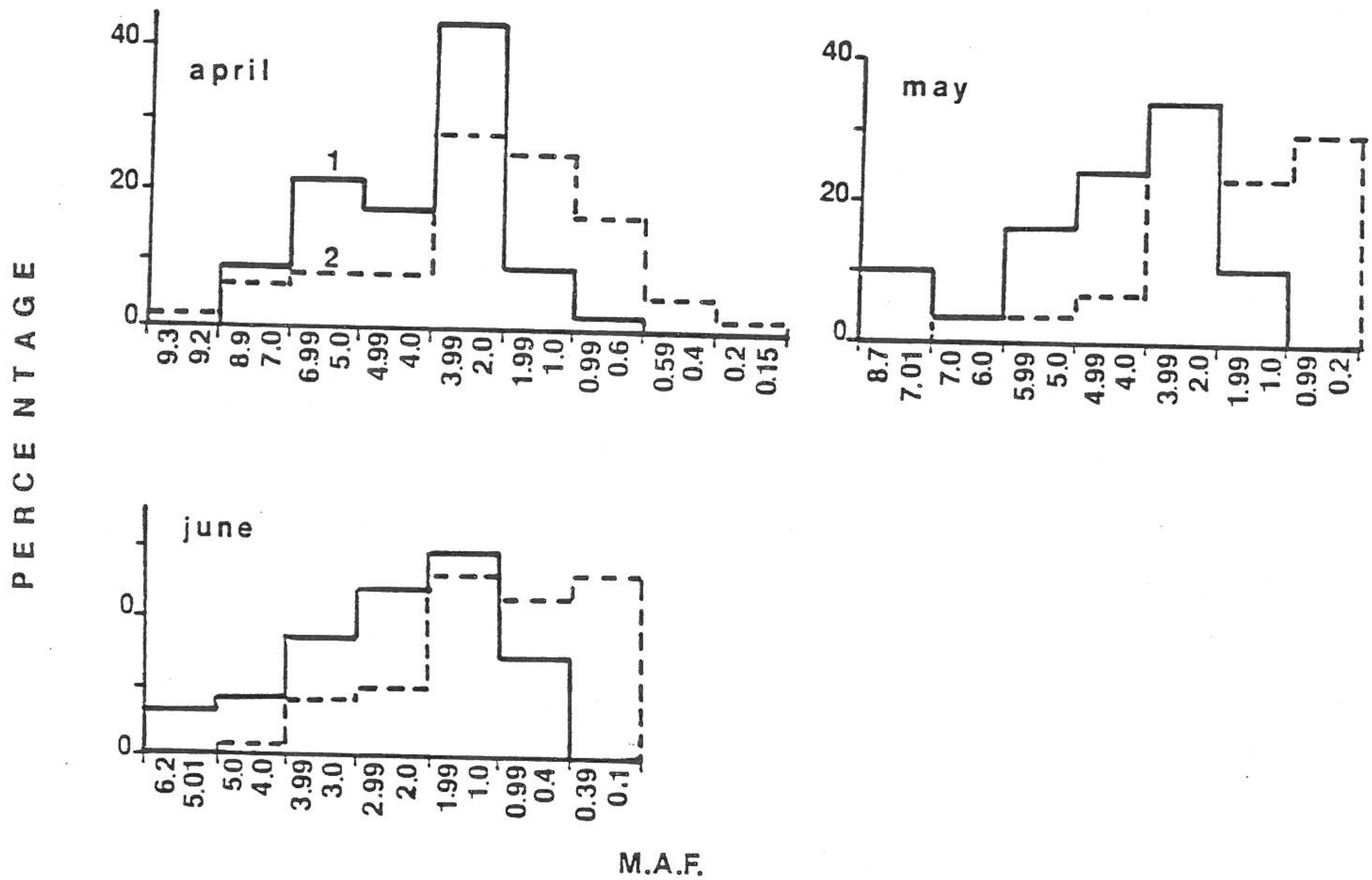


Fig.II.11. Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1922-82) Delta Outflow to the Bay for the Spring Months.

the estuarine system may undergo a gradual transformation, insidious for the first ten to fifteen years but becoming noticeable later on.

SUMMER

Of these months, only July's regulated runoff variables (RRI, RDO) manifest the same trend in their fluctuations as the natural runoff variables for the total period of observations.

But that is not the case for August whose monthly runoff has pronounced differences particularly for the post-project period. Suffice to say that their statistical parameters are so different that in August (as will be seen later for autumn) we are dealing with a new artificial river inflow, the major part of which originates from returning water discharges. Some of the striking properties of summer runoff transformation can be seen from the following:

1. The steady decline of RRI and RDO in July resulted in increases in the number of critical and dry months of July and a reduction in the number of wet ones (Table II. 21).

2. RDO of July is characterized by a pronounced increase in the number of critical dry months of July and at the same time, it demonstrates the essential reduction in the number of wet, sub-normal and dry July months (2-5 times).

3. However, the amount of wet and sub-normal August months of RRI increased 1.2-1.4 times.

4. The number of wet and sub-normal months of August was reduced significantly, while the number of critical dry increased several times (Table II. 22).

Such transformation of RRI and RDO should be considered the result of climatological changes, but rather is the result of flow regime changes that have taken place in the basin since the late 1960's when diversion reached its peak.

Therefore, the hydrological summer consists of two months which differ not only from each other (as never before under natural conditions) but also from the natural trend of runoff fluctuation and its statistics (see Part II.2.6).

The overall picture of runoff redistribution of river inflow/Delta outflow for July can be drawn from the histogram (Fig. II. 12, 13) whose striking feature is that RRI shifted towards a predominant lower range whose configuration resembles that of August under would-be natural conditions. The rare but highest values of the would-be NRI ceased to exist and was substituted by the occurrence of runoff of lower value.

Table II.21 The number of years of different wetness in relation to "normal" monthly runoff - July

Runoff Character-istics	Wettest and Wet Years	Years	Sub-normal and Dry Years	Years	Critical Dry Years	Years
Qnri	1922, 1941, 1942, 1952, 1953, 1956, 1958, 1963, 1965, 1967, 1969, 1971, 1974, 1975, 1978	15	1925, 1928, 1929, 1930, 1933, 1940, 1947, 1949, 1951, 1954, 1955, 1959, 1960, 1961, 1964, 1966, 1968, 1972	18	1924, 1926, 1931, 1934, 1939, 1961, 1976, 1977	8
Qrri	1938, 1962 1971, 1974	4	1927, 1932, 1945, 1948, 1956, 1957, 1959, 1960 1961, 1962, 1963, 1964, 1966, 1968, 1976	15	1924, 1925, 1926, 1928, 1929, 1930, 1931, 1933, 1934, 1935, 1936, 1937, 1939, 1940, 1943, 1944, 1946, 1947, 1949, 1950, 1951, 1954, 1955, 1977	24
Qndo	1922, 1938, 1941, 1942, 1952, 1953, 1956, 1958, 1963, 1965, 1967, 1969, 1970, 1974, 1975, 1978	16	1928, 1930, 1933, 1940, 1946, 1950, 1951, 1954, 1955, 1964, 1972	11	1924, 1926, 1929, 1931, 1934, 1939, 1947, 1949, 1959, 1960, 1961, 1966, 1968, 1972, 1976, 1977	16
Qrdo	1938, 1952, 1967	3	1923, 1948, 1956, 1974, 1975	5	1924, 1925, 1926 1927, 1928, 1929, 1930, 1931, 1932, 1933, 1934, 1935, 1936, 1937, 1939, 1940, 1944, 1945, 1946, 1947, 1948, 1949, 1950, 1951, 1953, 1954, 1955, 1957, 1959, 1960, 1961, 1962, 1963, 1964, 1965, 1966, 1968, 1970, 1972, 1973, 1976, 1977, 1978	43

Note:

1. Wettest and wet years - the Qnri and Qrri and Qndo and Qrdo of any year are 25% or more above "normal" (1.04 and 0.33 MAF, respectively.)
2. Sub-normal and dry years of wetness - when the same runoff parameters are 25% or more below "normal."
3. Critical dry years of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

Table II.22 The number of years of different wetness in relation to "normal" monthly runoff - August

Runoff Characteristics	Wettest and Wet Years	Years	Sub-normal and Dry Years	Years	Critical Dry Years	Years
Qnri	1938, 1941, 1942, 1952, 1956, 1958, 1963, 1965, 1967, 1969, 1971, 1974, 1975, 1978	14	1924, 1926, 1929, 1930, 1931, 1933, 1934, 1939, 1947, 1977	10	1931	1
Qrri	1958, 1959, 1961-76, 1978	19	1925, 1927, 1928, 1930, 1932, 1935, 1936, 1940, 1943, 1944, 1955, 1977	12	1924, 1926, 1931, 1933, 1934, 1937, 1939	7
Qndo	1938, 1941-43, 1952, 1953, 1956, 1958, 1963, 1965, 1967, 1969-71, 1974, 1975, 1978	17	1924, 1926, 1928, 1930, 1933, 1934, 1936, 1937, 1940, 1944, 1949, 1950, 1955, 1959-61, 1964, 1966, 1972	19	1924, 1926, 1929, 1930, 1931, 1933, 1934, 1939, 1977	9
Qrdo	1958, 1965, 1967, 1969, 1970, 1971, 1974, 1975	8	1946, 1949, 1950, 1953, 1954, 1957, 1961, 1976, 1977	9	1921-37, 1939, 1940, 1943, 1944, 1947, 1955	23

Note:

1. Wettest and wet years - the Qnri and Qrri and Qndo and Qrdo of any year are 25% or more above "normal" (0.54 and 0.32 MAF, respectively.)
2. Sub-normal and dry years of wetness - when the same runoff parameters are 25% or more below "normal."
3. Critical dry years of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

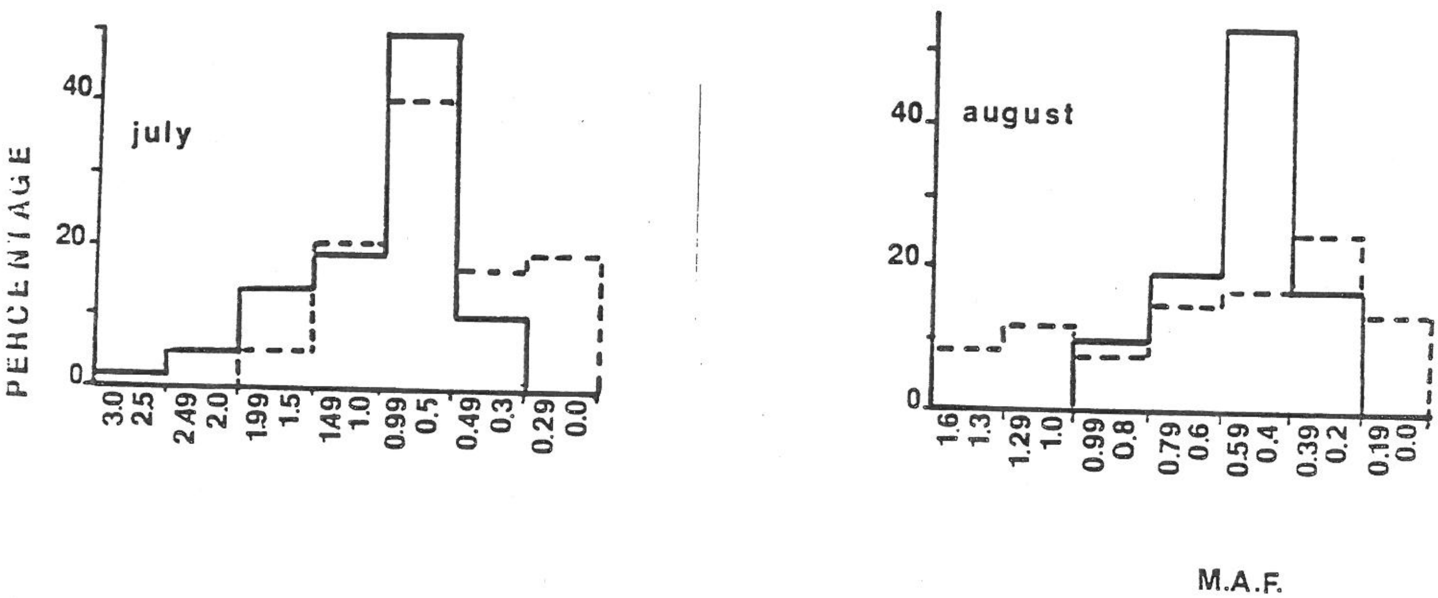


Fig. II.12 . Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1921-82) River Inflow to the Delta for the Summer Months.

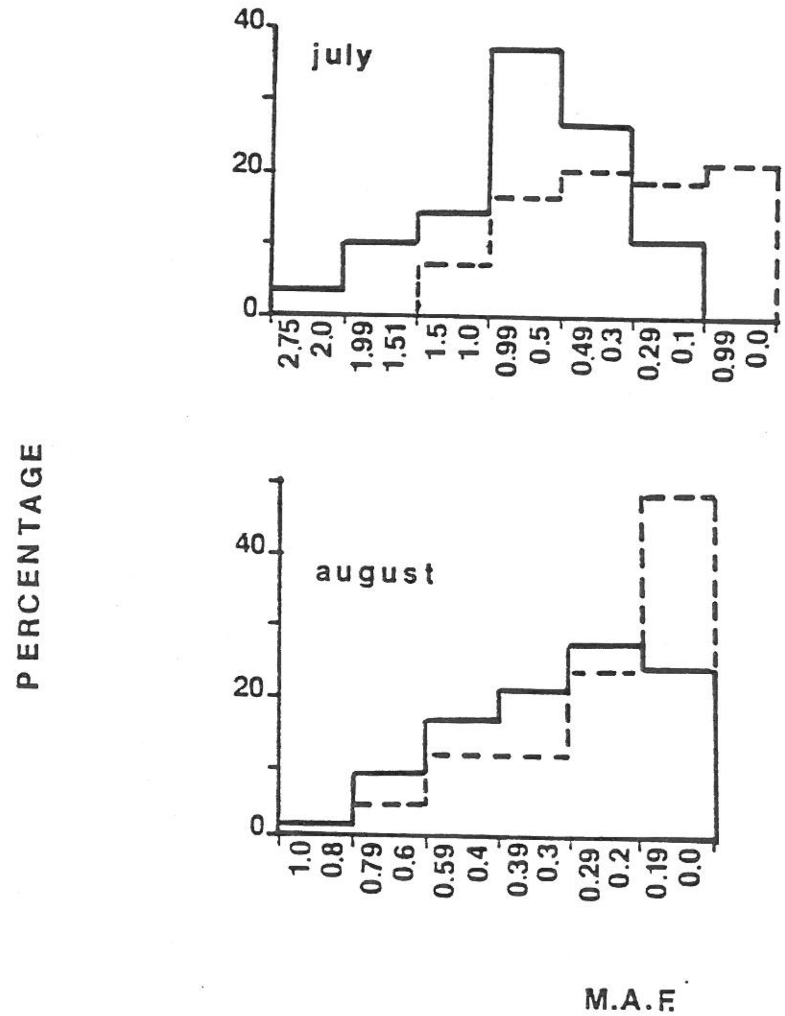


Fig.II.13. Histograms of Occurrence of (1) Natural (1921-78)and (2) Regulated (1922-82) Delta Outflow to the Bay for the Summer Months.

Almost the same shifting took place for July's RDO, which resembles the frequency of occurrence of August NDO; the number of low flow ranges increased and the highest values of the would-be NDO ceased to exist. Overall, the maximums for RRI and RDO and their frequency of occurrence were truncated by the diversions. Therefore, July is not a month which may show the impact of returning water discharge to the river-Delta ecosystem, as appears to be the rule for August RRI.

The presence of the discussed new properties of the RRI distribution for <u>August</u> can be seen from the histogram (Fig. II. 12, 13). The specific features of this histogram are: 1) the overall leveling of the probability of occurrence of the highest and lowest values of runoff despite, 2) the appearance of the new ranks of highest values of runoff.

Therefore, August is the first month exposed to the strong influence of the new water management policy comprising the releases of significant amounts of water to the river basins from different sources, whose volumes may be several times higher than NRI, especially for summers of abnormal or close-to-normal years of wetness.

<u>AUTUMN</u>

As was discussed earlier, there are not many similarities between the monthly natural and regulated variables of runoff during autumn, especially for the post-project period. It is likely that the major cause of the differences is the amount of returning water from the drainage network emptying into the river Delta system. The combined result has led to noticeable increases in water supply to the river and Delta. These increases transformed the major statistics of runoff for these months so that they cannot be identified with their natural values.

For example, for each of these months, the number of the so-called wet years for regulated runoff characteristics increased several times, although no climatological changes were documented over the Sacramento-San Joaquin Rivers' watershed or the adjacent vast areas. (Tables II. 23-25). At the same time, we can trace some differences between these months in regard to the number of sub-normal and dry and critical dry years which we relate to the post-project changes in flow fluctuations.

For example, RDO for <u>October</u> has a number of sub-normal and dry years 2.3 times lower than the would-be natural runoff and equal amount of critical dry years.

In <u>November</u> the number of sub-normal and dry years of RRI was reduced as much as 1.5 times and the critical dry years for the RRI were reduced 1.3 times of the NRI. At the same time, the number of sub-normal, dry and critical dry years of RDO did not experience significant changes, although the number of wet years for RDO was reduced almost three times in comparison with the would-be natural Delta outflow.

Therefore, the project operations did bring about some relatively positive changes in the number of years of relative high wetness for both RRI and RDO, primarily for September and October, but since this was accomplished largely as a result of increasing agricultural return flows, their role in the "improvement" of the river-Delta water quality is very much in question.

The changes in frequency distribution of absolute values of river inflow and Delta outflow regulated variables in comparison with the natural can be seen from the histograms (Figs. II. 14, 15):

First, in general, the range of regulated runoff fluctuations increased significantly; second, high new ranges of regulated runoff fluctuations appeared, while the predominant range of small water supply to the Delta (NRI) was truncated, especially for September and October.

It should be noted that for these months, as for August, one may say that practically we are dealing with a new hydrological regime of combined Sacramento-San Joaquin runoff whose statistics, especially for the post-project conditions, changed beyond the natural scale of a frequency curve (Figs. II. 20, 21).

This implies that the amount of water which at present is discharged to the Delta, and from the Delta to the Bay, corresponds routinely to the values which would be observed under natural conditions at least once in 10, 20 or more years. However, there is no indication that this increase in autumn runoff has enhanced the fall run of chinook salmon or contributed to the improvement of any other significant biological characteristics.

It should be emphasized that the absolute value of RRI entering the Delta of 1.1 MAF (September 1974), 0.9 MAF (October 1975) and 0.9 MAF (November 1975) were 1.8, 1.5 and 1.3 times higher than the NRI, but this was not the case for the RDO.

However, at the time more than 90% of the RRI for September and October was higher than the NRI (since the 1940's) the volumes of RDO were much less than the RRI, but higher than the values of the would-be NDO (in some instances as much as twice). That means that returning and released water is able to replenish channel depletion in the Delta and even demonstrate the presence of water surplus if regulated values of Delta outflow are of concern.

Therefore, San Francisco Bay has enjoyed an increase in water discharges within the dominant range of 60-80% (September), 25-40% (October), and 15-25% (November) for the period 1945-58, and for the same months of the period from 1962-75, the increases

Table II.23 The number of years of different wetness in relation to "normal" monthly runoff - September

Runoff Characteristics	Wettest and Wet Years	Years	Sub-normal and Dry Years	Years	Critical Dry Years	Years
Qnri	1938, 1941, 1952, 1956, 1958, 1959, 1967, 1969, 1971, 1974, 1975, 1978	12	1924, 1926, 1929, 1931, 1933, 1934	6		0
Qrri	1948, 1951, 1952, 1953, 1956, 1957, 1958, 1959, 1962-75, 1978	23	1924, 1931, 1934, 1937, 1939	5		0
Qndo	1941, 1942, 1943, 1952, 1953, 1957, 1958, 1959, 1963, 1967, 1969, 1971, 1972, 1974, 1975, 1978	16	1926, 1928, 1929, 1930, 1932, 1933, 1934, 1935, 1936, 1937, 1939, 1944, 1947, 1949, 1964	15	1924, 1931, 1934	3
Qrdo	1948, 1952, 1953, 1956, 1957, 1958, 1959, 1962-65, 1967, 1969, 1970, 1971, 1972, 1973, 1974, 1975, 1978	20	1922, 1925-30, 1935, 1936, 1937, 1939, 1944, 1945, 1976, 1977	15	1921, 1924 1931, 1932, 1933, 1934	6

Note:
1. Wettest and wet years - the Qnri and Qrri and Qndo and Qrdo of any year are 25% or more above "normal" (0.45 and 0.3 MAF, respectively.)
2. Sub-normal and dry years of wetness - when the same runoff parameters are 25% or more below "normal."
3. Critical dry years of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

Table II.24 The number of years of different wetness in relation to "normal" monthly runoff - October

Runoff Characteristics	Wettest and Wet Years	Years	Sub-normal and Dry Years	Years	Critical Dry Years	Years
Qnri	1946, 1948, 1951, 1957, 1958, 1963, 1970, 1974, 1976	9	1922, 1925, 1927, 1929, 1930, 1931, 1932, 1933, 1934, 1935, 1936, 1937, 1950, 1956, 1961, 1962, 1967, 1978	18		0
Qrri	1957, 1958, 1963, 1964, 1966, 1968, 1970-76	13	1925, 1932, 1935, 1978	4		0
Qndo	1939, 1946, 1948, 1951, 1957, 1958, 1963, 1964, 1970, 1973, 1974, 1976	12	1927, 1929, 1931, 1932, 1933, 1934, 1935, 1937, 1950, 1956, 1961, 1962, 1967, 1978	14	1930	1
Qrdo	1939, 1946, 1948, 1949, 1951, 1952, 1953, 1954, 1957, 1958, 1959, 1963, 1964, 1966, 1968, 1970-76	22	1932, 1933, 1935, 1961, 1962, 1977	6	1978	1

Note:

1. Wettest and wet years - the Qnri and Qrri and Qndo and Qrdo of any year are 25% or more above "normal" (0.58 and 0.46 MAF, respectively)
2. Sub-normal and dry years of wetness - when the same runoff parameters are 25% or more below "normal."
3. Critical dry years of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

Table II.25 The number of years of different wetness in relation to "normal" monthly runoff - November

Runoff Character-istics	Wettest and Wet Years	Years	Sub-normal and Dry Years	Years	Critical Dry Years	Years
Qnri	1921, 1927, 1928, 1938, 1945, 1946, 1951, 1964, 1966, 1967, 1971, 1973, 1974	13	1923, 1926, 1929, 1939, 1941, 1942, 1948, 1949, 1953, 1956, 1957, 1959, 1961, 1962, 1968, 1970, 1972, 1975	18	1922, 1924, 1930, 1931, 1932, 1933, 1934, 1936, 1937, 1940 1944, 1949, 1950, 1951, 1960, 1977, 1978	17
Qrri	1938, 1951, 1974	3	1925, 1929, 1935, 1939, 1941, 1942, 1944, 1947, 1948, 1953, 1956, 1961	12	1924, 1926, 1930, 1932, 1933, 1934, 1936, 1937, 1940, 1960, 1962, 1977, 1978	13
Qndo	1921, 1927, 1928, 1938, 1946, 1964, 1966, 1967, 1971, 1973, 1974	11	1923, 1929, 1939, 1941, 1942, 1948, 1953, 1957, 1962, 1963, 1970, 1972, 1975	13	1922, 1924, 1926, 1930, 1931, 1932, 1933, 1936, 1937, 1940, 1944, 1950, 1959, 1960, 1968, 1977, 1978	17
Qrdo	1927, 1938, 1951, 1974	4	1923, 1925, 1929, 1935, 1939, 1941, 1942, 1948, 1953, 1954, 1956, 1961, 1973	13	1921, 1922, 1924, 1930, 1931, 1932, 1933, 1934, 1936, 1937, 1940, 1943, 1950, 1956, 1960, 1962, 1969, 1977, 1978	19

Note:

1. Wettest and wet years - the Qnri and Qrri and Qndo and Qrdo of any year are 25% or more above "normal" (1.14 and 1.25 MAF, respectively.)
2. Sub-normal and dry years of wetness - when the same runoff parameters are 25% or more below "normal."
3. Critical dry years of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

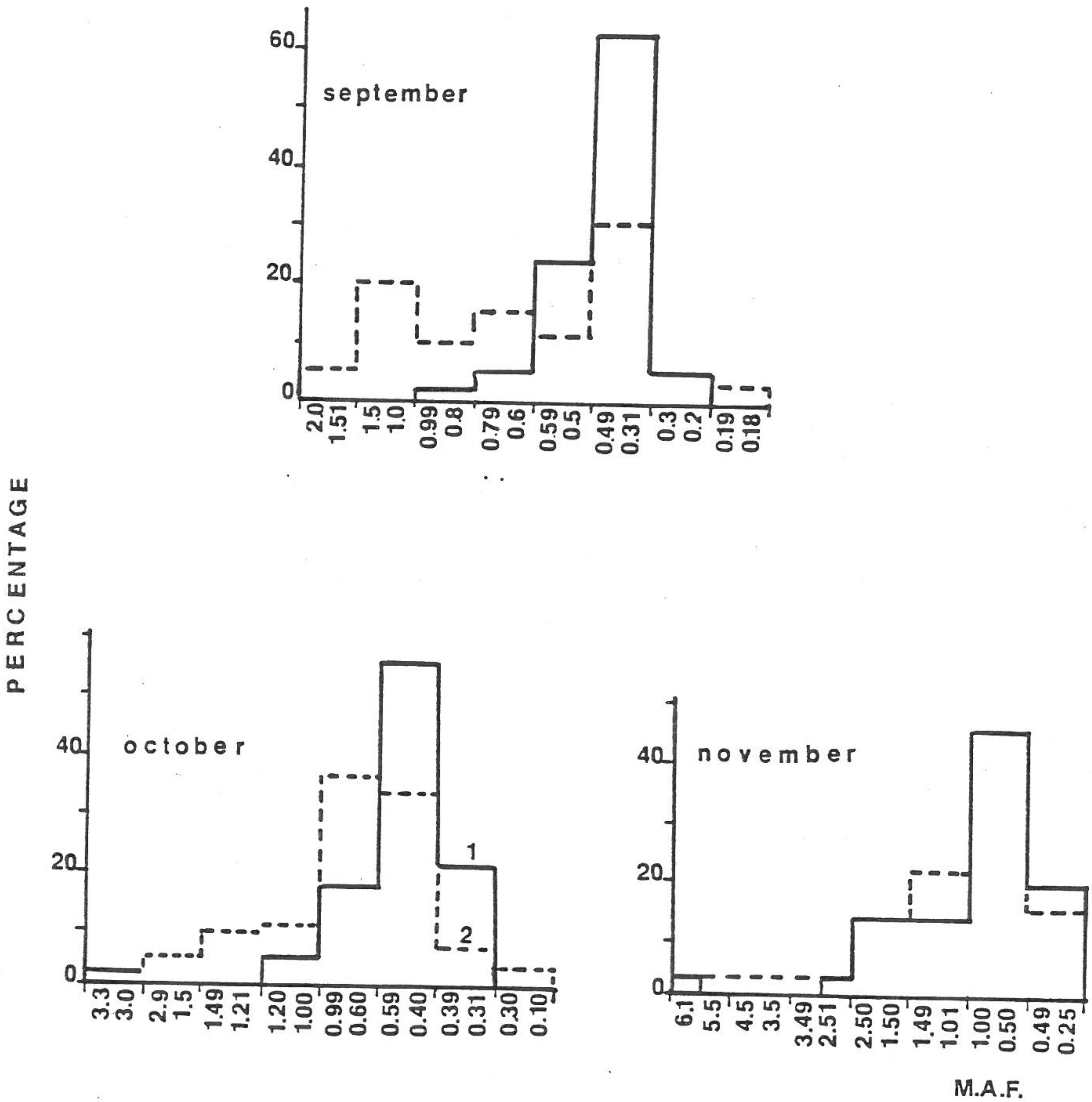


Fig.II.14. Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1921-82) River Inflow to the Delta for the Autumn Months.

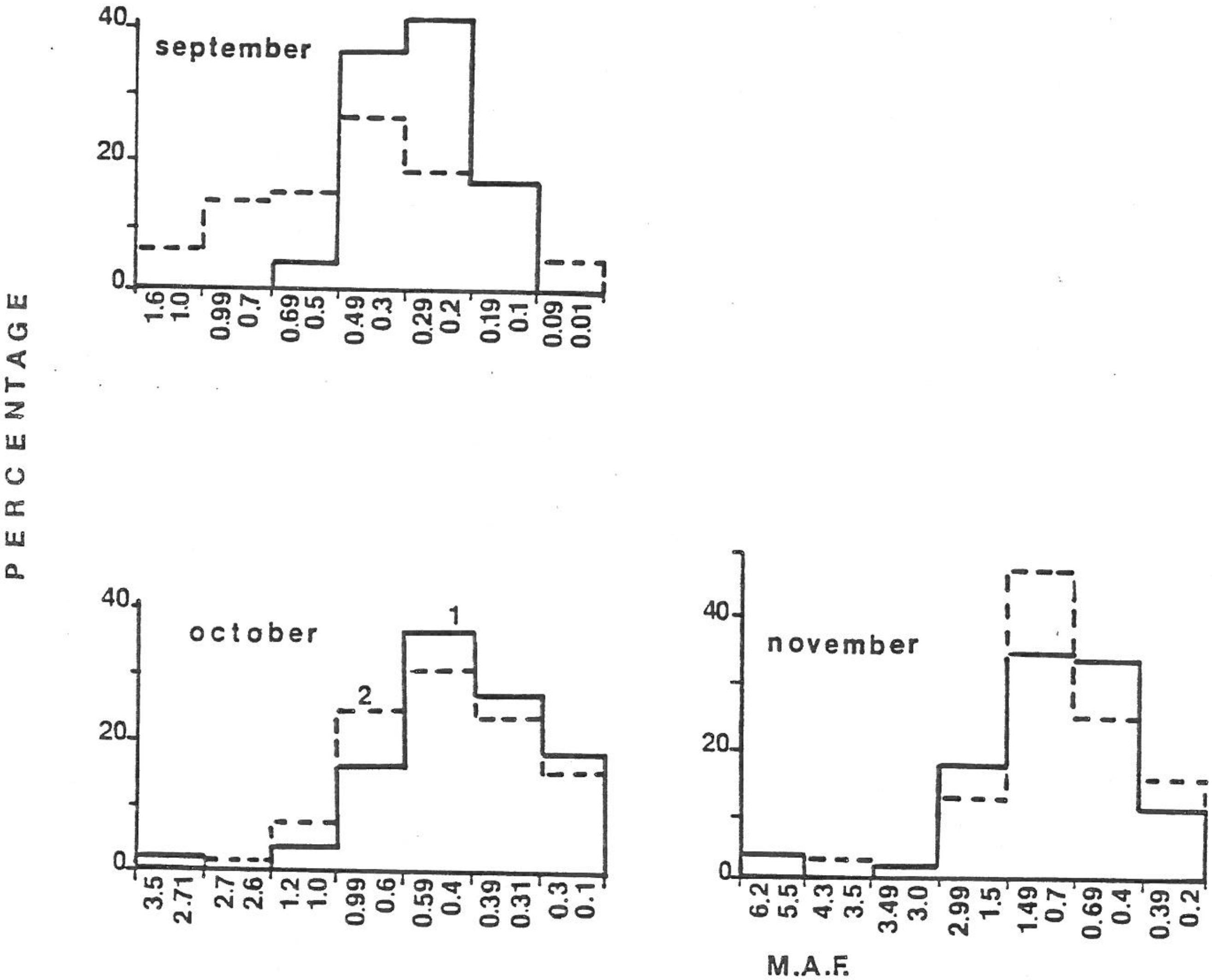


Fig.II.15 Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1922-82) Delta Outflow to the Bay for the Autumn Months.

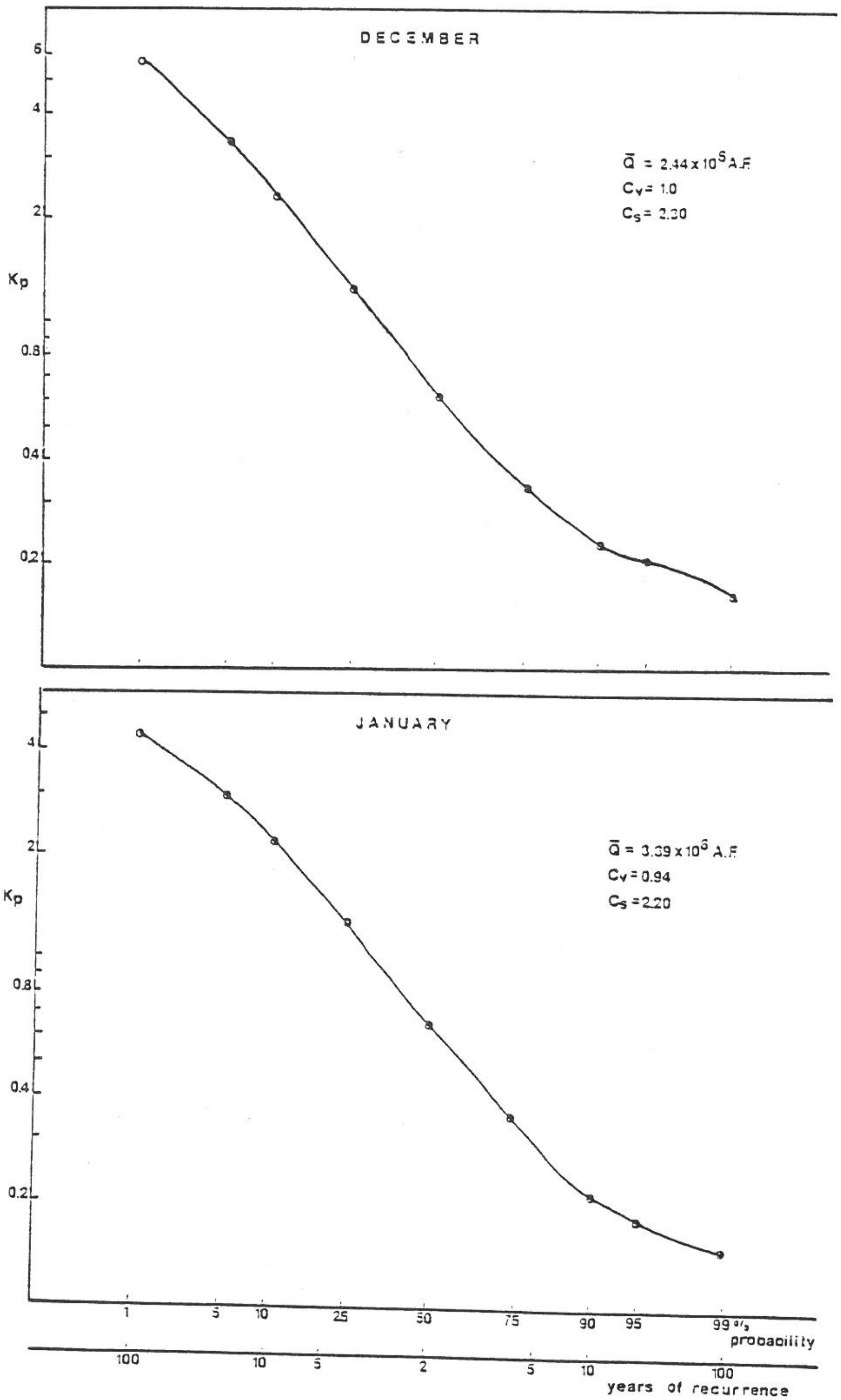
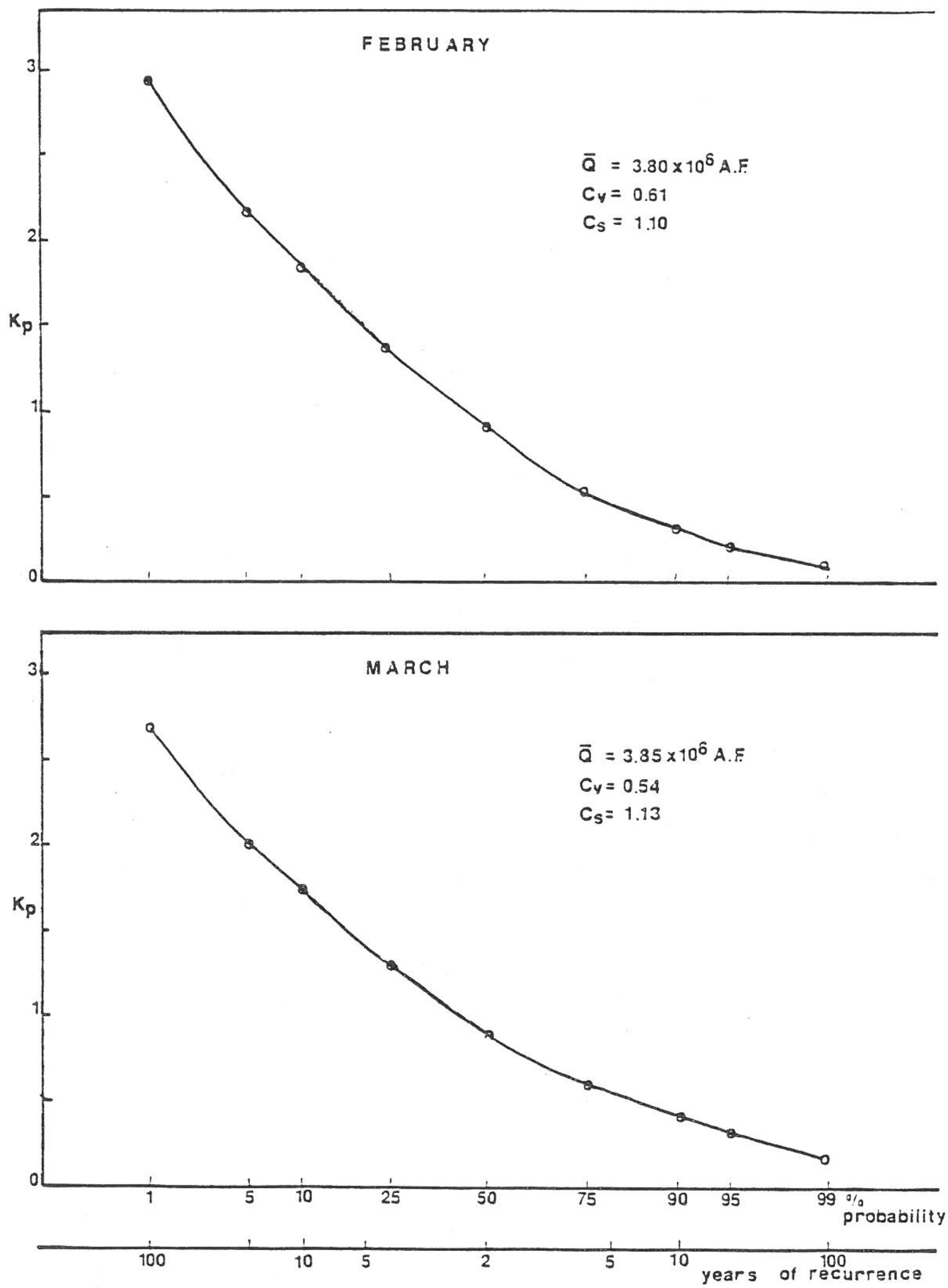


Fig.II.16.Probability Curve of Natural River Inflow for the months of December and January (1921-78).



FigII.17.Probability Curve of Natural River Inflow for the months of February and March (1921-78).

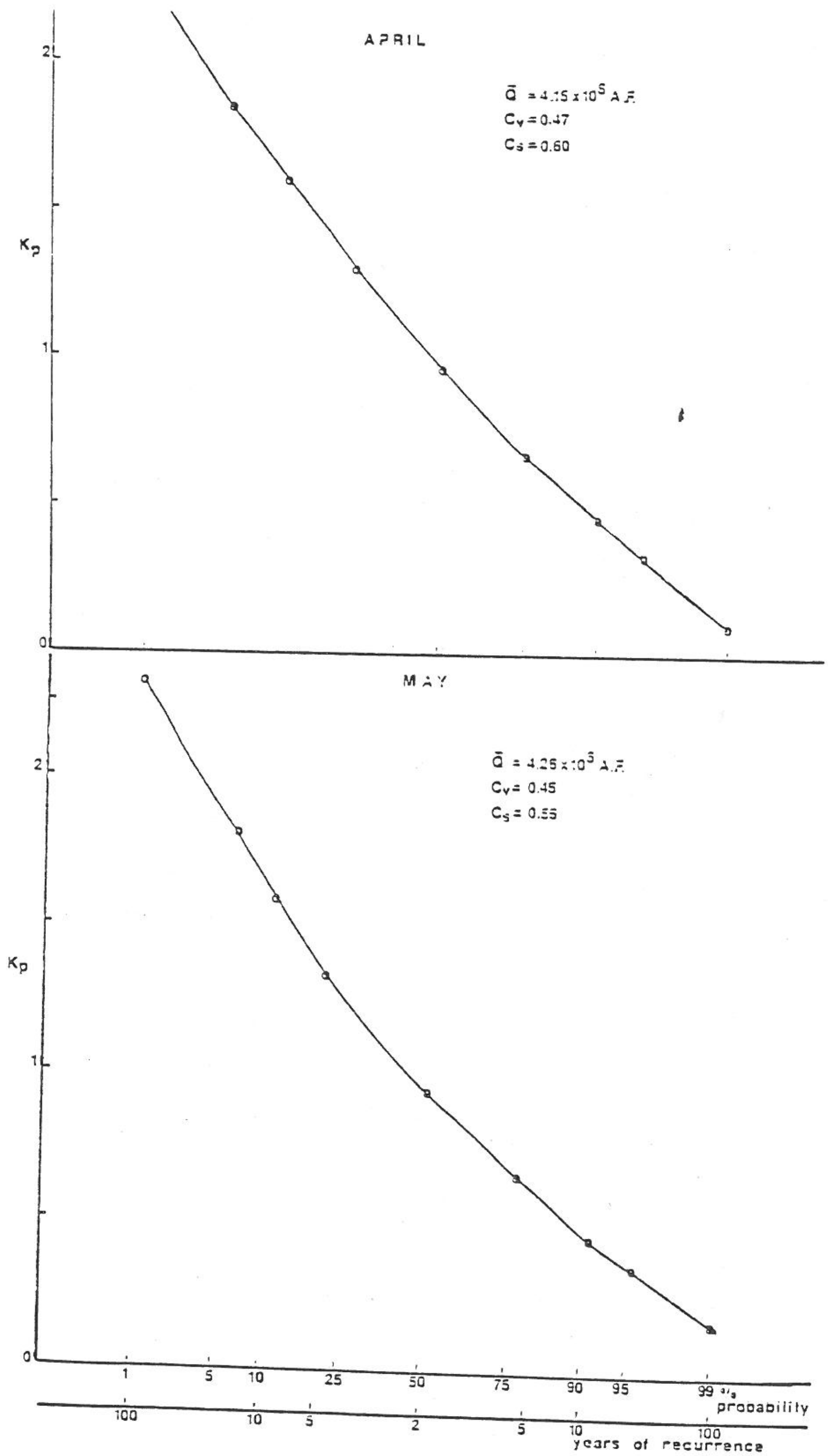


Fig.II.18.Probability Curve of Natural River Inflow for the months of April and May (1921-78).

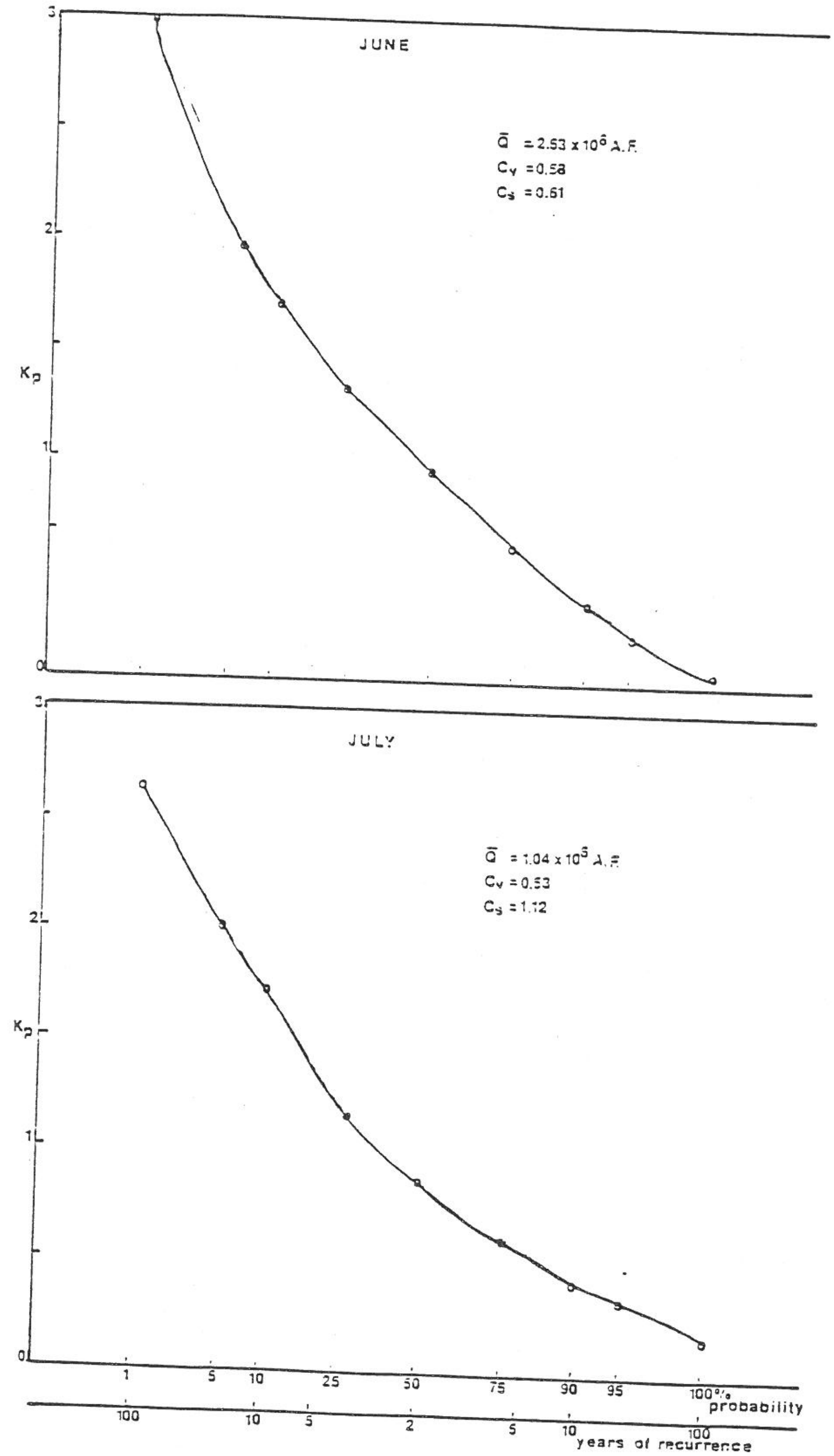


Fig.II.19.Probability Curve of Natural River Inflow for the months of June and July (1921-78).

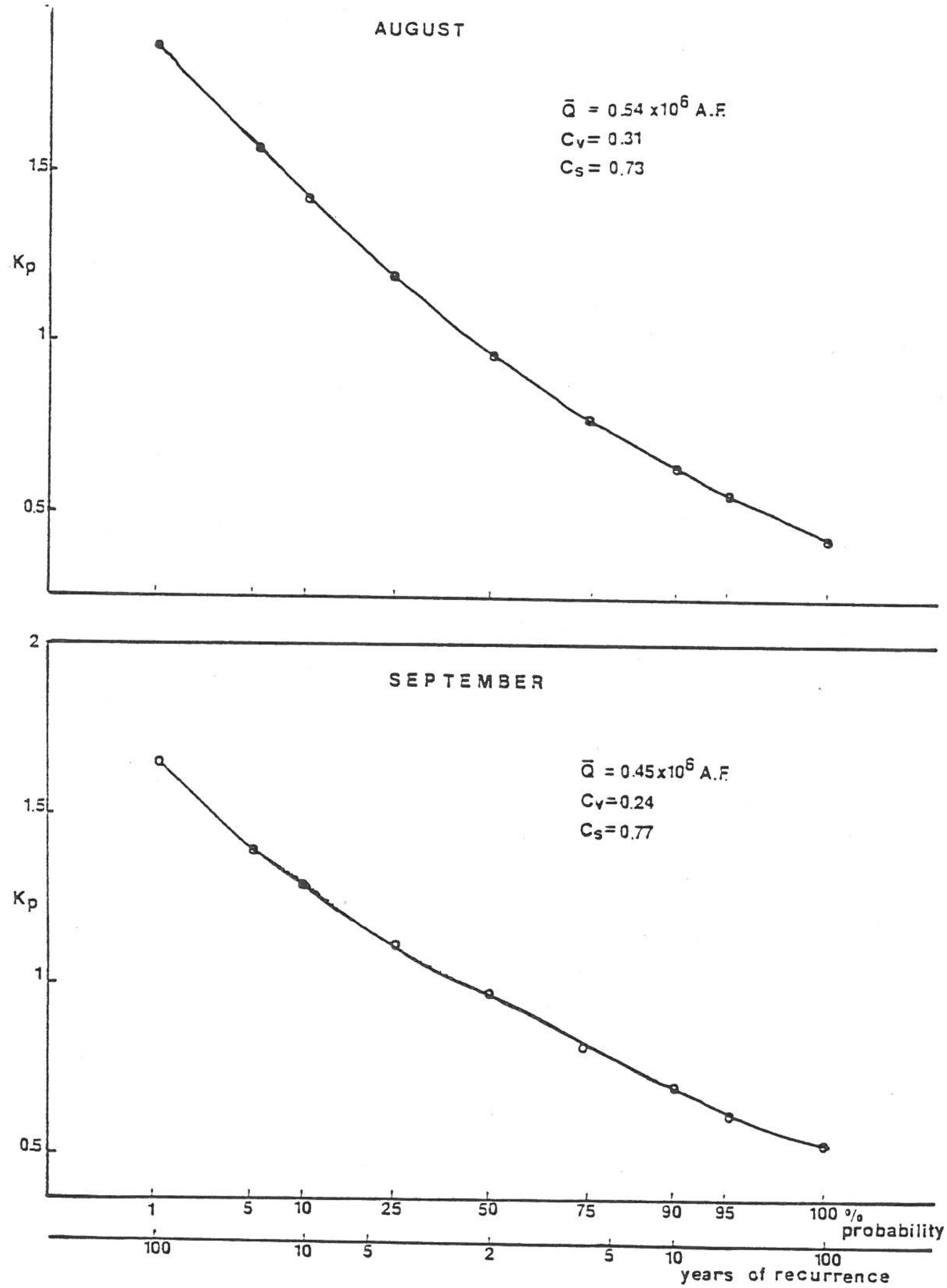


Fig.II.20.Probability Curve of Natural River Inflow for the months of August and September (1921-78).

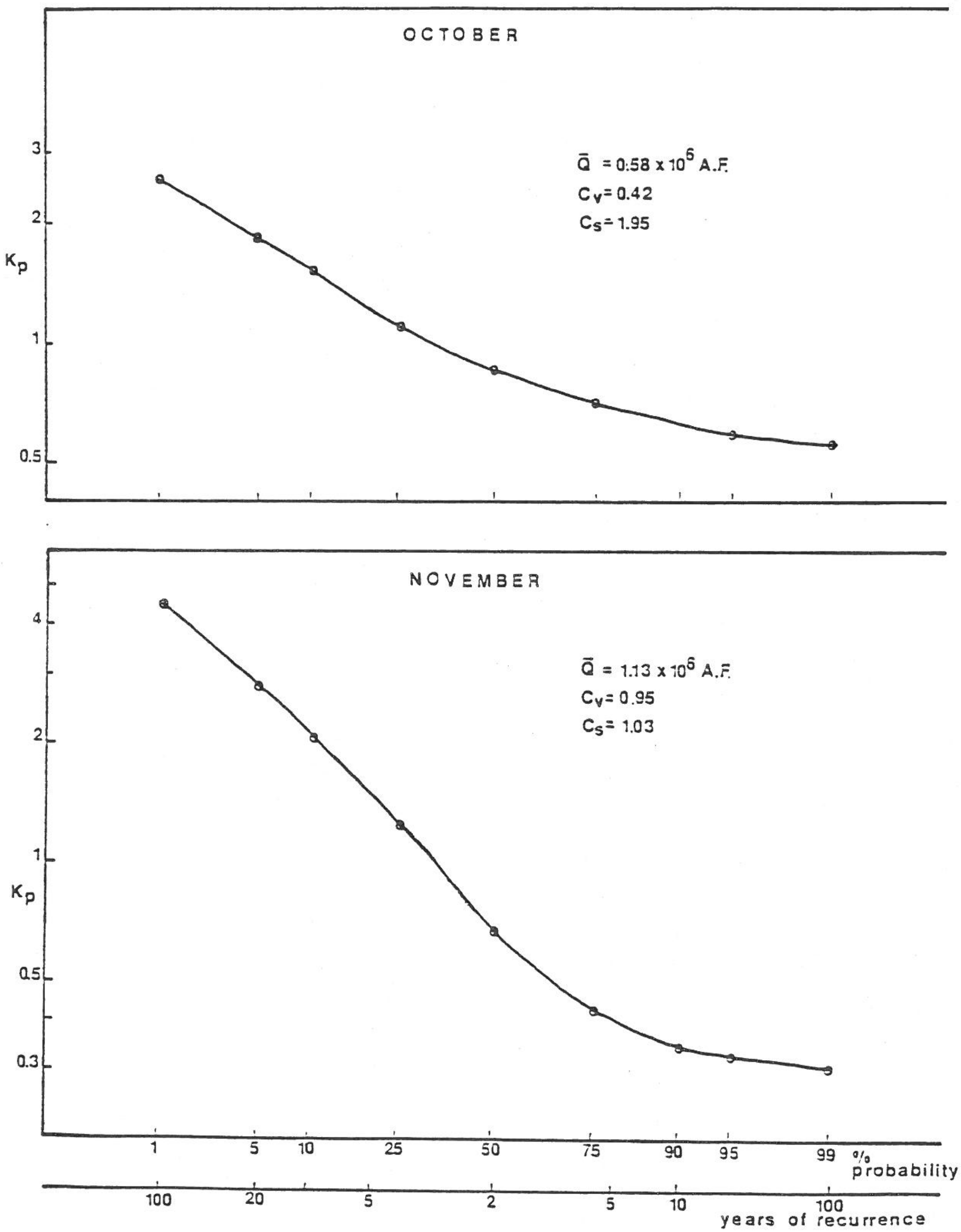


Fig.II.21.Probability Curve of Natural River Inflow for the months of October and November (1921-78).

ranged from 80-100%, 40-80% and ± 15% of their natural flow.

II.2.3 <u>The Trend of Monthly Upstream Diversions During a Typical Cycle of Wetness</u>

In order to illustrate the trend of upstream water development (which takes the lion's share of water out of the Delta-Bay system), the period 1956-1980 was chosen. During this span of time, the major local water facilities were put in operation.

Moreover, this period is interesting because:

1. It includes three distinct phases of wetness (Table II. 5): 1958-1964, decline; 1964-1975, rise; and the shortest, critical dry phase of 1976-1977, with relatively moderate alternation of twelve sub-normal and above-normal years of river inflows.

2. This period may be considered, with the exception of 1976-1977, as the most favorable for the operation of the CVP and SWP facilities to meet growing needs for water in California.

This period may give some additional information about how the upstream water withdrawals, representing more than 60% of total diversions, accelerated changes in the seasonal patterns of the river inflow to the Delta on the average. One may assume that the decline of the striped bass index and fish population as well as many other biological changes widely publicized in numerous reports and articles began prior to 1976 and 1977. These critical dry and drought years may have exacerbated the impact of the preceding two decades of intensive diversion on the water quality and biological resources of the Delta-Bay ecosystem.

Figures II. 22-26 and Tables II. 26-27 present the following:

1. The monthly distribution of the NRI and NDO in percentage of their annual mean for each of the five-year periods (except for 1971-75) did not change significantly.

This means that the projects' operation tends to maintain the would-be natural percentage of monthly flow distribution. However, this measure cannot change the fact that the absolute values of NRI and RDO are quite different.

2. During the winter and particularly spring, the RRI volumes discharged to the Delta for all periods discussed was 1.5-2.9 times lower than the NRI.

3. Meanwhile, for the late summer and autumn, especially September and October, the values of RRI were 1.3-2.9 times higher than the would-be natural.

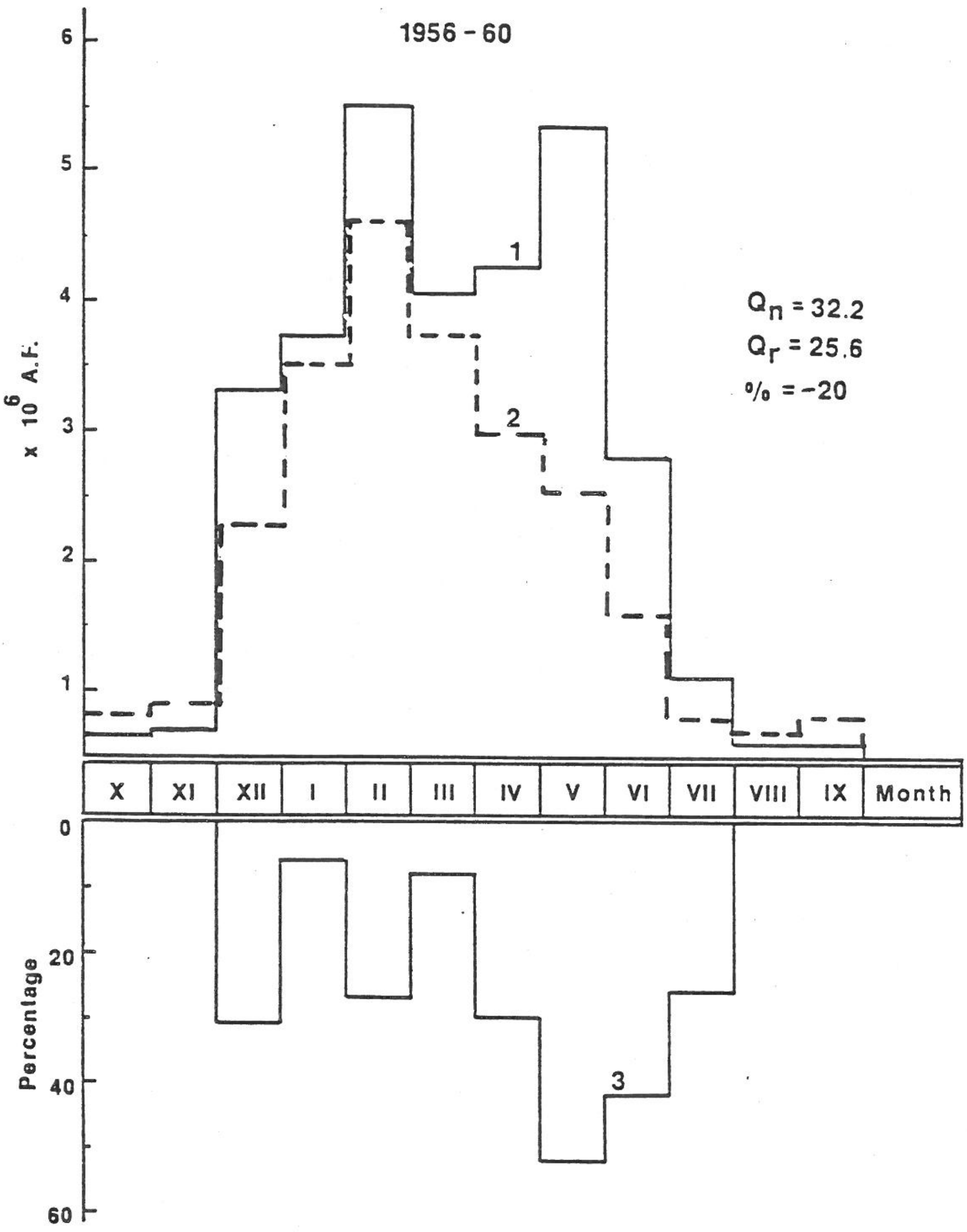


Fig.II.22 .The five year (1956-60) mean monthly fluctuation of (1) natural and (2) regulated inflow to the Delta and (3) upstream diversions (expressed as a percentage of natural river inflow).

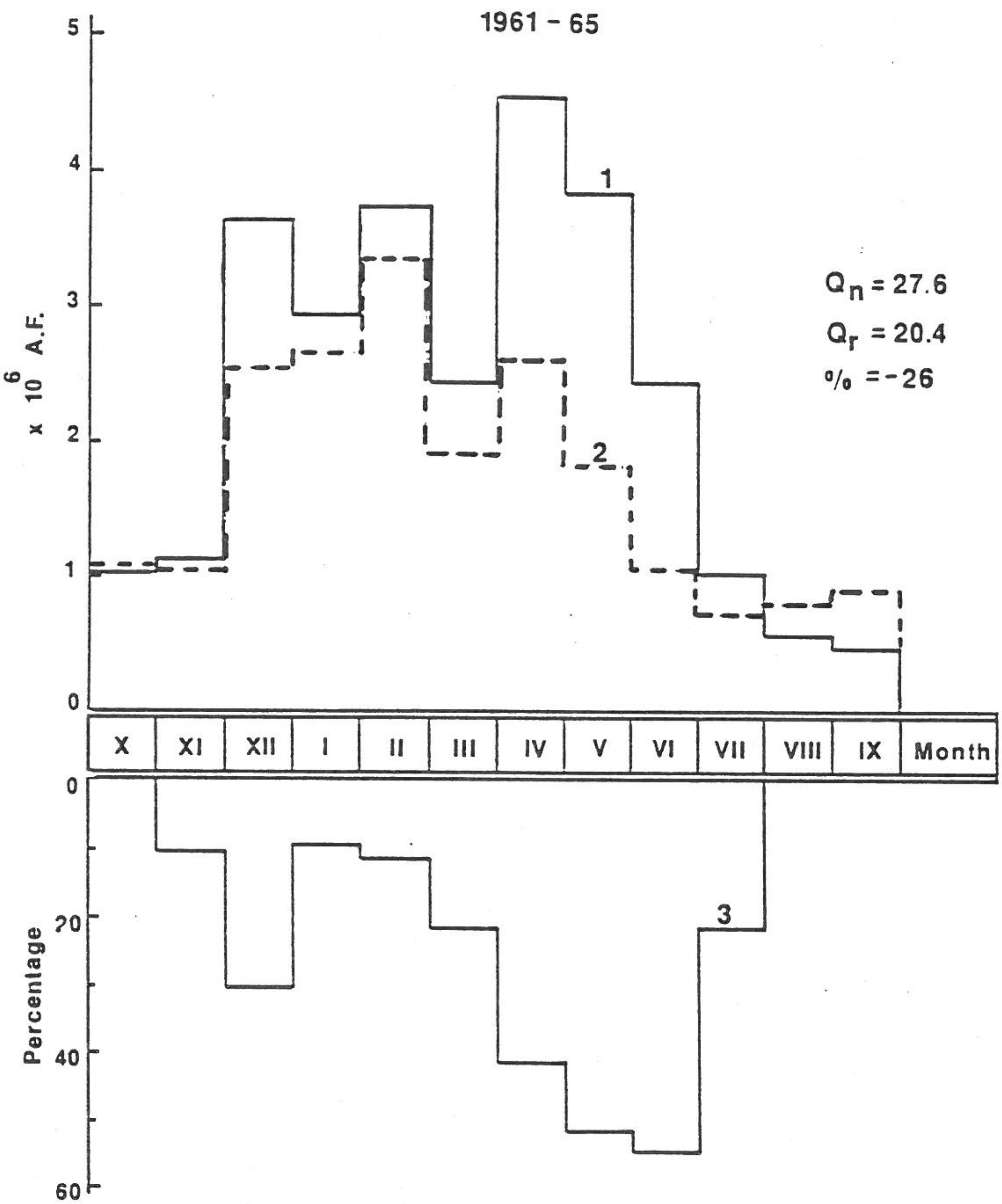


Fig.II.23 .The five year (1961-65) mean monthly fluctuation of (1) natural and (2) regulated inflow to the Delta and (3) upstream diversions (expressed as a percentage of natural river inflow).

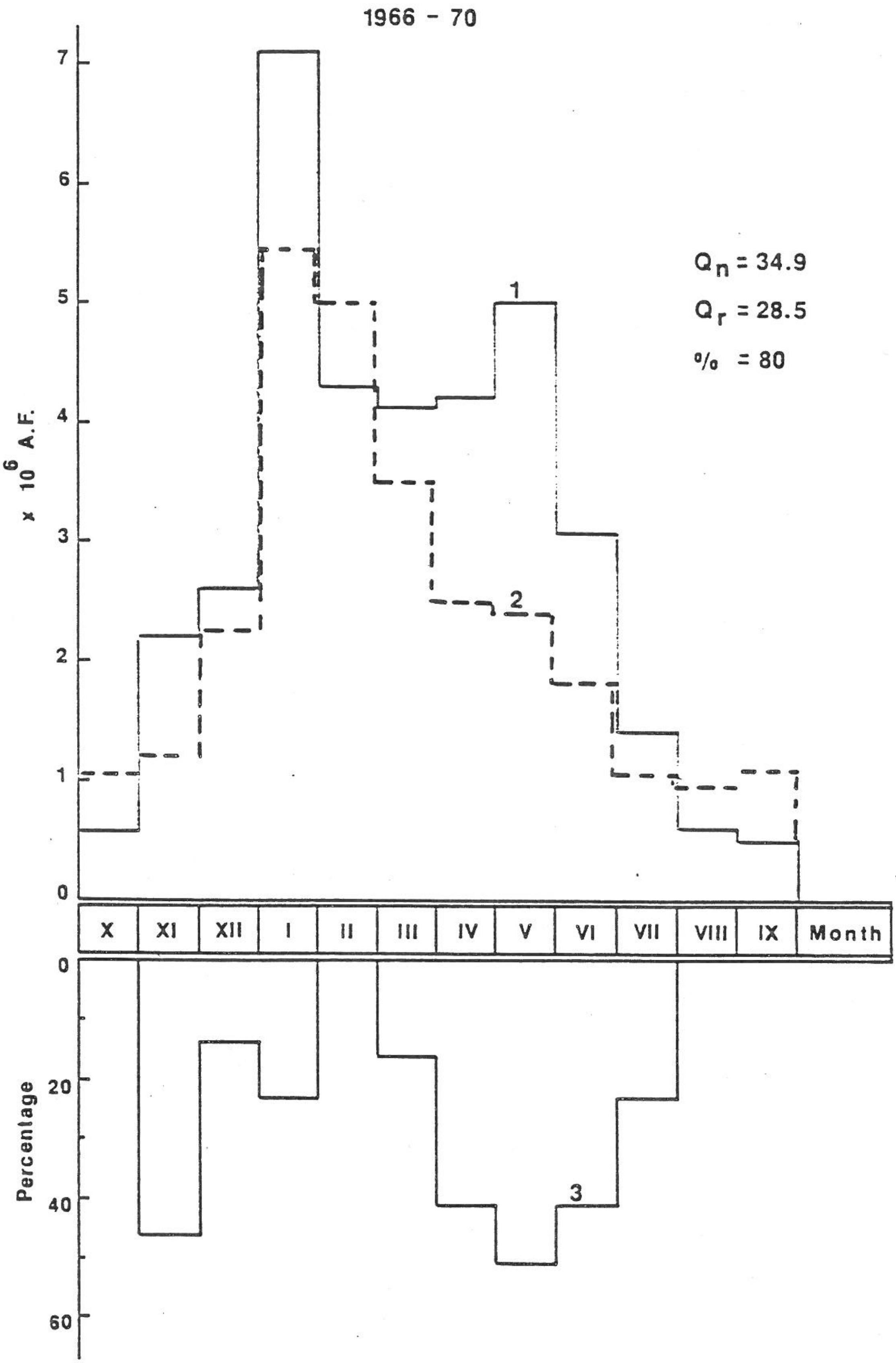


Fig.II.24 .The five year (1966-70) mean monthly fluctuation of (1) natural and (2) regulated inflow to the Delta and (3) upstream diversions (expressed as a percentage of natural river inflow).

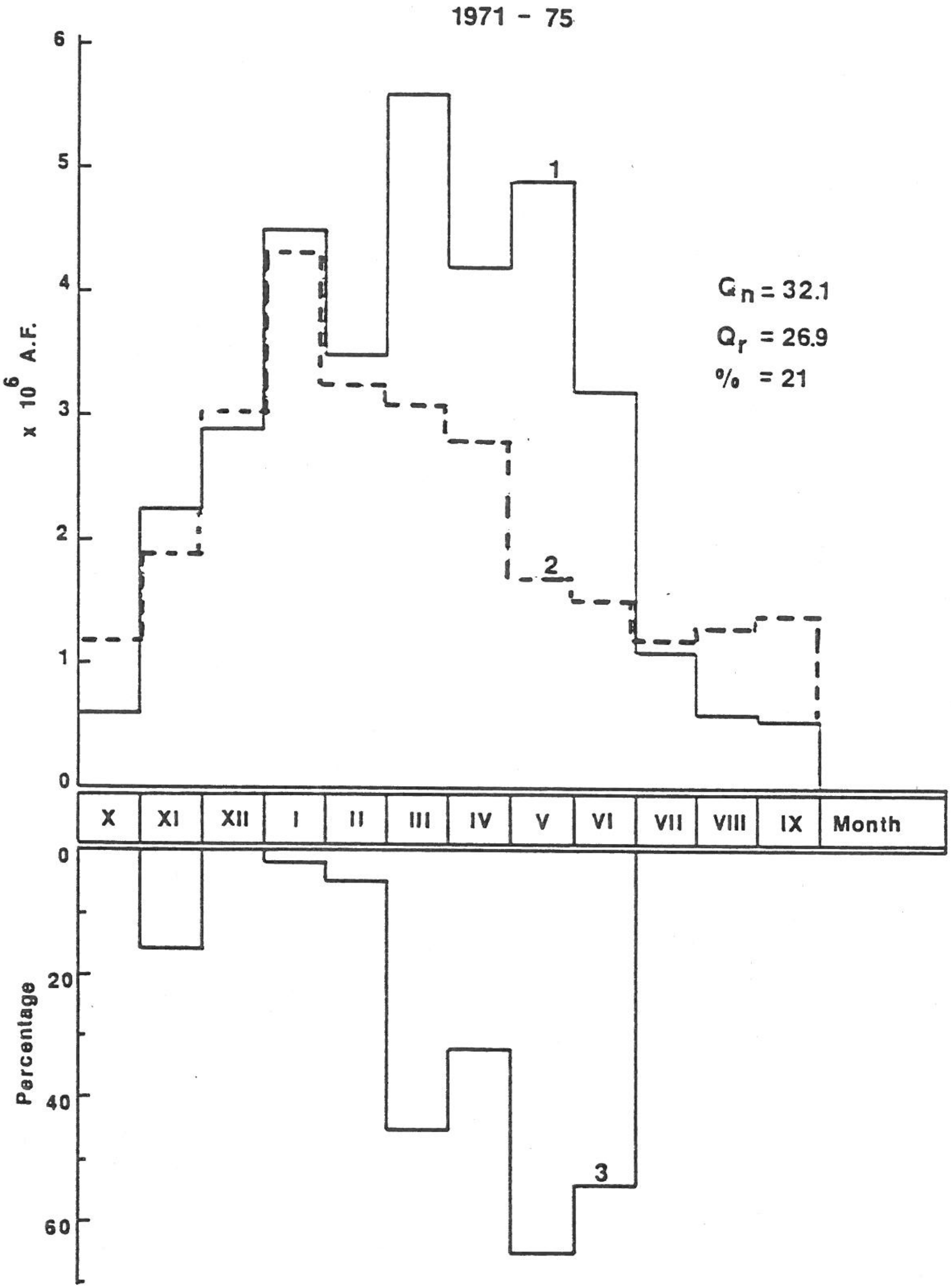


Fig.II.25 .The five year (1971-75) mean monthly fluctuation of (1) natural and (2) regulated inflow to the Delta and (3) upstream diversions (expressed as a percentage of natural river inflow).

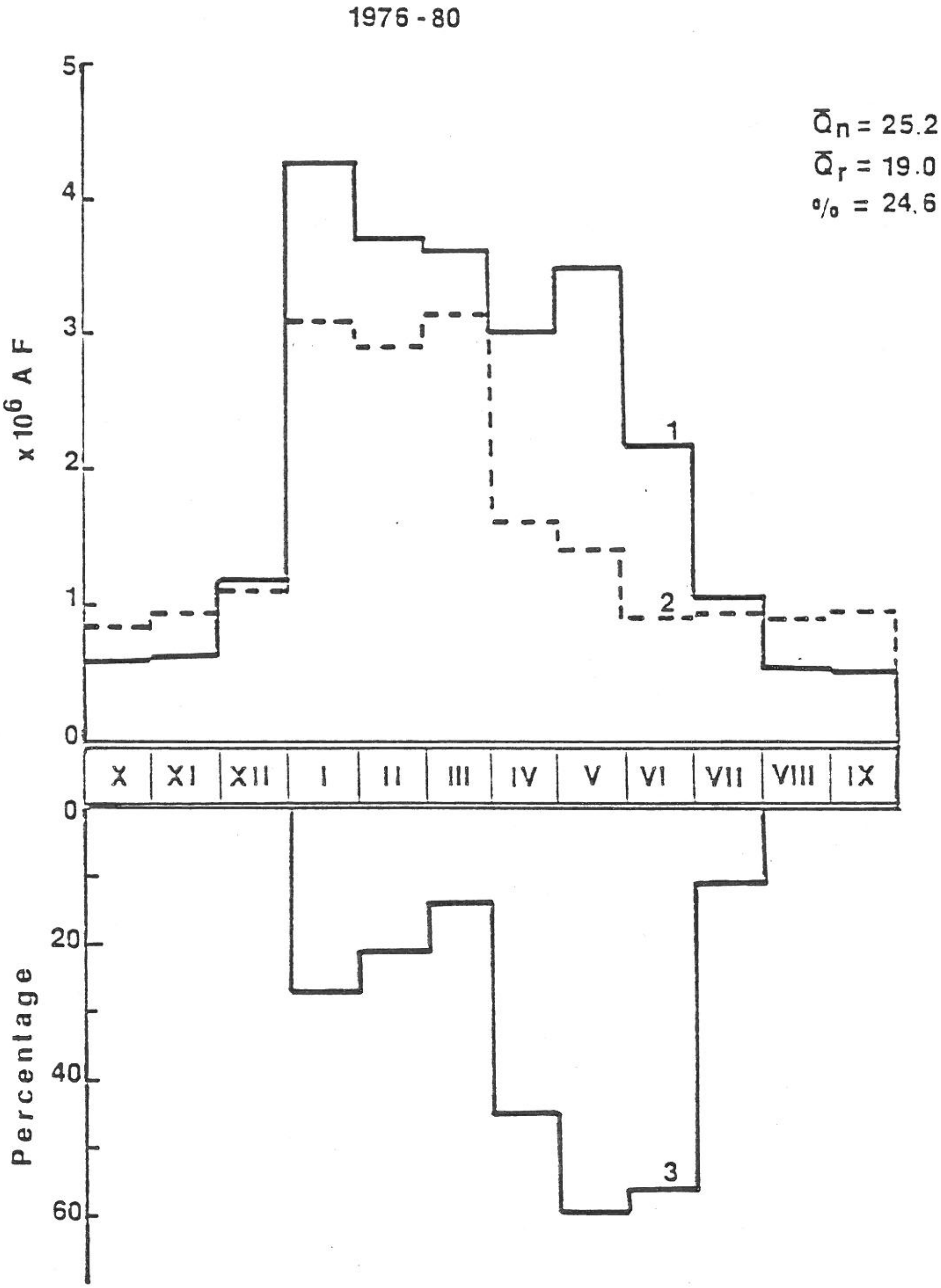


Fig. II.26 .The five year (1976-80) mean monthly fluctuation of (1) natural and (2) regulated inflow to the Delta and (3) upstream diversions (expressed as a percentage of natural river inflow).

Table 11.26 Mean Monthly Seasonal Distribution of Natural (Qn) and Regulated (Qr) River Inflow in Absolute Values (MAF) and Percentage of the Mean Annual (Qy) Runoff for the Five-year Periods Between 1956-1980

Month Period	X	XI	XII	I	II	III	IV	V	IV	VI	VIII	IX	Hydrological Year
	AUTUMN		WINTER				SPRING		SUMMER			AUTUMN	
1956-1960													
Qn	0.648	0.688	3.31	3.74	5.52	4.08	4.24	5.38	2.83	1.12	0.61	0.56	32.17
Qn in % of Qy	2.0	2.1	10.3	11.5	17.1	12.7	13.2	16.7	8.8	3.5	1.9	1.7	100%
Qr	0.85	0.90	2.28	3.50	4.57	3.75	2.977	2.558	1.639	0.832	0.751	0.865	25.60
Qr in % of Qy	3.3	3.5	8.9	13.7	11.9	14.7	11.6	10.0	6.4	3.2	2.9	3.4	100%
1961-1965													
Qn	1.05	1.12	3.63	2.91	3.70	2.42	4.51	3.81	2.40	1.00	0.59	0.45	27.62
Qn in % of Qy	3.8	4.1	13.2	10.5	13.4	8.8	16.3	13.8	8.7	3.6	2.2	1.6	100%
Qr	1.092	0.996	2.503	2.603	3.269	1.887	2.654	1.812	1.083	0.773	0.778	0.900	20.44
Qr in % of QY	5.3	4.9	12.3	12.7	16.0	9.2	13.0	8.9	5.3	3.8	3.8	4.4	100%
1966-1970													
Qn	0.87	2.26	2.62	7.11	4.37	4.16	4.21	4.97	3.16	1.41	0.66	0.50	34.93
Qn in % of Qy	1.6	6.5	7.5	20.4	12.5	12.0	12.1	14.2	9.0	4.0	1.9	1.4	100%
Qr	1.042	1.216	2.256	5.443	5.013	3.481	2.468	2.409	1.864	1.084	0.953	1.129	28.50
Qr in % of Qy	3.7	4.3	7.9	19.1	17.6	12.2	8.7	8.5	6.5	3.8	3.3	4.0	100%
1971-1975													
Qn	0.64	2.26	2.90	4.45	3.44	5.66	4.21	4.92	3.22	1.14	0.64	0.56	34.06
Qn in % of Qy	1.9	6.6	8.6	13.1	10.1	16.6	12.4	14.4	9.4	3.2	1.9	1.7	100%
Qr	1.22	1.90	3.07	4.34	3.27	3.11	2.85	1.71	1.47	1.22	1.29	1.43	26.89
Qr in % of Qy	4.5	7.1	11.4	16.2	12.2	11.6	10.6	6.4	5.5	4.5	4.8	5.3	100%
1976-1980													
Qn	0.62	0.74	1.19	4.27	3.72	3.68	3.08	3.52	2.17	1.07	0.55	0.54	25.17
Qn in % of Qy	2.5	2.9	4.7	17.0	14.8	14.6	12.2	14.0	8.6	4.2	2.2	2.2	100%
Qr	0.49	0.58	0.74	2.81	0.27	2.87	1.385	1.02	0.42	0.34	0.25	0.39	14.00
Qr in % of Qy	3.5	4.1	5.3	20.1	1.9	20.5	9.9	7.3	3.0	2.5	1.8	2.8	100%

Table II.27 Mean Monthly Seasonal Distribution of the Natural (Qn) and Regulated (Qr) Delta Outflow in Absolute Values (MAF) and Percentage of the Mean Annual Natural (Qy) Runoff for the Five-Year Periods Between 1956-1980

Month / Period	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Hydrological Year
	------AUTUMN-------		-------------WINTER--------------			--------------SPRING---------------			----------SUMMER---------------			AUTUMN---	
1956-1960													
Qn	0.568	.652	3.395	3.882	5.648	4.267	4.215	4.550	2.686	.909	.383	.420	31.592
Qn in % of Qy	1.8	2.1	10.7	12.3	17.9	13.5	13.3	14.4	8.5	2.9	1.2	1.3	100
Qr	.662	.783	2.383	3.674	4.735	3.717	2.886	2.380	1.294	.337	.320	.578	23.730
Qr in % of Qy	2.79	3.39	10.04	15.48	19.95	15.16	12.16	10.02	5.45	1.42	1.35	2.44	100
1961-1965													
Qn	1.008	1.166	3.669	2.991	3.769	2.547	4.463	3.694	2.258	.787	.376	.287	26.925
Qn in % of Qy	3.7	4.3	13.63	11.1	14.0	9.45	16.6	13.7	8.38	2.9	1.4	1.0	100
Qr	.902	.947	2.483	2.654	3.249	1.800	2.494	1.500	.669	.229	.311	.557	17.805
Qr in % of Qy	5.1	5.3	13.94	14.90	18.25	10.10	14	8.4	3.75	1.3	1.7	3.1	100
1966-1970													
Qn	.480	1.227	2.714	7.337	4.434	4.192	4.157	4.844	3.012	1.197	.447	.337	34.379
Qn in % of Qy	1.4	3.5	7.9	21.3	12.53	11.8	11.7	13.7	8.5	3.4	1.26	0.9	100
Qr	.759	1.134	2.204	5.382	5.141	3.210	2.206	1.990	1.442	.592	.477	.785	25.404
Qr in % of Qy	2.9	4.46	8.67	21.2	20.2	12.6	8.7	7.8	5.67	2.3	1.8	3.1	100
1971-1975													
Qn	.591	2.345	3.009	4.527	3.508	5.711	4.143	4.797	3.070	.950	.418	.405	33.474
Qn in % of Qy	1.7	7.0	8.9	13.5	10.47	17.1	12.4	14.3	9.17	2.8	1.2	1.2	100
Qr	.870	1.810	2.873	4.113	3.108	3.012	2.435	1.156	.844	.513	.560	.903	22.202
Qr in % of Qy	3.9	8.1	12.9	18.5	14	13.56	10.9	5.2	3.8	2.3	2.5	4.1	100
1976-1980													
Qn	.524	.651	1.115	4.204	3.661	3.596	2.959	3.400	2.048	.939	.426	.435	23.947
Qn in % of Qy	2.2	2.7	4.7	17.5	15.2	14.9	12.3	14.1	8.5	3.9	1.7	1.8	100
Qr	.450	.560	.739	2.817	2.677	2.865	1.371	1.037	.429	.344	.242	.392	14.326
Qr in % of Qy	3.1	3.9	5.15	19.6	18.7	20	9.6	7.2	2.9	2.4	1.7	2.7	100

For example, the mean RRI for August, September and October of the period 1971-75 had a range of 1.2-1.4 MAF, while their natural characteristics had a range of 0.5-0.6 MAF. This implies that during these months of the 1971-1975 period, as in other similar periods, the Delta experienced a water surplus, which may originate in water releases and drainage discharges to the river system. The maximum was reached at the end of the following summer and fall (August and September). This, as will be illustrated in more detail below, is the principal new feature of fall's runoff regime.

It is difficult to judge whether these mainly agricultural releases have a positive or negative effect on the regime characteristics of the Delta and Bay inasmuch as there is no appropriate data on the chemical constituents of these waters or how they differ from what the river-Delta ecosystem experiences under natural conditions and how their accumulation or dilution changed with time and space. This is especially necessary to know since the average volume of these mixed waters discharged to the Delta is almost equal to the volume of the Delta water body (1.3 MAF). In addition, it appears that there are no publications or reports which show whether this water increment, usually during fall periods of low flow under natural conditions, has brought about any improvement in the sanitary or changes in any other conditions (biological resources, circulation patterns in the Delta, or increased repulsion of salt intrusion, or flushing brackish waters from the western Delta and Suisun Bay).

4. It appears that the patterns of diversion (in percentage) of these periods reflect more the contractual demands for water, regardless of the wetness of the different periods, than the water needs of the San Francisco Bay.

For example, the predominant range of mean water withdrawals during winter and spring is 15-30 and 50-60%, respectively, which infers that during a seven-month period, large quantities of water were diverted from the NRI.

The range of average water withdrawals was 7.5-11.6 MAF (the latter was diverted in 1976-80, or 47% of the mean annual of 24.6 MAF).

Therefore, even without the drought periods of 1976-77, such volumes of winter-spring diversions during the preceding twenty years may have had a strong cumulative impact on the Delta-Bay environment.

Documentation of the declines of recreational fish and shellfish catches as well as of flow-related changes in the entrapment zone (the nursery ground of estuarine organisms), reduction of more than 70% of the sediment load and other important changes, began to appear prior to the drought of 1976 and 1977 (Chadwick, 1982; Krone, 1979; Herrgesell et al., 1983; Kjelson et al., 1981, 1982; Moyle, 1976).

Similar symptoms of estuarine deterioration have appeared in other areas after ten to twenty years of extensive late-winter-spring water withdrawals where the residual spring runoff to the estuarine system had the predominant probability of accedence of 95-97% (i.e., very rare events under natural conditions). Unfortunately, this became the pronounced feature of the river supply to the Delta, itself under strong pressures of inner diversions which undoubtedly exacerbate its ecological conditions as well as those of San Francisco Bay.

<u>In sum</u>, it would not be an exaggeration to say that upstream winter-spring diversions accounting for more than 40% of their seasonal averages have led to the reduction of natural river discharges to levels which would be observable under natural flow conditions once in twenty or more more years, while the high unimpaired values for the same periods would have a recurrence of once or more times in two to five years.

II.2.4 <u>Monthly Runoff Statistics for Typical Years of Wetness Before and After Projects' Operations</u>

1) From the intra-annual runoff distributions for the hydrological years of <u>1936-37 (pre-project)</u> and <u>1961-62 (post-project)</u>, which were both very close to the mean seasonal fluctuation of runoff variables, it follows that the upstream and combined upstream and downstream diversions brought about significant changes in absolute values of flow as well as percentage of water diverted (Figs. II. 27-30). Before the water project operations, the major impact of diversions on river inflow/Delta outflow was concentrated in the spring period. However, after the projects became operational and significant amounts of water were used to recharge storage facilities in winter-spring seasons, the impact of water diversions was spread over more than eight months of the year, and their absolute values (Tables II. 28-29) were 2-5 times higher than was observed for the pre-project conditions.

For both characteristics of impaired runoff, i.e., RRI and RDO, the annual diversions were 2.4-3.1 times higher than for the pre-project conditions, and the amount of water left to be discharged to the Delta and from the Delta to the Bay in 1962 had a very low probability of accedence of 80 and 90%, or not less than once in 5 and 10 years, respectively, though at the same time, the value of natural runoff had a recurrence interval of once in 2-3 years.

Therefore, in 1962, the upstream diversions were equal to:

$$Qnri-Qrri = 2.51-16.4 = 8.7 \text{ MAF}$$

and from the entire water basin,

Table II.28 Seasonal Distribution of Natural (Qnri) and Regulated (Qrri) River Inflow to the Delta (in Million Acre Feet) for Two Typical Years of Average Wetness and Percentage of Gross Diversion Before and After the CVP and SWP Operation

Hydrological Year 1936-37

	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
Qnri	0.36	0.36	0.53	0.68	3.72	4.57	4.73	5.74	2.76	0.89	0.42	0.34	25.12
% of Total	1	1	2	3	15	18	19	23	11	3	2	1	100
Qrri	0.46	0.49	0.62	0.81	3.30	4.83	4.24	3.81	1.97	0.44	0.18	0.31	21.48
% of Total	2	2	3	4	15	22	20	18	9	2	1	1	100
Qrri-Qnri	0.1	0.13	0.1	0.13	-0.43	0.26	-0.49	-1.93	-0.79	-0.45	-0.24	-0.03	-3.64
% of Gross Diversion	27	33	19	19	-11	6	-10	-34	-29	-50	-56	-7	-14

---FALL----- ------WINTER------ ------SPRING------ -------SUMMER------ FALL--

Hydrological Year 1961-62

	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
Qnri	0.43	0.66	1.44	1.07	5.63	3.19	4.50	3.54	2.78	1.00	0.50	0.40	25.12
% of Total	2	3	6	4	22	13	18	14	11	4	2	1	100
Qrri	0.46	0.53	1.03	0.70	3.83	2.98	1.89	1.43	1.06	0.70	0.77	0.79	16.42
% of Total	3	3	6	4	23	18	11	9	6	4	5	5	100
Qrri-Qnri	0.03	-0.13	-0.41	-0.37	-1.80	-0.21	-2.61	-2.11	-1.72	-0.30	0.27	0.39	-8.70
% of Gross Diversion	8	-19	-28	-34	-32	-7	-58	-59	-61	-30	55	99	-35

Table II.29 Seasonal Distribution of Natural (Qndo) and Combined Regulated (Qrdo) Delta Outflow (in Million Acre Feet) to the San Francisco Bay for Two Typical Years of Average Wetness and Percentage of Gross Diversion Before and After the CVP and SWP Operation

Hydrological Year of 1936-1937

	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
Qndo	0.29	0.32	0.63	0.76	3.42	4.81	4.65	5.62	2.62	0.67	0.19	0.18	24.68
% of Total	1.2	1.2	2.5	3.1	15.7	19.5	18.8	22.8	8.6	2.7	1.0	0.7	100
Qrdo	0.36	0.38	0.67	0.90	3.71	5.21	4.20	3.71	1.80	0.22	-0.03	0.16	21.25
% of Total	1.7	1.8	3.1	4.2	17.4	24.5	20.0	17.4	8.5	1.0	0.0	1.0	100
Qrdo-Qndo	0.07	0.06	0.04	0.14	0.29	0.40	-0.45	-1.91	-0.82	-0.45	-0.19	-0.02	-3.43
% of Diversions	24	19	6	18	8	8	-10	-34	-31	-67	-100	-11	-14
	---FALL-----		------WINTER------			------SPRING------			-------SUMMER------			FALL--	

Hydrological Year of 1961-1962

	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
Qndo	0.33	0.71	1.45	1.08	5.93	3.20	4.40	3.41	2.63	0.78	0.27	0.23	24.44
% of Total	1.3	2.9	6.0	4.4	24.3	13.1	18.0	14.0	10.8	3.2	1.1	1.0	100
Qrdo	0.23	0.49	0.97	0.66	4.15	2.96	1.63	1.10	0.64	0.17	0.28	0.49	13.76
% of Total	1.7	3.5	7.0	4.8	30.2	21.5	11.8	8.0	4.6	1.2	2.1	3.5	100
Qrdo-Qndo	0.10	-0.22	-0.48	-0.42	-1.78	-0.24	-2.77	-2.31	-1.99	-0.61	0.01	0.26	-10.68
% of Diversions	30	-31	-33	-39	-30	-8	-63	-68	-76	-78	4	113	-44

$$Qndo-Qrdo = 24.4-13.8 = 10.6 \text{ MAF}$$

Consequently, the amount of water conveyed through the Delta was equal to:

$$10.6-8.7 = 1.9 \text{ MAF}$$

and the inner Delta consumptive use was 0.7; in sum 2.6 MAF were the Delta losses. But in 1937 the upstream diversion was 3.6 MAF and the combined diversions were 3.4 MAF. The positive difference of 0.2 MAF may mean the amount of water accumulated during the year through the releases which were higher than the Delta diversions during that year.

2) The hydrological years of 1937-38 (pre-project conditions) and 1968-69 (post-project conditions) were both typical wettest years and were both preceded by years of sub-normal flow, namely, 1936-37 had a runoff of 25.1 MAF, and 1967-68 had a runoff of 20.3 MAF. Therefore, it is logical to expect that the diversions in 1969 had to be higher than in 1938 in order to replenish the losses sustained by the system and the storage facilities of CVP and SWP. This is well illustrated by Figs. II.30, 31. With the exception of several months when the necessity of emergency releases was obvious, the upstream and downstream water withdrawals in 1969 had longer duration, and even more important, the absolute value of water diverted was as much as two times higher for the year and more than 2-10 times for some of the spring months (Figs. II. 31-34 and Tables II. 30, 31).

If in 1938, after total diversions of 3.2 MAF, the residual annual flow to the system of 53 MAF corresponds to the probability of exceedence of almost 5% (recurrence of not less than once in 20 years), then the residual Delta outflow of 1969 of 38.6 MAF after diversion of more than 13 MAF, corresponded to a probability of exceedence of about 20% (or recurrence of not less than once in five years). Thus, the system, even after huge amounts of water were diverted, experienced the condition of abnormal wetness. So, in 1969, from the total water withdrawals about 3.6 MAF were conveyed from the Delta (including Delta consumptive use), while in 1938, the total upstream and downstream diversions were only 2.8 MAF.

It is obvious from this comparison that even if the annual and seasonal runoff corresponded to the wettest year (i.e., the historical unimpaired runoff), this level of diversion is not only able to significantly truncate its seasonal and annual peaks, but also may reduce its long-term capability to flush San Francisco Bay of natural and man-induced waste and to repel salt intrusion into the Delta, etc.

3) The hydrological years of 1923-24 and 1976-77 are so well known as typical dry, even drought years, that they have become the prototype among water resources specialists, as will be seen below. It is likely that the occurrence of very low flow in 1929-34 may have justified the need for the development of the

Table II.30 Seasonal Distribution of Natural (Qnri) and Regulated (Qrri) River Inflow to the Delta (in Million Acre Feet) for the Wettest Years and Percentage of Gross Diversion Before and After the CVP and SWP Operation

Hydrological Year 1937-38

	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
Qnri	0.45	2.08	6.23	2.53	8.25	11.08	7.60	8.79	5.95	2.15	0.84	0.57	56.53
% of Total	1	4	11	4	14	20	13	15	10	4	1	1	100
Qrri	0.58	2.46	6.01	2.46	10.4	11.60	7.31	7.34	4.96	1.59	0.53	0.51	55.76
% of Total	1	4	11	4	19	21	13	13	9	3	1	1	100
Qrri-Qnri	0.13	0.38	-0.22	-0.07	2.15	0.52	-0.29	-1.45	-0.99	-0.56	-0.31	-0.06	-0.77
% of Gross Diversion	29	18	-3	-2	26	5	-4	-16	-16	-26	-37	-10	-1

---FALL----- ------WINTER------ ------SPRING------ -------SUMMER------ FALL--

Hydrological Year 1968-69

	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
Qnri	0.58	1.05	2.44	11.21	7.53	5.13	7.00	8.68	5.05	2.04	0.83	0.59	52.14
% of Total	1	2	5	21	14	10	13	17	10	4	1	1	100
Qrri	0.81	0.92	1.67	7.72	8.85	5.95	4.36	4.30	3.13	1.28	1.31	1.49	42.24
% of Total	2	2	4	18	21	14	10	10	7	3	3	3	100
Qrri-Qnri	0.23	-0.13	-0.77	-3.49	1.32	0.82	-2.64	-4.38	-1.92	-0.76	0.48	0.90	-9.90
% of Gross Diversion	40	-13	-32	-31	17	16	-38	-50	-38	-37	58	154	-19

Table II.31 Seasonal Distribution of Natural (Qndo) and Combined Regulated (Qrdo) Delta Outflow (in Million Acre Feet) to the San Francisco Bay for the Wettest Years and Percentage of Gross Diversions Before and After the CVP and SWP Operation

Hydrological Year of 1937-1938

	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
Qndo	0.37	2.12	6.36	2.59	8.58	11.25	7.54	8.67	5.80	1.44	0.62	0.42	56.2
% of Total	0.7	3.8	11.3	4.6	15.2	20.0	13.4	15.4	10.3	3.4	11.0	7.5	100
Qrdo	0.47	2.04	5.51	2.63	9.29	11.92	7.33	6.92	4.80	1.36	0.32	0.37	52.9
% of Total	0.9	3.8	10.4	5.0	17.5	22.5	13.8	13.1	9.1	2.6	0.6	0.7	100
Qrdo-Qndo	0.1	-0.08	-0.85	0.04	0.71	0.67	-0.21	-1.75	-1.0	-0.8	-0.3	-0.05	-3.3
% of Diversion	27	-4	-13	2	8	6	-3	-20	-17	-30	-48	-10	-6
	---FALL-----		------WINTER------			------SPRING------			-------SUMMER------			FALL--	

Hydrological Year of 1968-1969

	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
Qndo	0.49	1.09	2.54	11.53	7.77	5.13	6.93	8.55	4.90	1.83	0.61	0.43	51.80
% of Total	0.9	2.1	4.9	22.3	15.0	9.9	13.4	16.5	9.5	3.5	1.2	0.8	100
Qrdo	0.33	0.63	1.54	7.62	9.34	5.52	4.15	3.86	2.78	0.79	0.74	0.17	38.61
% of Total	0.9	1.6	4.0	20.0	24.5	14.5	10.9	10.0	7.3	2.1	2.0	3.4	100
Qrdo-Qndo	-0.16	-0.46	-1.0	-3.9	1.57	0.39	-2.78	-4.69	-2.12	-1.04	0.13	-0.26	-13.19
% of Diversion	-33	-42	-39	-34	20	8	40	-55	-43	-57	21	-60	-25

Table II.32 Seasonal Distribution of the Natural (Qnri) and Regulated (Qrri) River Inflow (in Million Acre Feet) to the Delta for the Driest Years and Percentageof Gross Diversions Before and After the CVP and SWP Operation

Hydrological Year 1923-24

	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
Qnri	0.51	0.47	0.55	0.65	1.40	0.76	1.21	1.21	0.48	0.38	0.30	0.29	8.20
% of Total	6	5	7	8	17	9	15	15	6	5	4	3	100
Qrri	0.62	0.50	0.55	0.62	1.25	0.58	0.62	0.35	0.11	0.08	0.10	0.18	5.57
% of Total	11	9	10	11	22	10	11	6	2	1	2	3	100
Qrri-Qnri	0.11	0.03	0	-0.03	-0.15	-0.18	-0.59	-0.86	-0.37	-0.03	-0.20	-0.11	-2.63
% of Gross Diversions	23	7	0	-5	-10	-23	-48	-71	-76	-79	-65	-37	-32

---FALL----- ------WINTER------ ------SPRING------ -------SUMMER------ FALL--

Hydrological Year 1976-77

	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
Qnri	0.45	0.44	0.40	0.56	0.53	0.63	0.77	1.01	0.81	0.38	0.35	0.42	6.76
% of Total	7	6	6	8	8	9	11	15	12	5	5	6	100
Qrri	0.58	0.36	0.54	0.67	0.49	0.44	0.37	0.49	0.42	0.52	0.48	0.42	5.95
% of Total	10	6	9	11	8	7	6	8	7	9	8	7	100
Qrri-Qnri	0.13	-0.08	0.14	0.11	-0.40	-0.19	-0.40	-0.52	-0.39	0.14	0.13	0	-0.81
% of Gross Diversions	29	-19	34	19	7.5	-31	-52	-51	-48	37	37	0	-12

Table II.33 Seasonal Distribution of the Natural (Qndo) and Combined Regulated (Qrdo) Delta Outflow (in Million Acre Feet) to the San Francisco Bay for the Driest Years and Percentage of Gross Diversions Before and After the CVP and SWP Operation

Hydrological Year - 1923-1924

	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
Qndo	0.42	0.48	0.56	0.69	1.44	0.76	1.11	1.08	0.33	0.17	0.08	0.12	7.20
% of Total	5.8	6.7	7.8	9.6	20.1	10.5	15.4	15.0	4.5	2.3	1.2	1.8	100
Qrdo	0.50	0.44	0.54	0.71	1.41	0.58	0.58	0.25	-0.06	-0.16	-0.11	0.03	4.71
% of Total	10.6	9.3	11.4	15.2	30.0	12.3	12.4	5.2	0	0	0	0.6	100
Qrdo-Qndo	0.08	-0.04	-0.02	-0.02	-0.03	-0.18	-0.53	-0.83	-0.33	-0.17	-0.08	-0.09	-2.49
% of Diversion	19	-8	-4	4	-2	-24	-48	-77	100	100	100	-75	-34
	---FALL-----		------WINTER------			------SPRING------			-------SUMMER------			FALL--	

Hydrological Year 1976 - 1977

	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	IX	Year
Qndo	0.36	0.42	0.41	0.58	0.53	0.64	0.69	0.94	0.68	0.17	0.13	0.28	5.80
% of Total	6.2	7.2	7.0	10.0	9.2	11.0	11.9	16.2	11.7	2.9	2.2	4.8	100
Qrdo	0.23	0.22	0.26	0.27	0.27	0.19	0.18	0.25	0.15	0.19	0.15	0.17	2.53
% of Total	9.2	8.5	10.2	10.6	11.0	7.4	7.2	9.8	5.9	7.7	5.9	6.8	100
Qrdo-Qndo	-0.13	-0.2	-0.15	-0.31	-0.26	-0.45	-0.51	-0.69	-0.53	0.02	0.02	-0.11	-3.27
% of Diversion	-36	-48	-36	-53	-49	-70	-74	-73	-78	12	15	-39	-56

unique CVP and SWP water storage and distribution facilities.

The Figs. II. 35-39 depict the scale of runoff deficit during these drought years as well as how the water facilities of the post-project period were developed for these years of catastrophic water scarcity.

The probability of exceedence of the 1923-24 NRI and NDO of 8.2 and 7.3 MAF respectively corresponded to the probability of almost 97% (i.e., recurrence of not less than once per 83 years). The same characteristics in 1977 corresponded to a recurrence interval of not less than one time in 100 years (99% probability of exceedance), and as such are representative of the natural drought years.

However, this was not the case for the pre-project drought because the preceding year, 1922-23, had a runoff of 23 MAF, and therefore was only 19% less than the normal. Thus, the condition of 1977 was in many ways unprecedented.

In 1924, when there were no significant storage facilities, the water diversions, especially upstream, were performed practically continuously, and therefore, by the end of the spring and during the summer (Tables II. 32, 33), there was no regulated Delta outflow to the Bay, i.e., 100% diversion. As a result, the Delta waterbody was not able to repel the massive salt intrusion from the adjacent part of the San Francisco Bay, and the isohaline of 1g/l spread over half of the Delta area. (Unfortunately, there are no data on the salt concentration in the shipping channels, but based on subsequent experience, it is likely that it was several times higher than in adjacent shallow areas.) And although the monthly upstream diversion was not very much higher (it was very low in comparison with the preceding and following years) the total annual diversion was equal to almost 2.6 MAF (35% of the mean of that year). As a result, the amount of water discharged to the Bay (RDO) was much lower than the minimum of annual NDO (of not more than 6 MAF),with a probability of exceedance of 99%, or recurrence of not less than once in 100 years.

When almost the same conditions developed in 1977 (54 years later), after the critical dry year of 1976, the storage water mitigated water supply depletion to a limited degree and one may assume that the impact of this historical drought on the river-Delta-estuarine system was less devastating because: <u>First</u>, there had been several releases during the fall and beginning of the winter, and <u>second</u>, the upstream and Delta water withdrawals together were slightly less than in 1924, although the annual withdrawal from the Delta was 3.9 times higher than in 1924 (3.5 MAF vs. 0.9 MAF, and therefore, almost three volumes of the Delta water body were siphoned upstream toward the water distribution systems). That is attributable to the fact that the residual flow (RDO) to San Francisco Bay was 1.9 times less than this value in 1924.

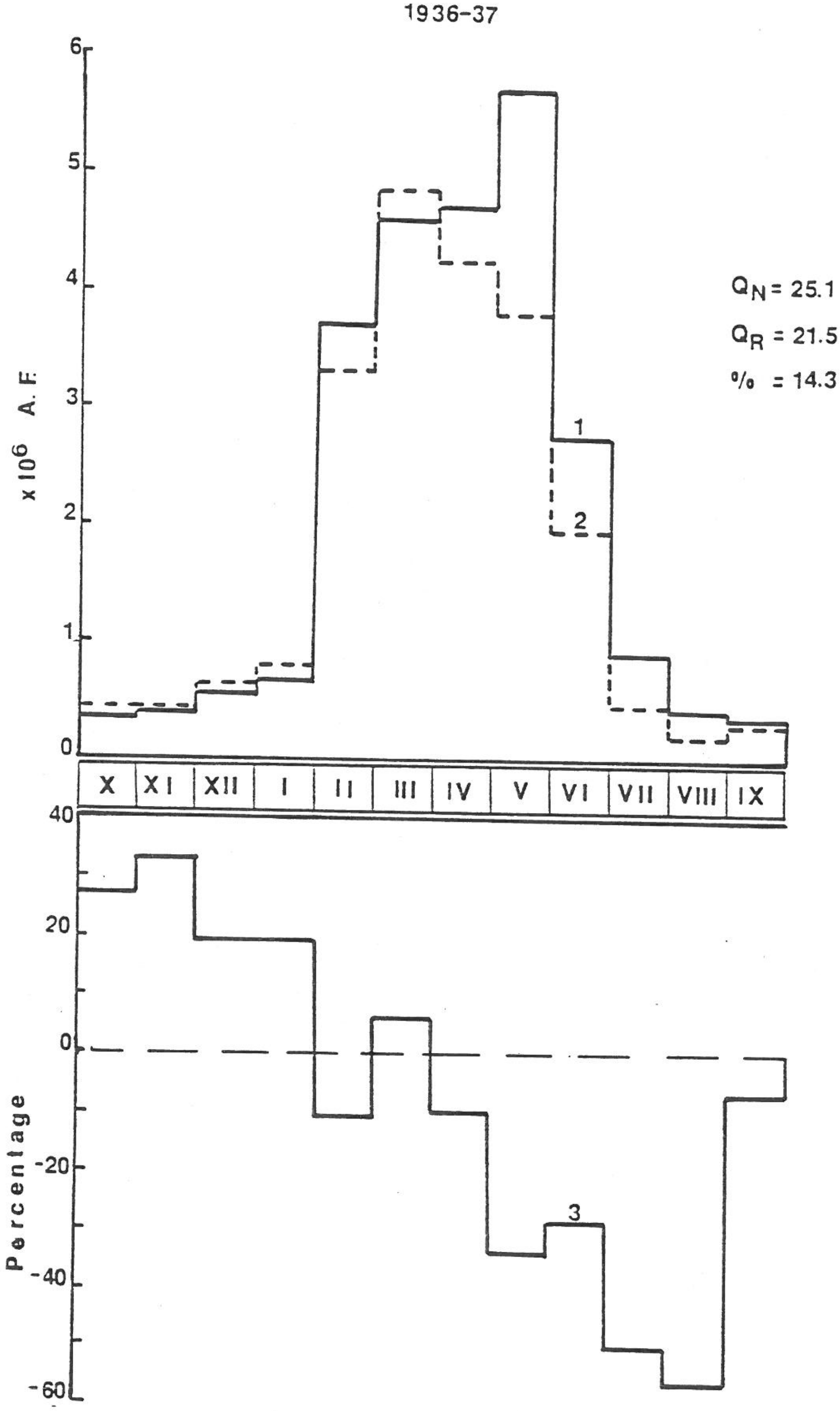


Fig.II.27 .Seasonal fluctuation of (1) natural and (2) regulated river inflow to the Delta, and (3) upstream diversion (expressed as a percentage of natural river inflow) in the average year 1936-37 (pre-project period).

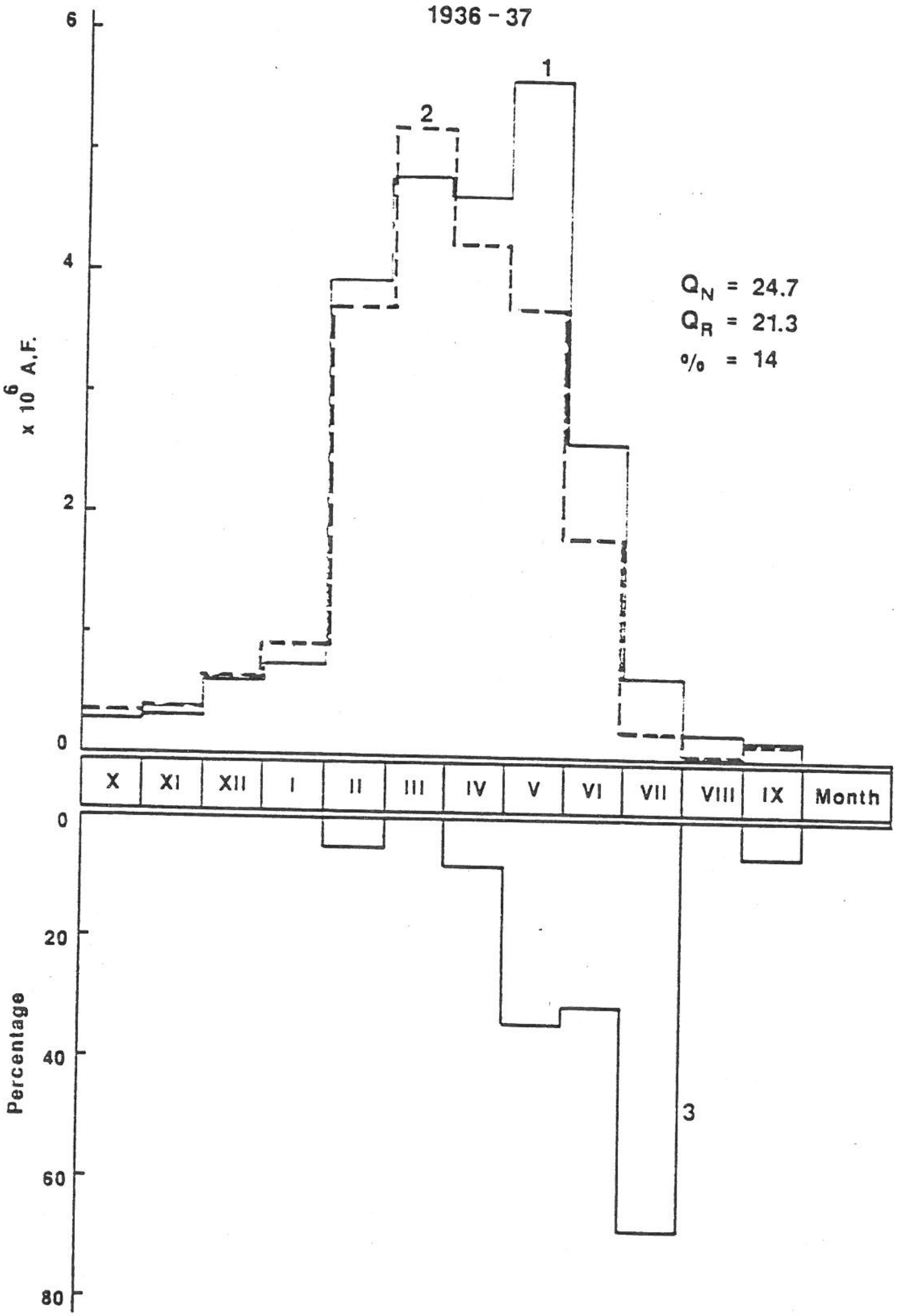


Fig. II.28 .Seasonal fluctuation of (1) natural and (2) regulated Delta outflow and (3) total diversion (expressed as a percentage of natural Delta outflow) in the average year 1936-37 (pre-project period).

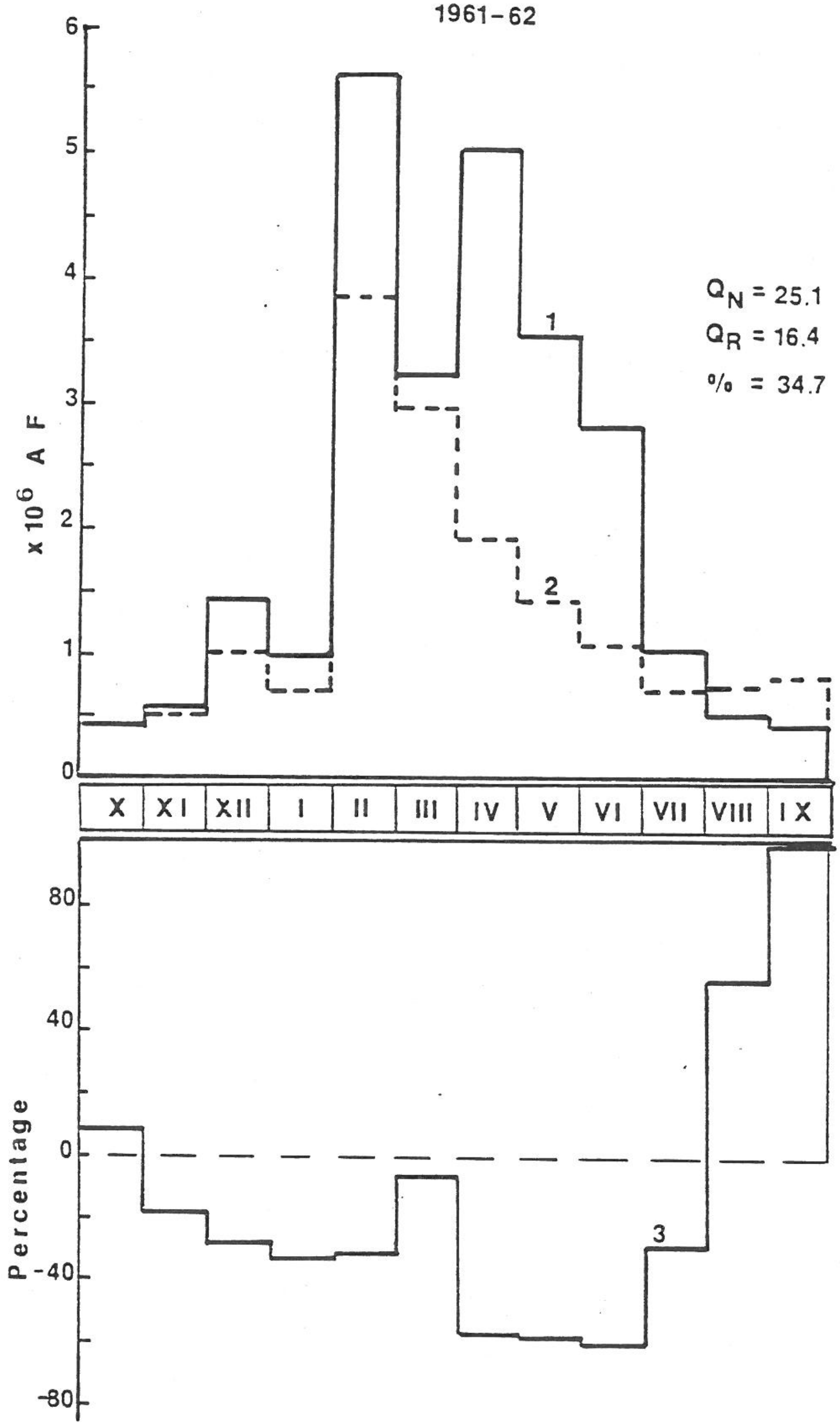


Fig. II.29 .Seasonal fluctuation of (1) natural and (2) regulated river inflow to the Delta, and (3) upstream diversion (expressed as a percentage of natural river inflow) in the average year 1961-62 (post-project period).

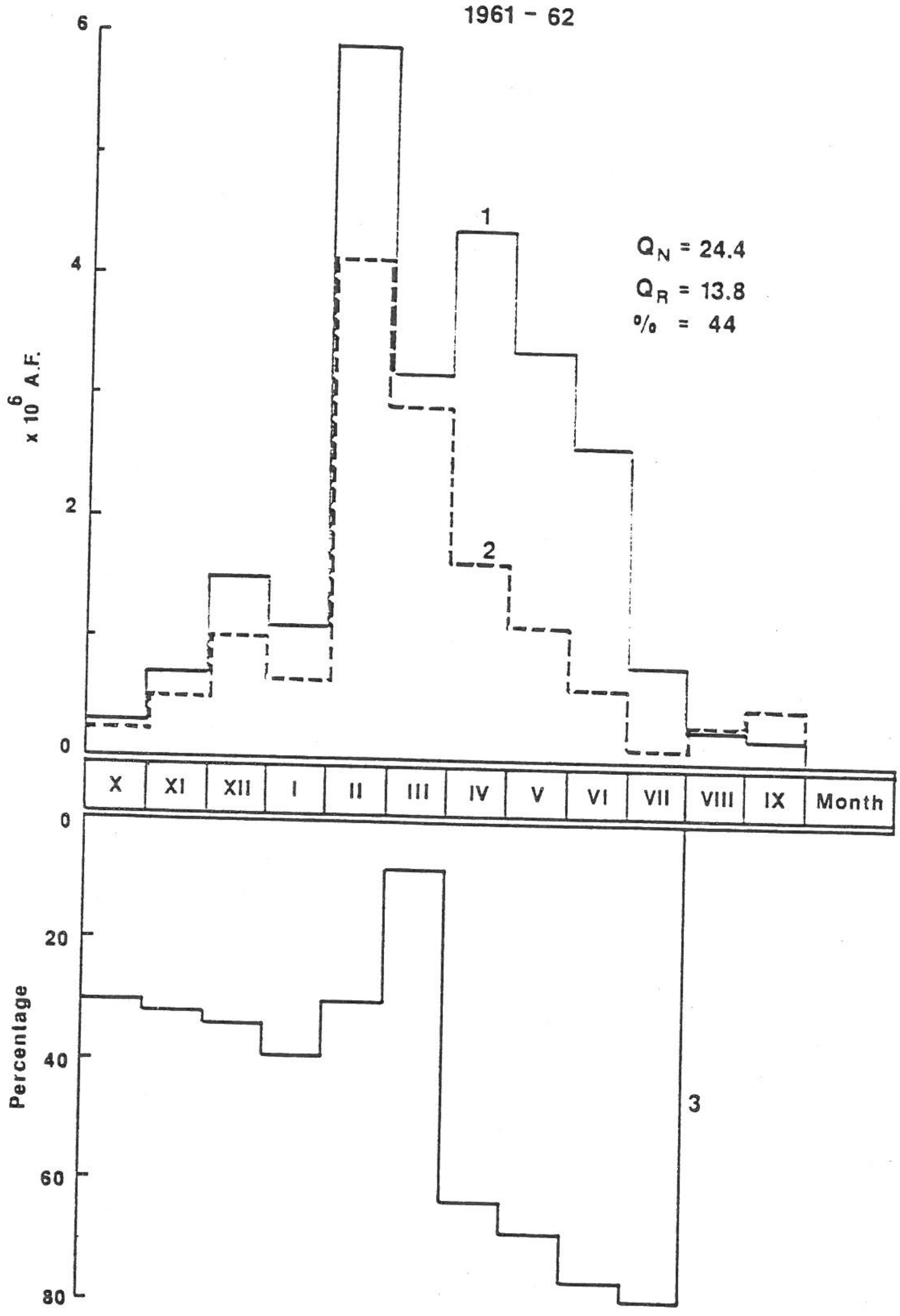


Fig. II.30 .Seasonal fluctuation of (1) natural and (2) regulated Delta outflow and (3) total diversion (expressed as a percentage of natural Delta outflow) in the average year 1961-62 (post-project period).

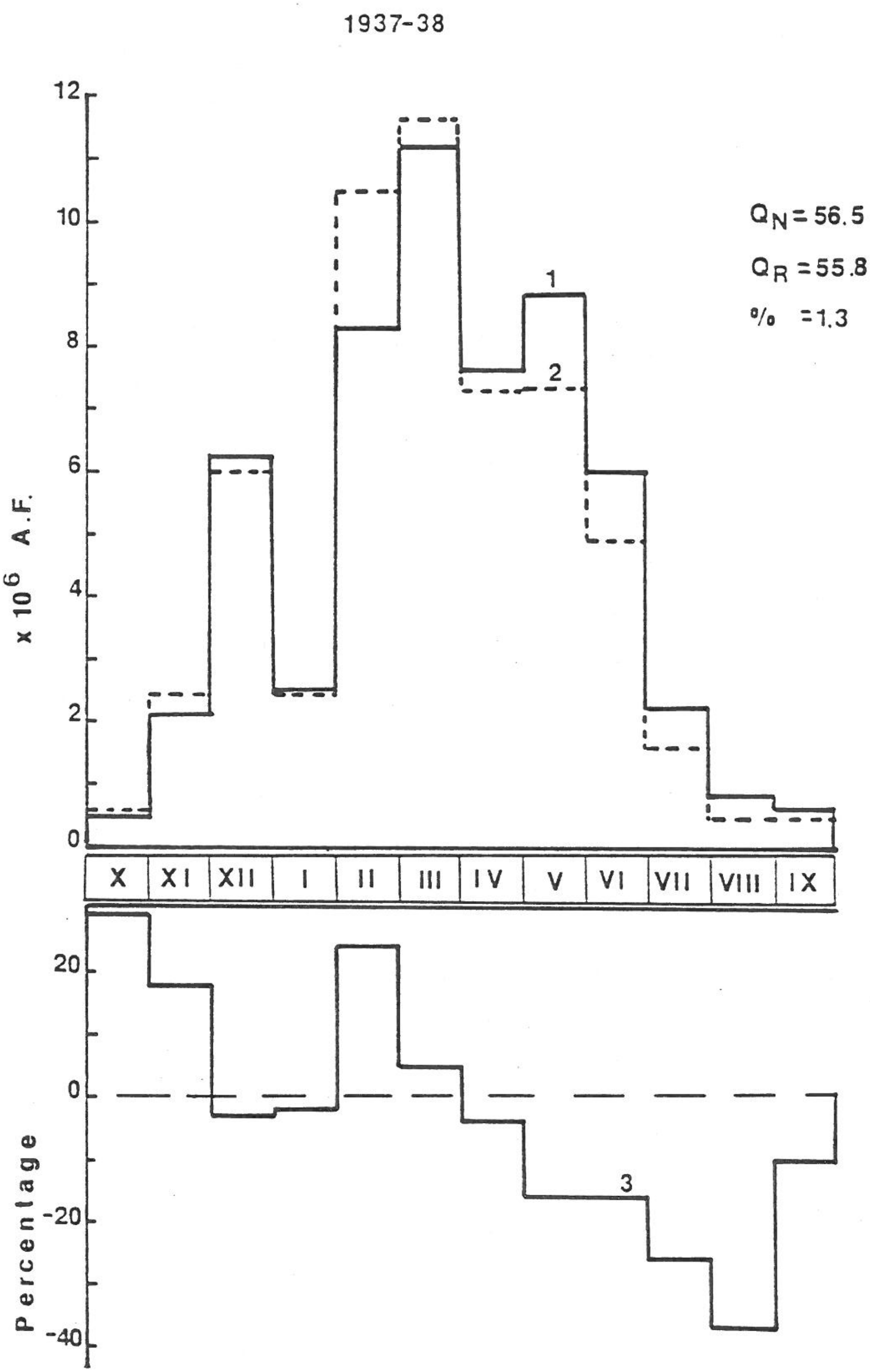


Fig.II.31 .Seasonal fluctuation of (1) natural and (2) regulated river inflow to the Delta, and (3) upstream diversion (expressed as a percentage of natural river inflow) in the wettest year 1937-38 (pre-project period).

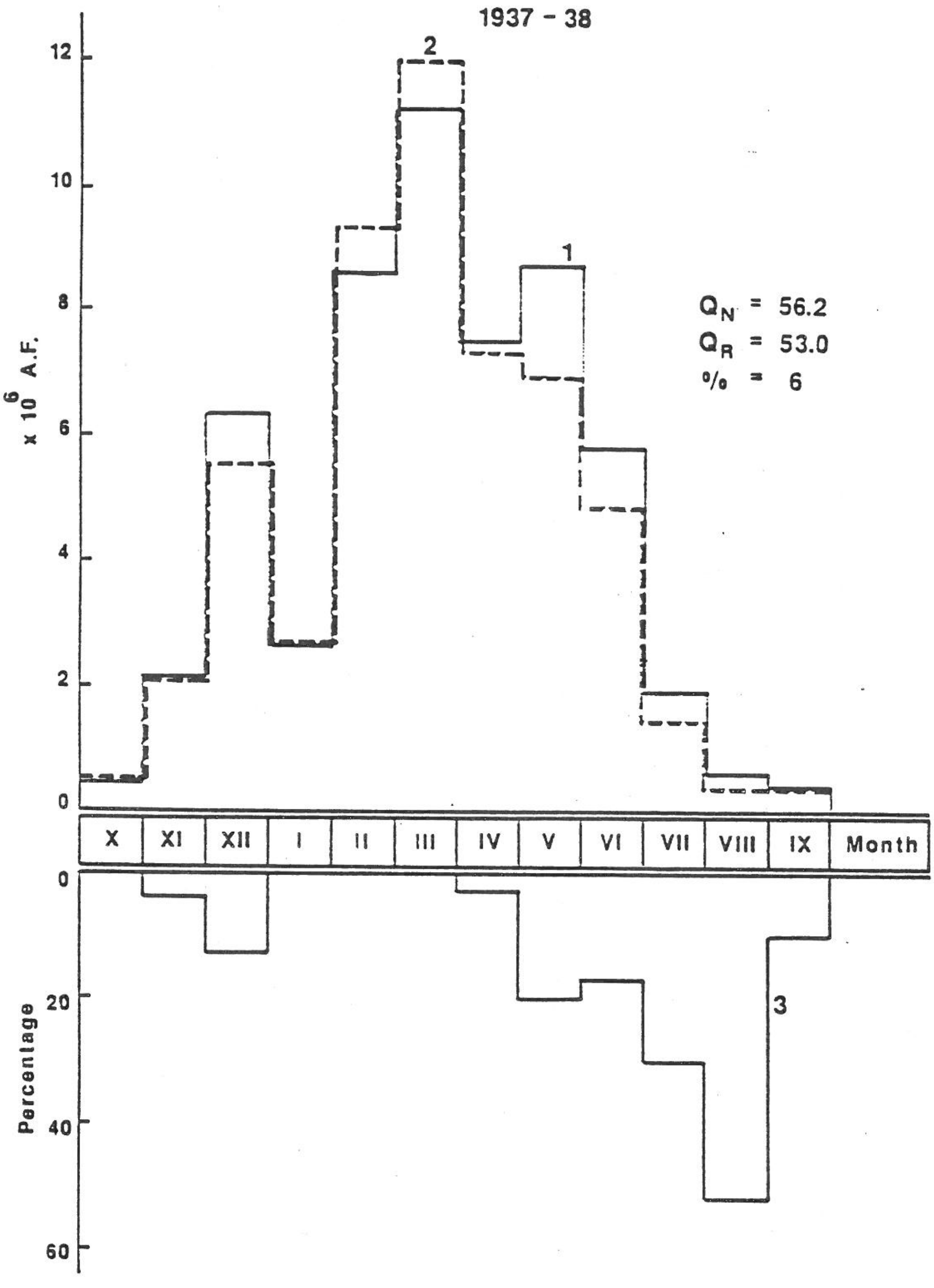


Fig.II.32 Seasonal fluctuation of (1) natural and (2) regulated Delta outflow and (3) total diversion (expressed as a percentage of natural Delta outflow) in the wettest year 1937-38 (pre-project period).

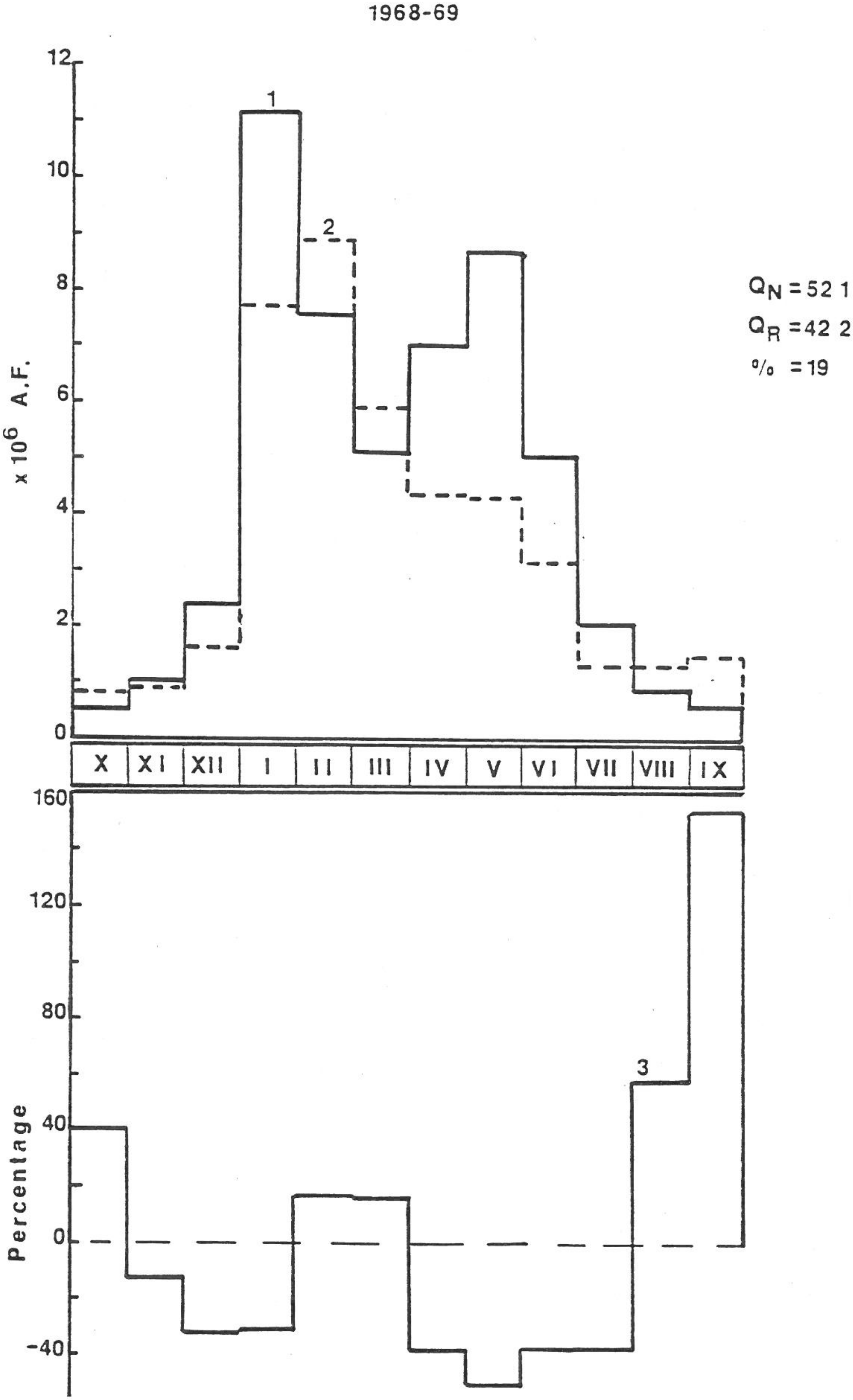


Fig.II.33 .Seasonal fluctuation of (1) natural and (2) regulated river inflow to the Delta, and (3) upstream diversion (expressed as a percentage of natural river inflow) in the wettest year 1968-69 (post project period).

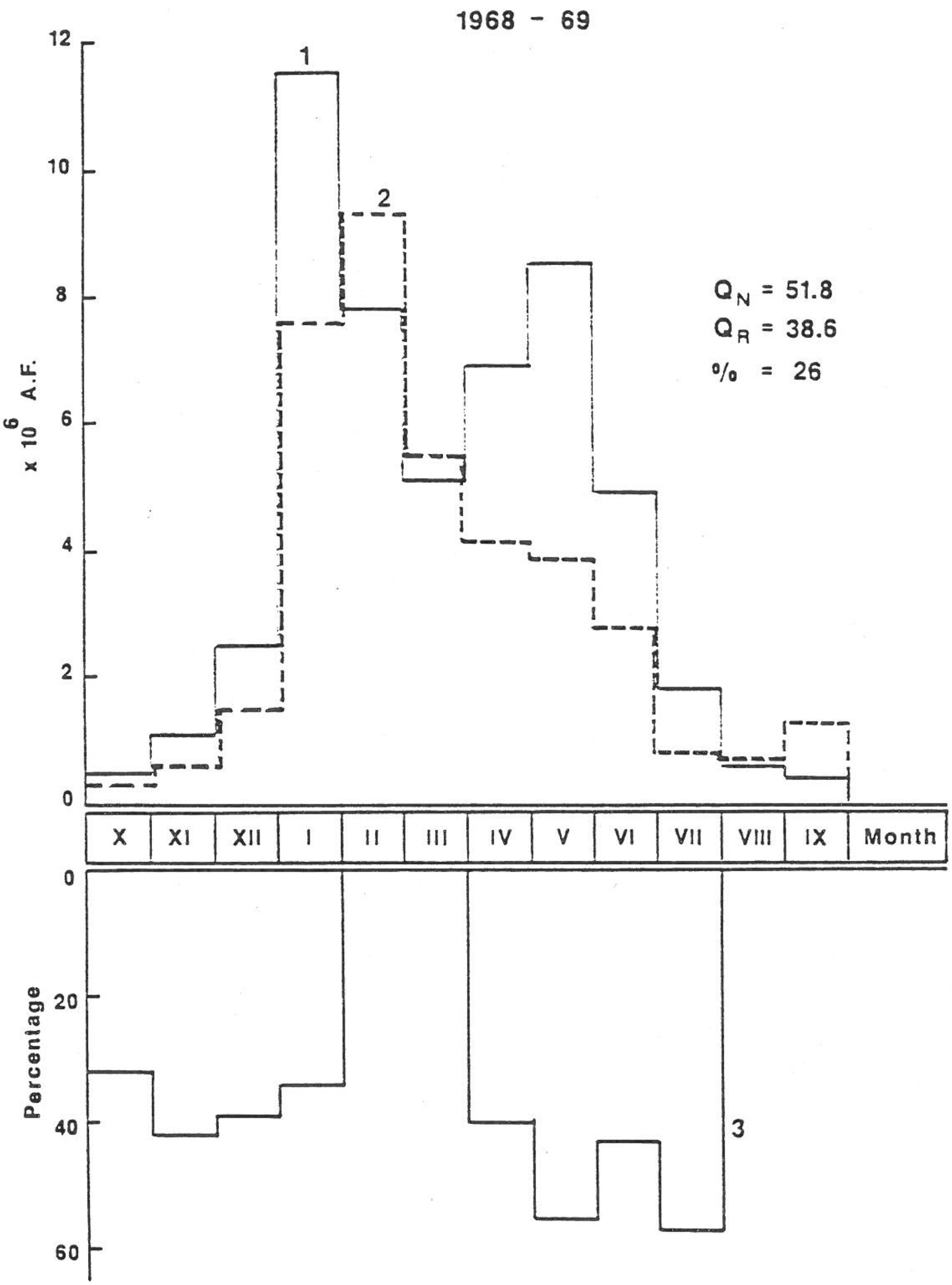


Fig.II.34 ..Seasonal fluctuation of (1) natural and (2) regulated Delta outflow and (3) total diversion (expressed as a percentage of natural Delta outflow) in the wettest year 1968-69 (post-project period).

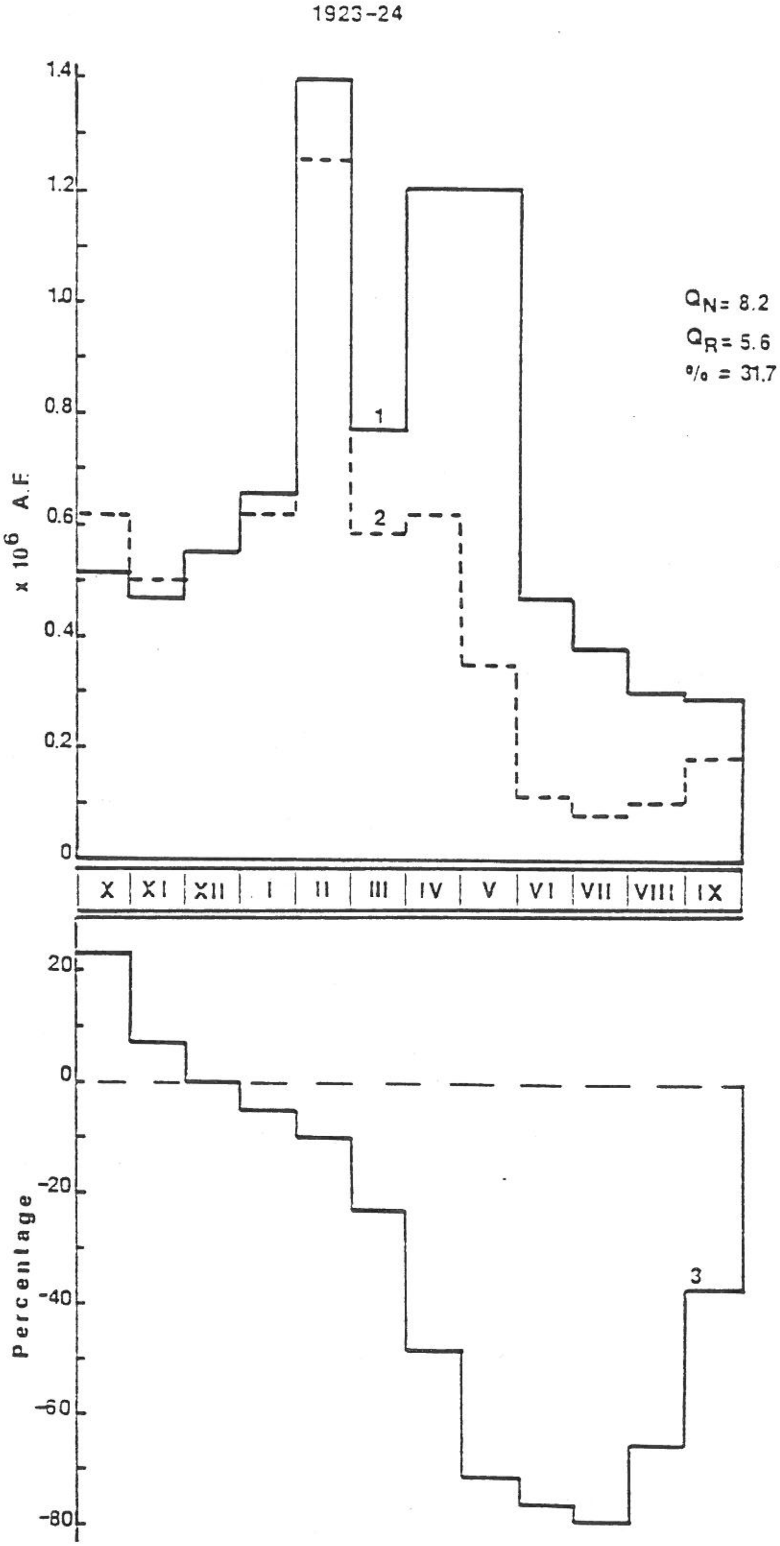


Fig.II.35 .Seasonal fluctuation of (1) natural and (2) regulated river inflow to the Delta, and (3) upstream diversion (expressed as a percentage of natural river inflow) in the critical dry year 1923-24 (pre-project period).

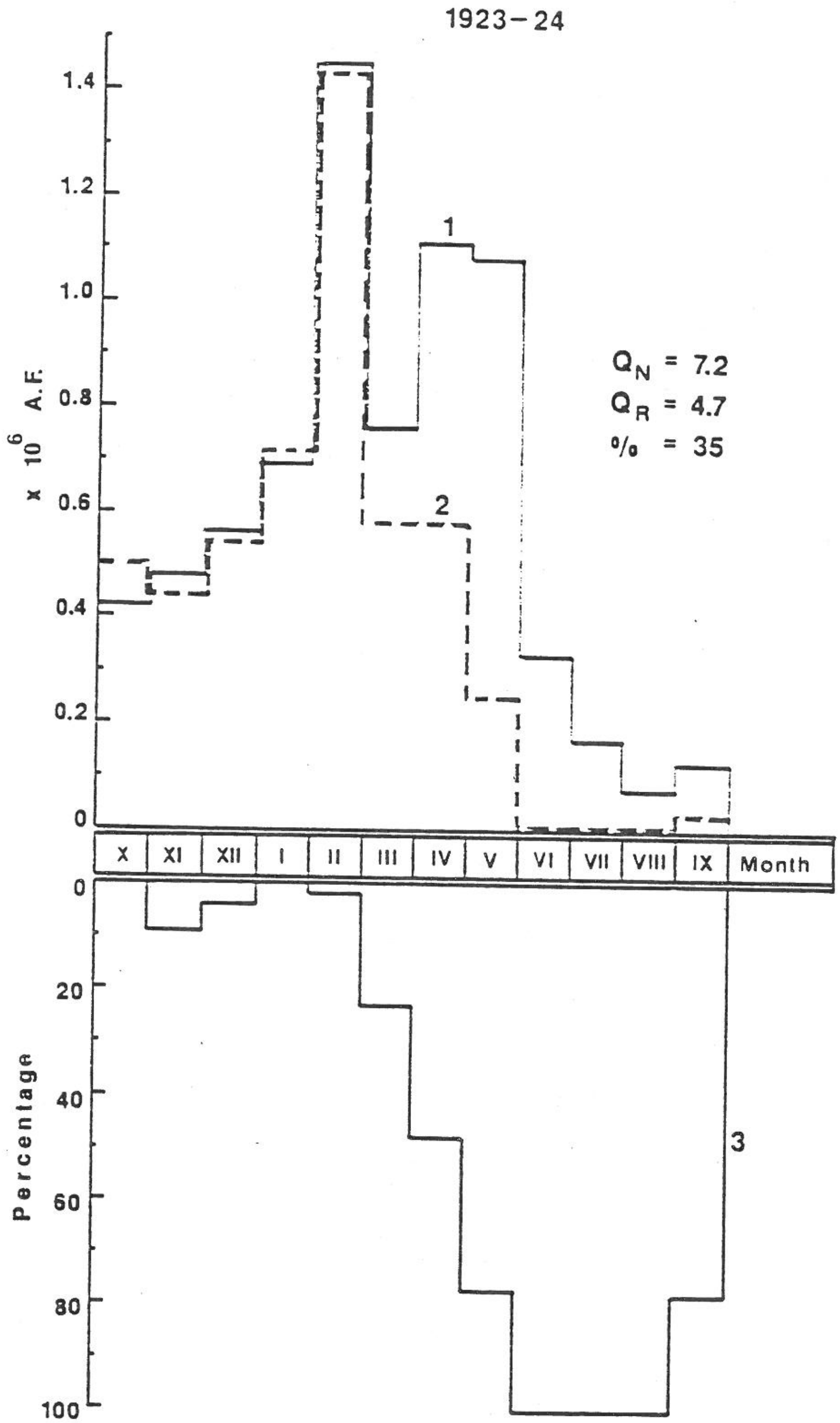


Fig. II.36 .Seasonal fluctuation of (1) natural and (2) regulated Delta outflow and (3) total diversion (expressed as a percentage of natural Delta outflow) in the critical dry year 1923-24 (pre-project period).

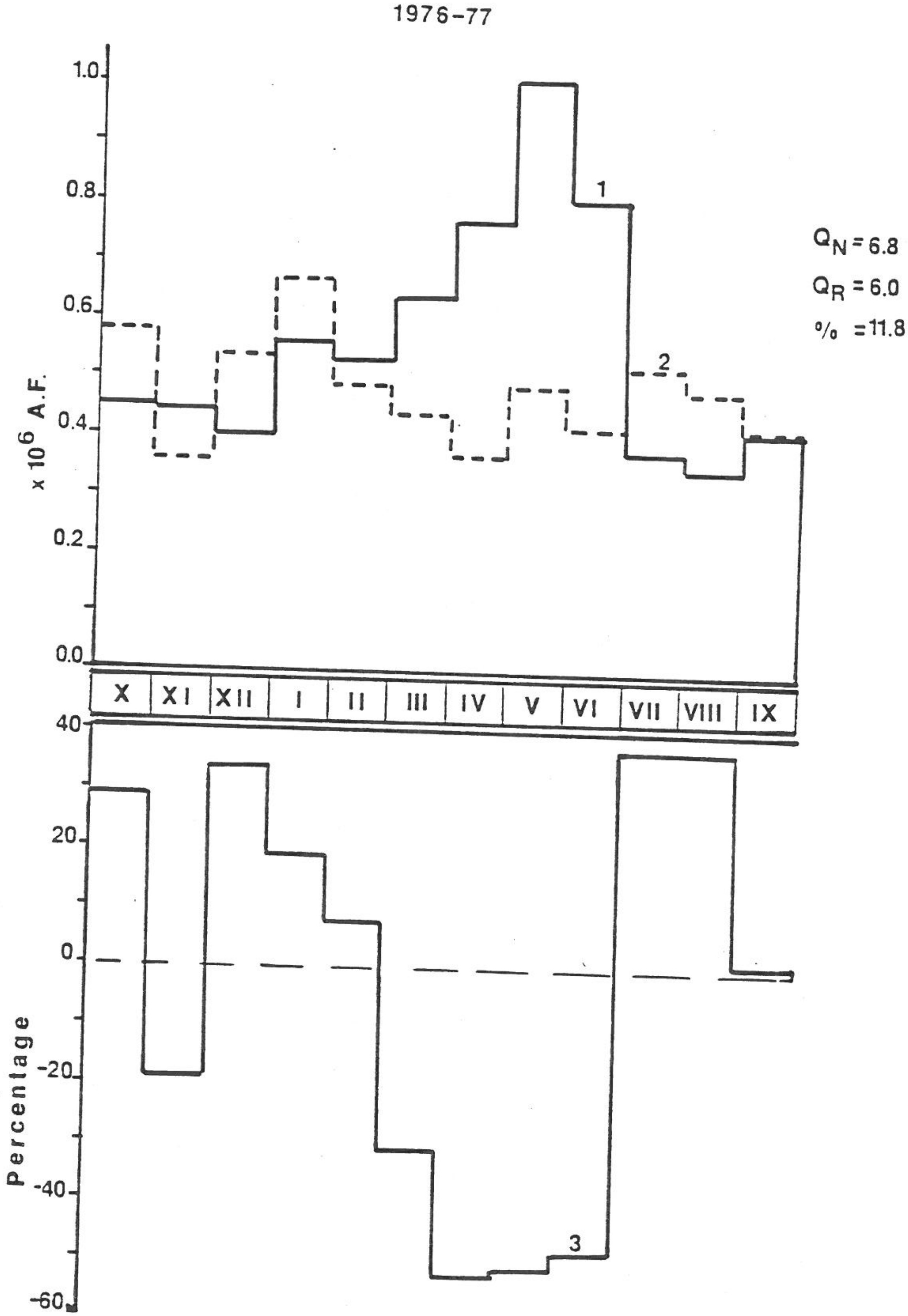


Fig.II.37 .Seasonal fluctuation of (1) natural and (2) regulated river inflow to the Delta, and (3) upstream diversion (expressed as a percentage of natural river inflow) in the critical dry year 1976-77 (post-project period).

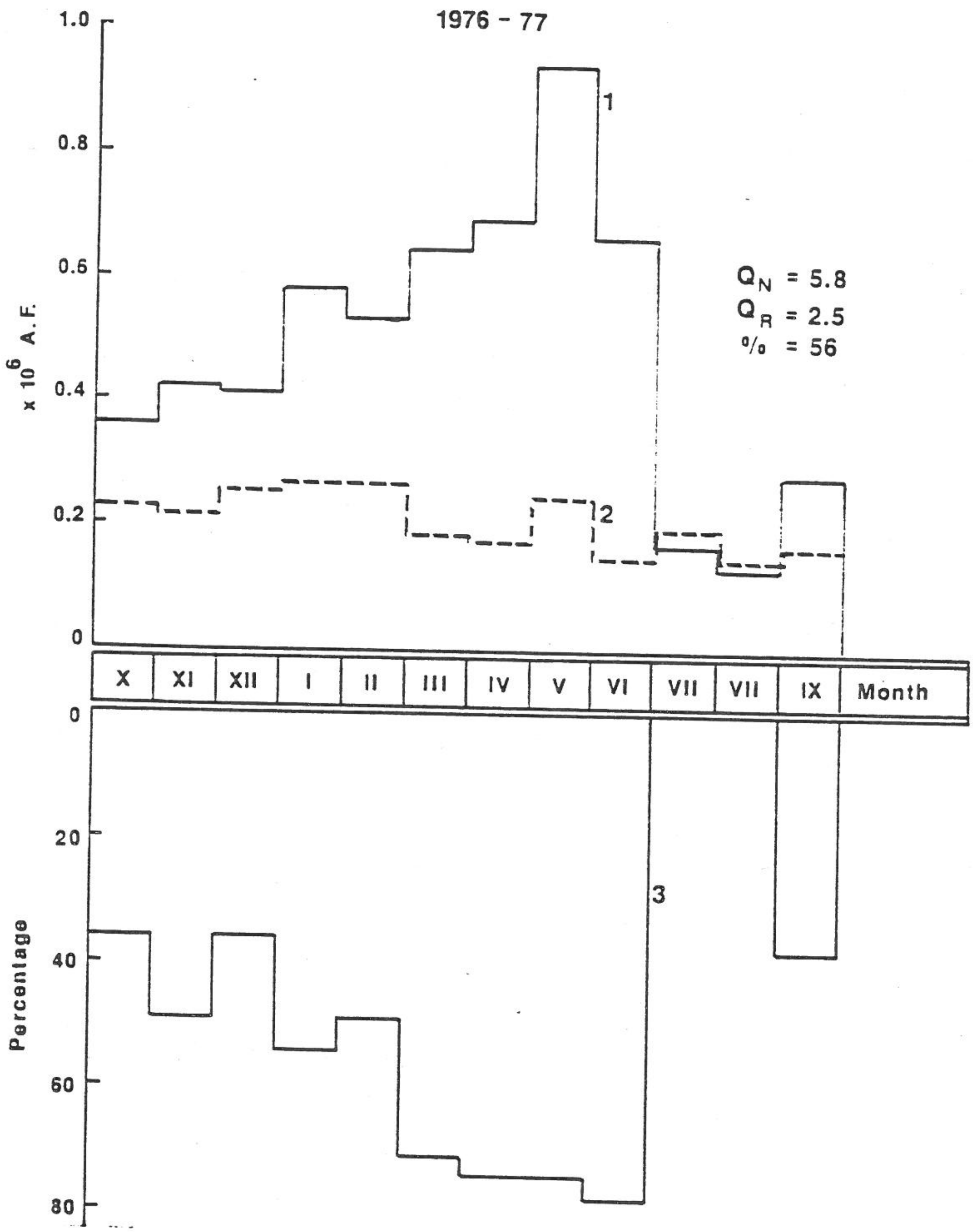


Fig. II.38 .Seasonal fluctuation of (1) natural and (2) regulated Delta outflow and (3) total diversion (expressed as a percentage of natural Delta outflow) in the critical dry year 1976-77 (post-project period).

Considering the value of precipitation minus evaporation over the Bay plus Qrdo of 2.5 MAF (mean of 1977), it becomes obvious that San Francisco Bay's water balance was practically without any of its freshwater component. In this case (even more than for 1924), the value of RDO does not correspond to any of the lowest flows observed under natural conditions and may have perhaps a recurrence under natural conditions of not less than once in several hundred years.

The events of 1977 might well raise questions about the necessity to improve some water storage facilities in order to provide the opportunities to store part of the surplus wet or abnormal years which could be used to correct critical dry or drought conditions, not only in the Delta but in Suisun Bay as well.

Conclusions

The projects' operations have resulted in a sharp increase in duration and of absolute values of upstream and inner Delta intra-annual water diversions in comparison with the pre-project conditions during typical years of wetness, i.e., normal, wet and critical dry. Winter and spring are the major periods of formation of water supply to meet the needs of different water users.

Before the projects, there was not much water diverted during winter because of the lack of storage facilities; after the projects' operation, winter became the first season of the hydrological year during which the upstream accumulation of water started.

Pre-Project	Post-Project
1. The duration of diversions covered mostly the period of spring.	1. The duration of diversion increased from 3-4 months to 8-9 months.
2. The range of upstream diversions during winter for average, dry and wet years was 0.1-0.5 MAF (-9 to 11% of the NRI), less than 0.2 MAF (-24 to 4%) and 1.1-2.2 MAF (-4 to 26%) respectively. The average upstream water withdrawals for winter were around 0.2 MAF.	2. The range of upstream diversions during winter for average, dry and wet years was respectively 0.2-2 MAF (-7 to -34%), 0.2-0.5 MAF (-36 to -70%) and 0.8 to 3.5 (with possible upstream releases reaching up to 1 MAF or more; or -31 to +16% from the monthly NRI for this period for given years, the positive percentage corresponds to the releases). The average upstream water withdrawals for winter were around 3 MAF. Therefore, the upstream diversions for winter increased 15 times from the observed

	<u>in the pre-project period</u>, and this volume constitutes about 30% of the mean winter inflow to the Delta (Table I. 26).
3. The range of upstream diversions during spring for average, dry and wet years was 0.5-2 MAF (-10 to -34%), 0.4-0.9 MAF (-50 to -100%) and 0.3-1.5 MAF (-4 to -16%) respectively. On the average the upstream losses for spring were 1.1 MAF.	3. The range of upstream diversions during spring for average, dry and wet years was 1.7-2.6 MAF (-58 to -51%), 0.4-0.5 MAF (-73 to 78%) and 2-4.4 MAF (-38 to -50%) respectively. On the average the upstream losses were 2.2 MAF, that is, double that observed for the pre-project period, or more than 50% of the spring normal.
4. The late summer and autumn experienced a strong deficit in water supply which is not very high for these seasons under natural conditions.	4. A water surplus amounting to 0.3-1 MAF or even more in the river-Delta system is observed during summer and autumn due to discharges of returning waters.

Because of an essential part of the total diversions is constituted by the upstream diversions (about 75%), the characteristics of monthly RDO are not very different from those mentioned above for river inflow.

In general, since the project operations, the winter and spring Delta outflow were significantly reduced because of combined upstream and Delta diversions. If the average years of wetness before and after the project operations can be used as typical examples, then we may state that the annual RDO constitutes 50% of normal.

II.2.5 Dynamics of Seasonal Inner Delta Diversions

General Remarks

The previous sections presented a quantitative analysis of some of the most visible changes in the perennial fluctuations of monthly and annual runoff which have resulted from the increasing degree of regulation of California water between 1921 and 1978, with major emphasis on the typical changes which took place in years of different wetness.

This section more graphically illustrates the dynamics of intra-annual diversions within the Delta and emphasizes the scale of the inner Delta diversions in terms of both percentage and absolute value. This analysis is designed to shed additional light on three important issues:

1) The seasonal dynamics of inner Delta diversions;

2) The relationship between the relative percentage and the absolute values of withdrawals;

Discussion of these issues may produce information useful for the modeling of Delta circulation patterns, the dynamics of salt intrusion into the Delta and salinization of the Delta water body, or for describing fish migration and spawning, or the activities of other biological resources. This information can also be useful in the development of standards and criteria for water quality in the Delta.

More to the point, the characteristics of the incoming waters like temperature, oxygen content, turbidity, sediment load, and other chemical constituents may be transformed to some extent due to the fact that the river's residual flow comes from different storage facilities which exert various influences in all these parameters. Therefore, there is no doubt that during the summer and fall, these incoming waters have very little in common with the runoff in its area of origin. Thus, the Delta in this regard, works like a sponge, i.e., recycles, processes and reproduces some new water whose quality depends on the quantity and quality of incoming waters, the level of diversions inside the Delta and many other hydrological and geomorphological factors of the Delta water body itself which are not easy to assess. Shedding light on this problem would only be possible if special chemical investigations were organized from the top of the mountains to the western part of the Delta along the riverbed. But we do not have these data and can only guess or use the experience obtained in other riverine-estuarine ecosystems. However, despite all these complexities, it is obvious to anyone that the Delta represents the final hydrologic entity whose changes may serve as a very specific mirror reflecting the scale of the role of upstream and downstream diversions. In this regard, the observed inner Delta seasonal diversions might be used to illustrate what happened to the river inflow to the Delta, but not as criteria for the integral impact on river basin modification on the San Francisco Bay ecosystem. As we have seen (and will be further demonstrated), the monthly inner Delta diversions are smaller than the upstream diversions. But that does not diminish the fact that the Delta losses may have a subtle but significant cumulative impact, in the long run, resulting in the gradual salinization of the Delta water body.

To underline some typical features of the dynamics of intra-annual diversions within the Delta as a result of the differences between the monthly RRI and RDO, we will comment on the Figures II. 39-46 according to their corresponding wetness classification as was first introduced in Table II. 3:

Wet Years:

There were 11 wet years out of 29 during the period 1956-84, that is, years whose annual runoff was above the normal by more than 25% (1956, 1958, Fig. II. 39; 1962, Fig. II. 40; 1965, 1967, 1969, Fig. II. 41; 1974, Fig. II. 43; 1978, Fig. II. 44; 1980, Fig II. 45; 1982 and 1983 Fig. II. 46).

For these years, more than 40-50% of the natural runoff entering the system was formed during the period between December and March. More often than not these years followed years of sub-normal wetness, or even two successive critical dry and drought years (1976, 1977).

One may assume that the major task of the diversions during the wet years was to replenish the exhausted storage facilities of the CVP, SWP as well as those of many local water facilities. Because of that, one may expect that during wet years the upstream withdrawals have to be the highest ones. This interception of water surplus would be available for use for much longer periods of sub-normal and critical wetness and hence to use the surplus for distribution for the years with pronounced deficit in water supply which usually take place, as we saw, during the phase following low water supply which may last for 2-5 years. But that was not the case in the flow regulation and accumulation for 1956-1984 period; on the contrary, the years of highest seasonal and annual natural river inflow/Delta outflow were, in general, characterized by the smallest upstream and downstream diversion (as we can see from the Figures II. 39-46 and Table II. 7 for the wet years and the previous discussion on upstream diversions). It follows that when there is plenty of natural runoff, not much water is needed from the storage facilities. But one of the major tasks of storage is not only to prevent the valley floor from flooding but at the same time to accumulate part of the surplus without damaging the riverine-estuarine system as has occurred many times (1956, 1969, 1974, 1982 and 1983). Had this been done it would be possible to better manage the hydrological regime of the river basin during sub-normal and dry years in a fashion beneficial for all water users, including the living resources of the estuarine system. However, this has not happened. During the wet years of this period, the water withdrawals out of the Delta were significantly smaller than during the sub-normal dry years.

In general the major pressure for water withdrawals began with May (40-85% from RRI, i.e., residual inflow) and reached its peak by July or August (60-85% from RRI), with little or no relief from upstream releases made during any of the three months.

The maximum annual diversion of all wet years of 5.3 MAF was observed, as it should be expected, in 1978, after two successive years of the lowest runoff since 1932.

In sum, the overall trend in water diversion for the wet years has been characterized by a gradual increase in its monthly and annual values since 1956, the exception being when the year was close to the normal, or intra-annual distribution of runoff was also close to the normal or even wet.

Sub-normal, Dry and Critical Dry Years:

Sub-normal, dry and critical dry years, such as 1959, 1961, 1964, 1968, 1972, 1976, 1977 and 1981 have 75%, 50% or less runoff than normal (Figs. II. 39-45, Table II. 3).

The picture describing the water diversions for these years is quite different from that mentioned above for the wet years. First, the inner Delta diversions start much earlier, i.e., February. Second, when one is dealing with the tense water supply in the river basin, as in years of sub-normal or critical wetness 1972, 1976, 1977 and 1981, there are year-round water withdrawals within the Delta which may be quite significant if conditions for migration and spawning activities of different species of fish, for example, striped bass, are in question.

These diversions, which account in the spring months for up to 0.7 MAF, with a progressive increase up to 0.9 MAF during the summer, compounded with upstream diversions, result in the development of such entangled detrimental conditions in the area which may influence not only the living resources but the water quality in the major part of the Delta as well. Not only the percentage of diversions was very high all year round for these years (30-60 and 40-85% during fall and the following spring, respectively), which indirectly describes the scale of reduction of RRI (percentage of reduction is equal to RRI-RDO*100), but RRI the volume of withdrawn water from RRI itself may be only slightly less than Delta diversions for wet years.

Such an approach to water diversion demonstrates that the pumping of water from the Delta as well as from the river basin in years of low wetness is based on the entitlement for water on behalf of different water users regardless of the category of a given year or season's wetness, its probability of occurrence and recurrence interval, and the possible short and long-term impact on water quality and living resources of the riverine-system in question.

More often than not the annual values of the volumes withdrawn from the Delta during these sub-normal years are as much as 1.3-2.3 times higher than for the wet years, even though the sub-normal year's monthly water withdrawals might be slightly less than those for the wet years (Table II. 3).

It should be noted that while the river system may have some surplus due to the incoming returning waters and, in our opinion, negligible releases, especially during the late summer and fall, that is not the case for the Delta outflow. Out of 24 years, based on the available data and plotted on these figures, we were not able to find any case when the regulated Delta outflow was higher than the RRI during the summer period which consistently experiences water deficit.

Therefore, even if some returning water managed to reach the Delta system, it is logical to expect that: First, an essential part of this water may slightly replenish the Delta deficit; second a significant part of this water will be consumed, and third the local residual discharges may have a high concentration of total dissolved solids, saturated with pesticides, herbicides, etc., and therefore, instead of dilution and improvement, the southern part of the Delta may experience salinization, and what is left may be more detrimental than beneficial to the water quality of the Delta and adjacent parts of San Francisco Bay.

For example, in 1976, almost 6.7 MAF were diverted from the Delta. That is as much as 5.2 times the volume of the Delta itself. To make conditions even worse, almost half that amount was diverted during the following drought year of 1977. But inasmuch as losses sustained by the Delta have to be replenished somehow because nature cannot withstand an empty niche (that is a very simplified definition of the law of conservation of mass and energy), it is not surprising that the salt intrusion appears, followed by the salinization of the Delta water body for many months to come.

This type of development, well-documented and described in the literature related to San Francisco Bay as well as other estuaries, resulted in the impairment of municipal, industrial and agricultural water intakes, destruction of spawning grounds of some fish whose eggs have very low tolerance for salinity (like striped bass), destruction of agricultural land and Delta levees, and resulted in a very specific hydraulic feature becoming dominant in these conditions: the increase in the recurrence of compensating currents which bring the salt into the Delta.

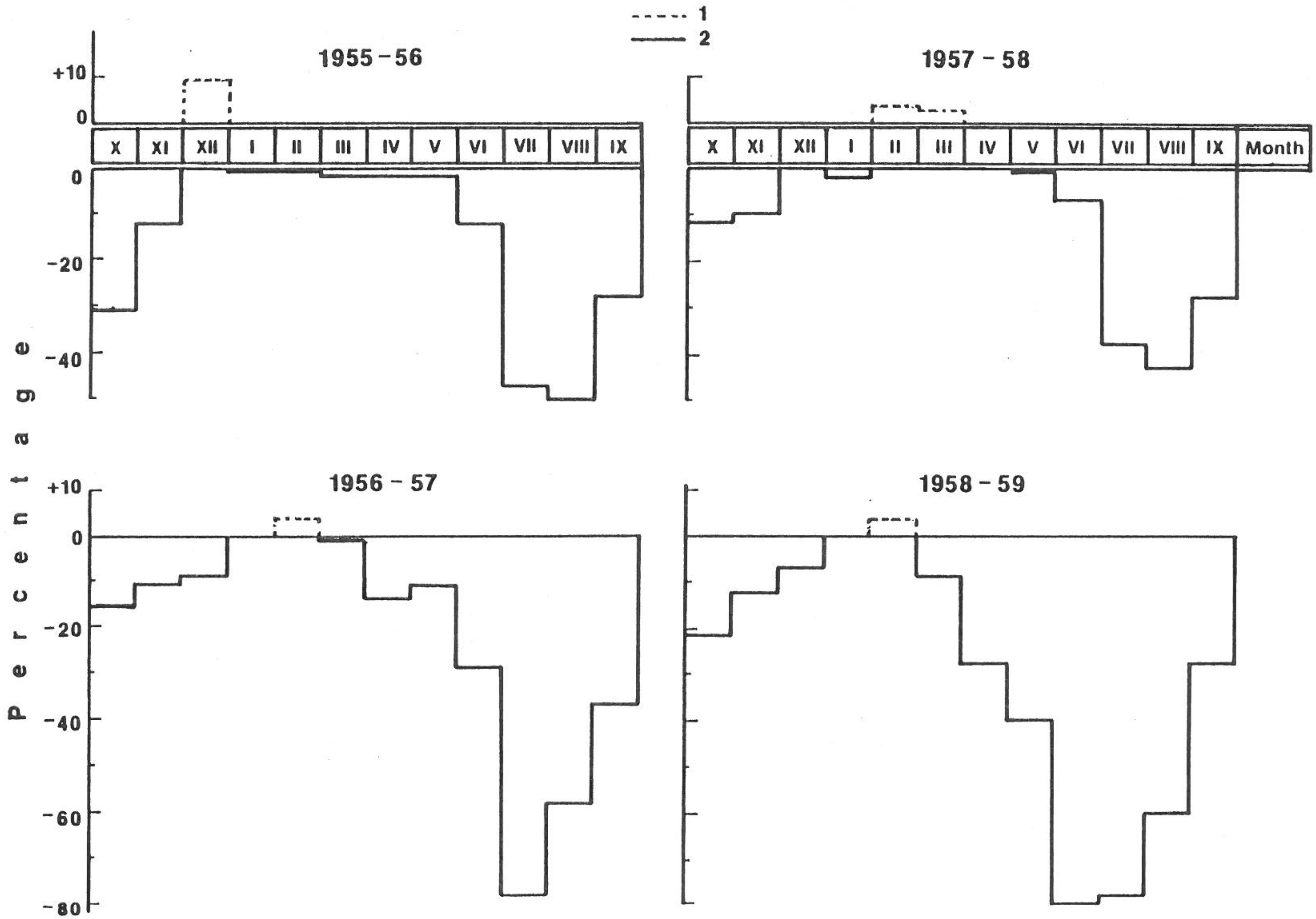


Fig.II.39 Total water withdrawal from the Sacramento-San Joaquin Delta system expressed as a percentage of regulated river inflow and Delta outflow. (1) Surplus of Delta regulated outflow; (2) gross diversion within the Delta under conditions of regulated inflow/outflow.

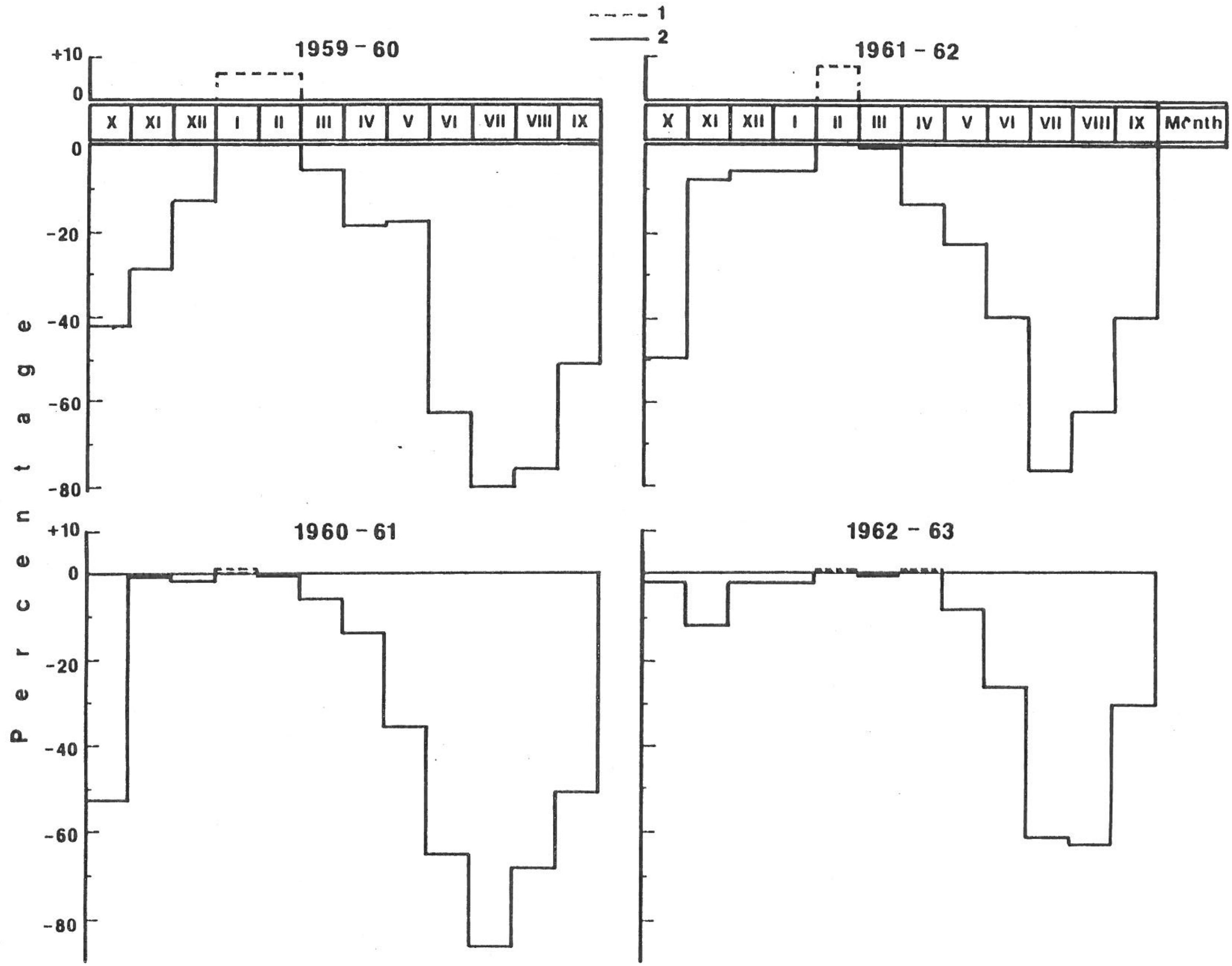


Fig.II.40 The percentage of total water withdrawal from the Sacramento-San Joaquin delta system as compared with regulated river inflow and delta outflow. (1) surplus of delta regulated outflow; (2) gross diversion within the delta under conditions of regulated inflow/outflow

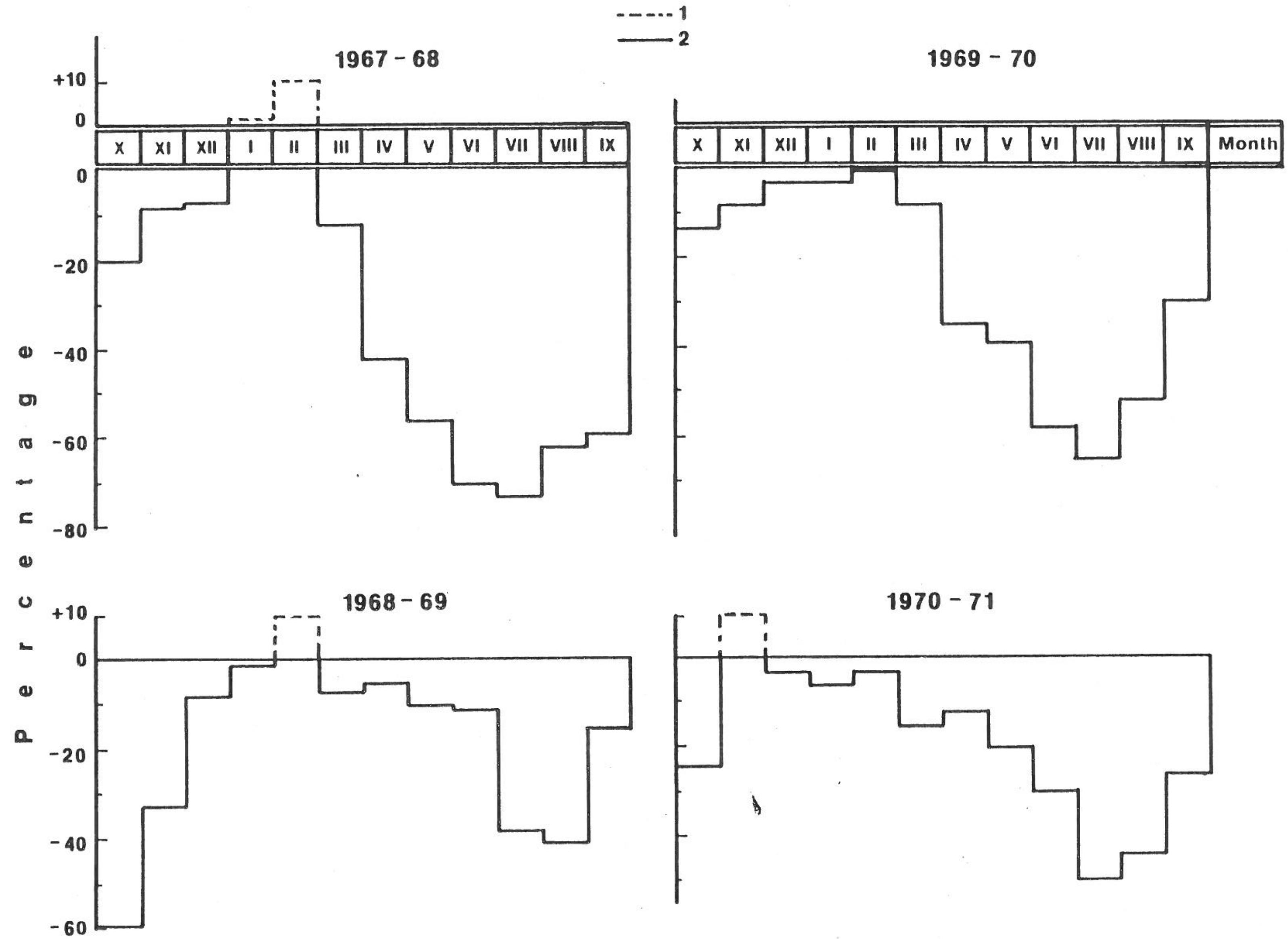


Fig.II.42 The percentage of total water withdrawal from the Sacramento- San Joaquin delta system as compared with regulated river inflow and delta outflow. (1) surplus of delta regulated outflow; (2) gross diversion within the delta under conditions of regulated inflow/outflow

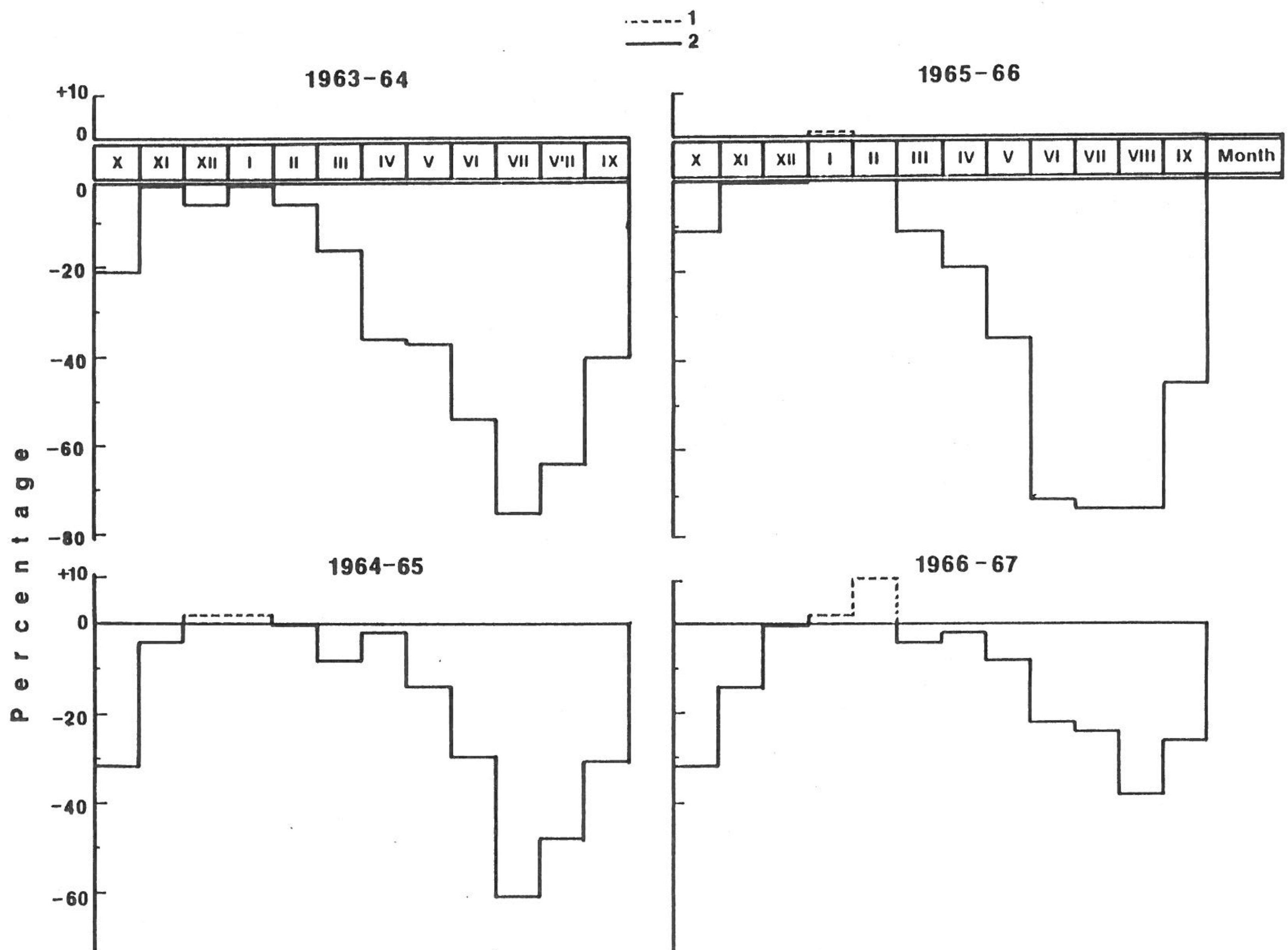


Fig.II.4 The percentage of total water withdrawal from the Sacramento-San Joaquin delta system as compared with regulated river inflow and delta outflow. (1) surplus of delta regulated outflow; (2) gross diversion within delta under conditions of regulated inflow/outflow

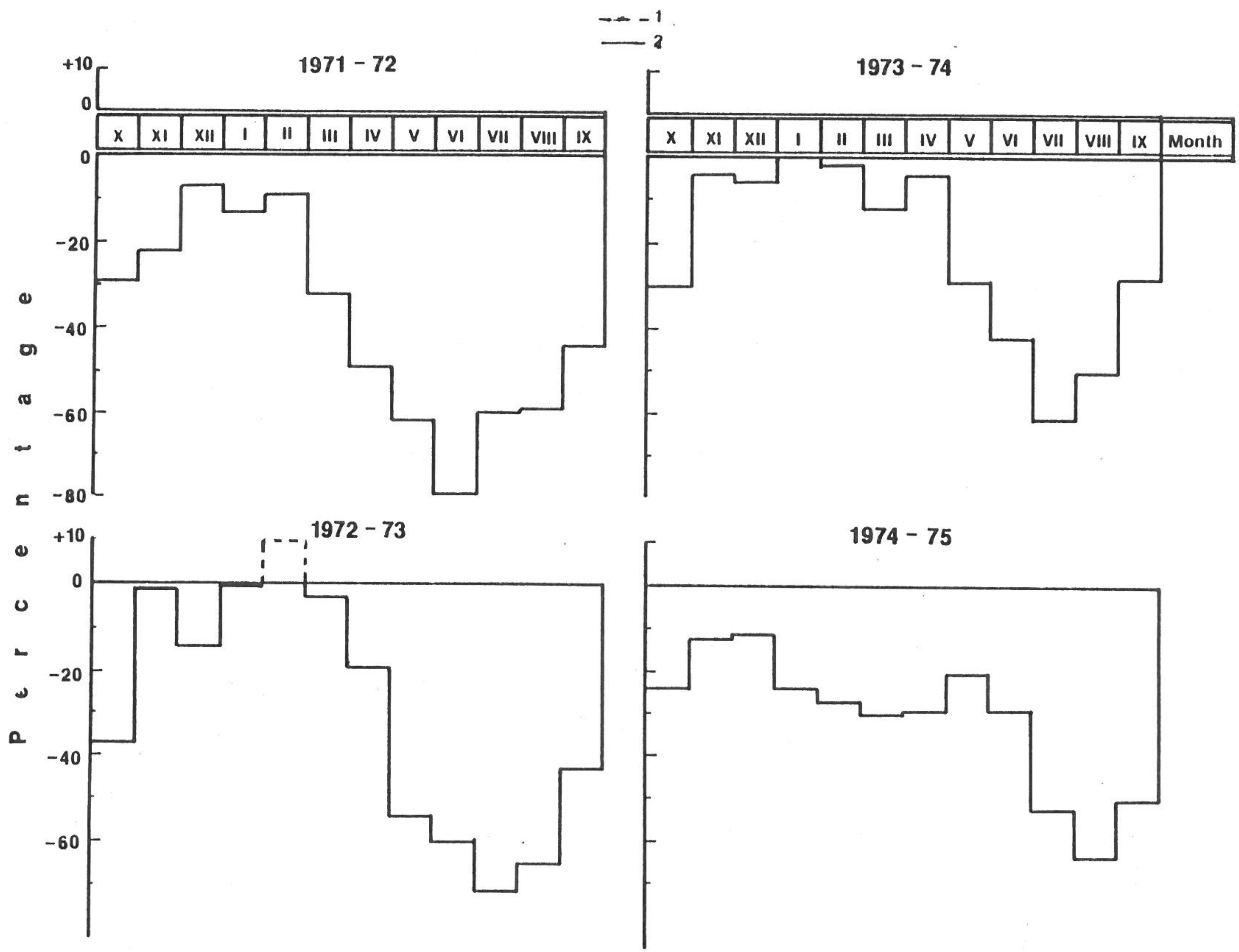


Fig.II.43 The percentage of total water withdrawal from the Sacramento-San Joaquin delta system as compared with regulated river inflow and delta outflow. (1) surplus of delta regulated outflow; (2) gross diversion within the delta under conditions of regulated inflow/outflow

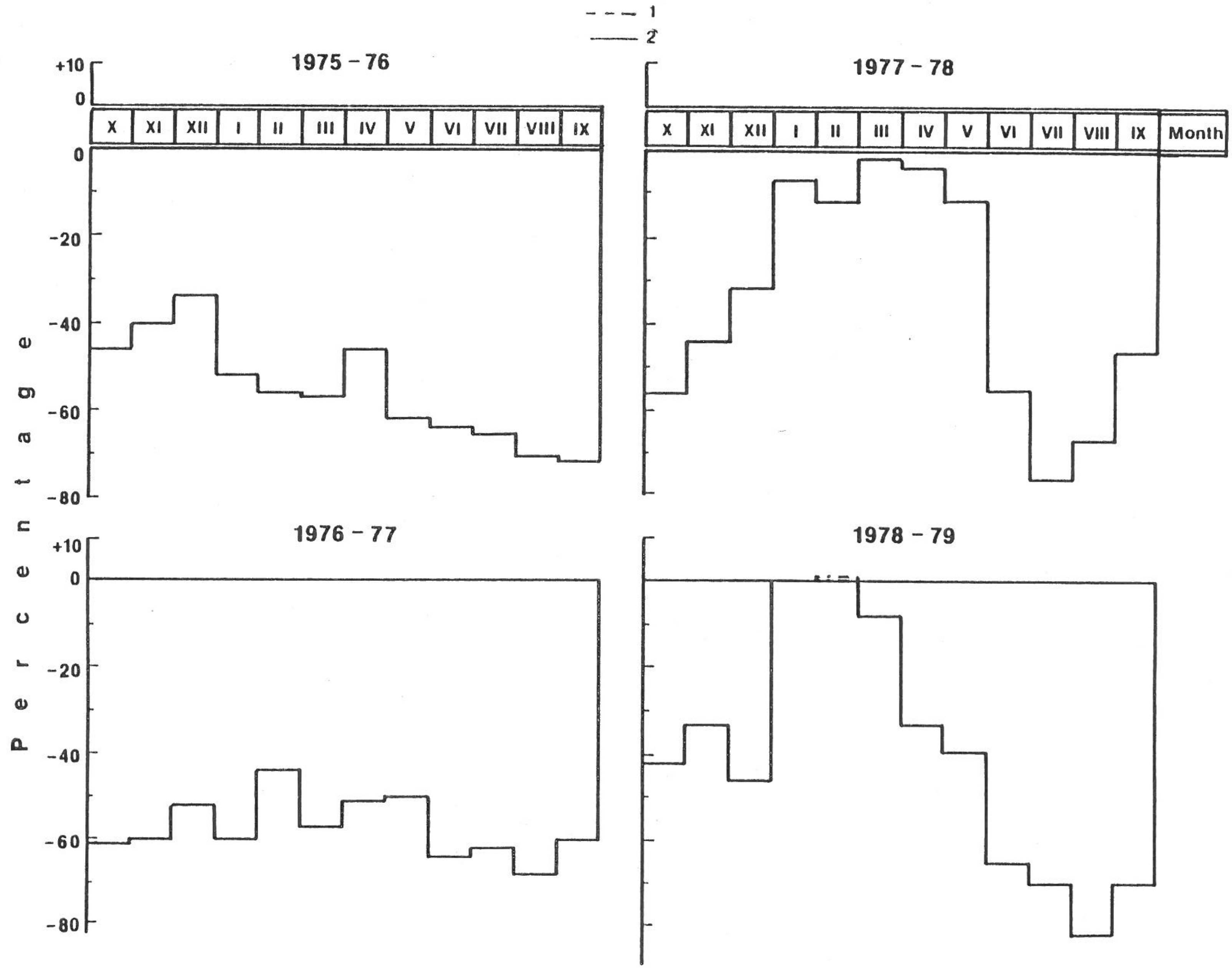


Fig. II.44 Total water withdrawal from the Sacramento-San Joaquin Delta system expressed as a percentage of regulated river inflow and Delta outflow. (1) Surplus of Delta regulated outflow; (2) gross diversion within the Delta under conditions of regulated inflow/outflow.

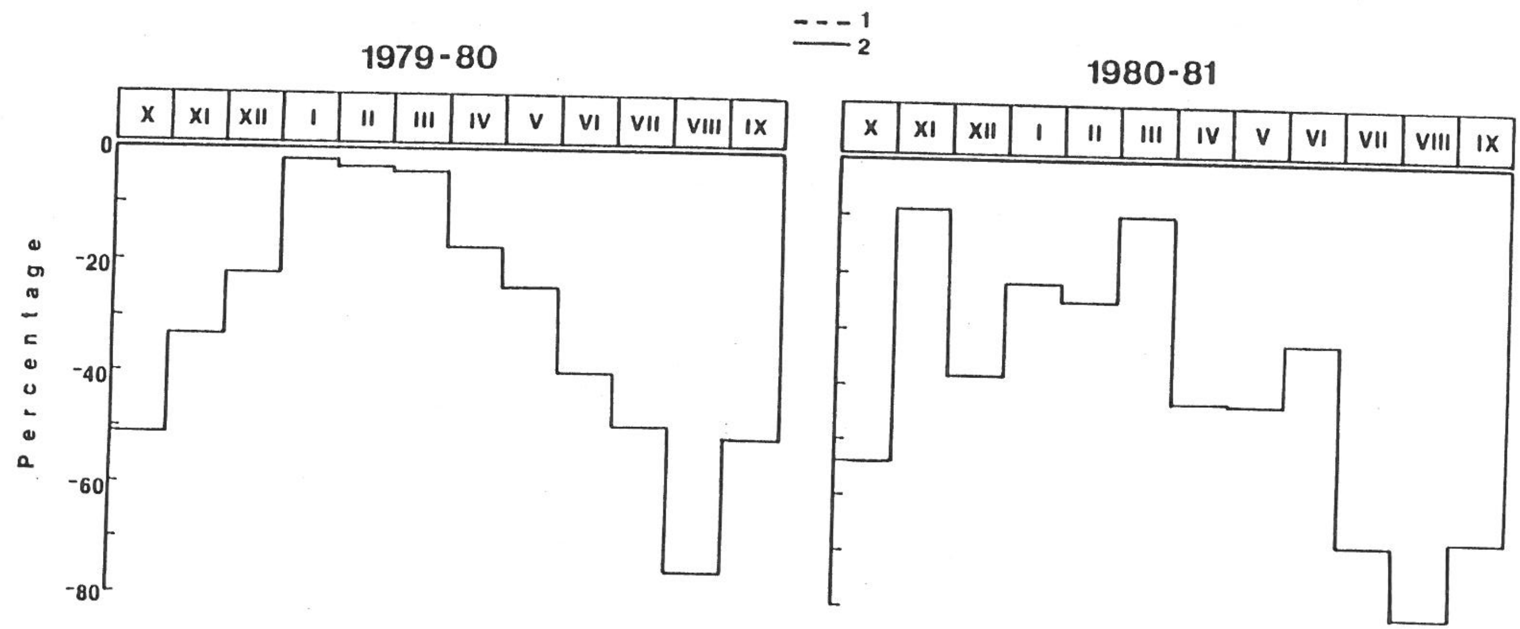


Fig. II,45. The Percentage of total water withdrawal from the Sacramento-San Joaquin Delta System as compared with regulated river inflow and delta outflow. (1) surplus of regulated delta outflow; (2) gross diversion within the delta under conditions of regulated inflow/outflow.

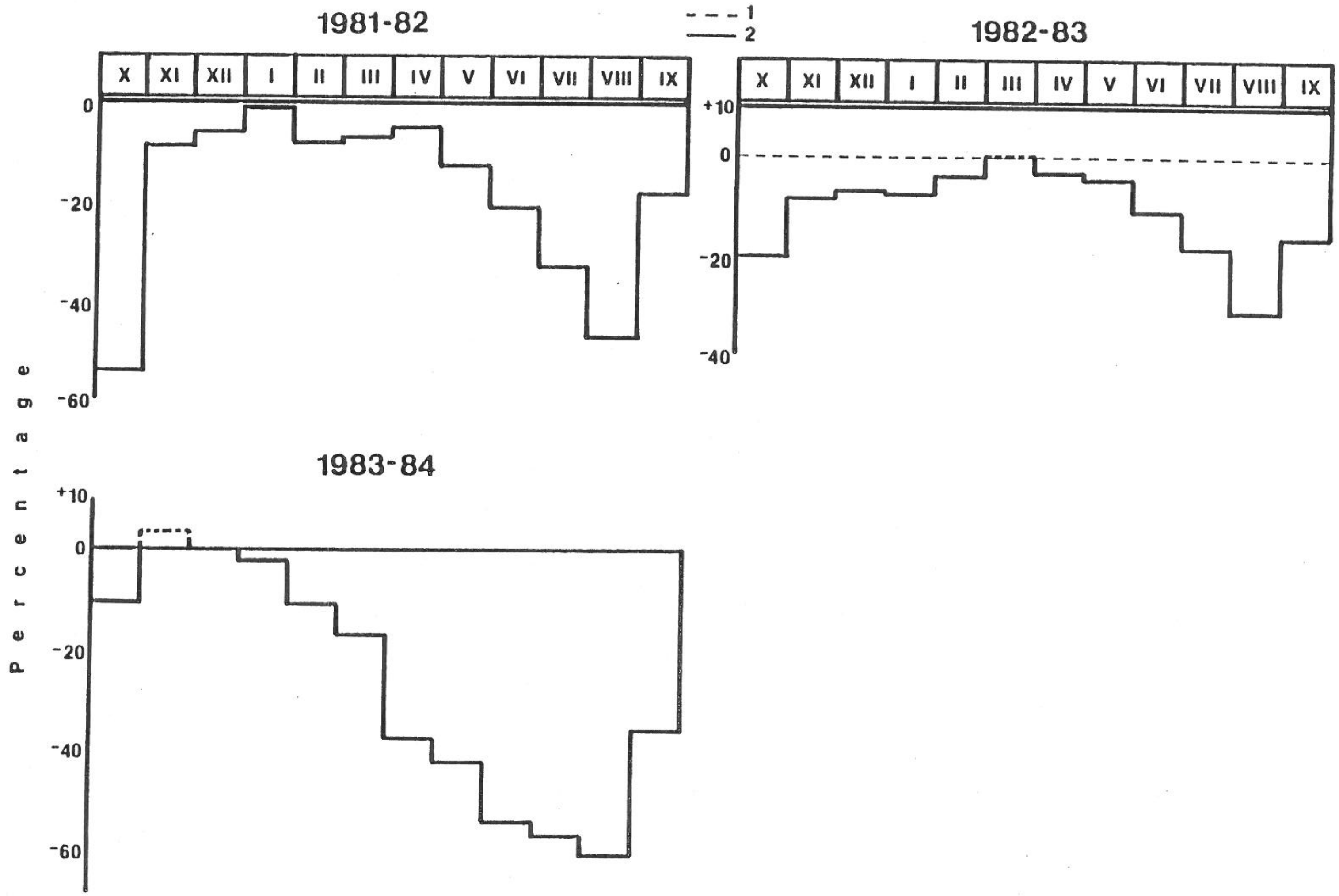


Fig.II.46. The Percentage of total water withdrawal from the Sacramento-San Joaquin Delta System as compared with regulated river inflow and delta outflow. (1) surplus of regulated delta outflow; (2) gross diversion within the delta under conditions of regulated inflow/outflow.

II.2.6 The Perennial Trend of Monthly Regulated Runoff and Water Diversions

General Remarks

The year-to-year fluctuations of regulated monthly runoff repeat the same patterns as observed with natural runoff, but their statistics (mean, amplitude, standard deviation, Cv and Cs, deviations of monthly normal runoff) as well as the number of years of different wetness and their probability of occurrence and years of recurrence interval, are much different. To make this comparison easily understandable and uniform, the mean values of normal runoff for each month of the 1921-78 period of observations are used as the basis for evaluating the deviations (from the mean values for the 58-year period) of variables of relative (%) and absolute values (MAF) of regulated river inflow and Delta outflow.

II.2.6.1 Statistics of Winter Runoff and Diversions

Winter (December, January, February, March)

This period of the hydrological year provides the major part of the water supply to the system, and as such, the curve of the normalized modulus for December, January, February and March illustrate (Fig. II. 47-50) almost the same three major cycles and their corresponding phases of wetness that were highlighted earlier for annual unimpaired inflow oscillations (Fig. I. 7, Table I. 5).

Of these four months, the normalized modulus fluctuations of February and March are characterized by relatively small and stable fluctuations. The predominant range of the average deviations of the modular deficits for these months from the phase of rise to the phase of decline is ± 30% of the deviations in the river water supply to the Delta-Bay system as calculated from the normal runoff for these months. This similarity in monthly modulus deviations to the normalized annual deviations of the same modulus may be taken as evidence that the winter natural cycle of wetness is responsible for the upcoming hydrological year water supply. Therefore, the water withdrawals during this period, especially if the preceding year is characterized as sub-normal or dry, may have a major impact on the characteristics of physical, chemical and biological Delta-estuary. This process may be exacerbated, as will be seen later, by significant water withdrawals during the following spring.

Statistics of Winter Runoff and Diversions

December

Pre-Project Period(1921-43)

The dynamics of upstream runoff withdrawals for December can be seen from Fig. II. 51A. The range of diversions for this month was very small (exception 1921) there appear to have been many cases when amounts of water were released from small storage facilities at that time (especially when runoff was higher than normal or corresponded to a year of high wetness).

For example, in December of 1927, RRI was very close to the normal, and the flow increment to the river system was highest, 0.33 MAF (or 13.3% surplus), while for the driest year of 1931 (with a probability of exceedance of 95%, or recurrence of not less than once in 20 years), the surplus of only 0.2 MAF corresponded to 40% of NRI. Therefore, here, as in many other examples of months of the hydrological year, the actual percentage of surplus or diversion alone is not meaningful without supplemental information on the absolute value of runoff.

Maximum upstream diversion of 1.0 MAF occurred in 1941-42 and 1942-43 (the wettest years) when December runoff corresponded to 15% probability of occurrence.

In general, the typical feature of upstream water development for this period was relatively minimal water consumption. In seven out of twenty-three years, releases ranged between 0.1 and 0.3 MAF.

For the remaining years, upstream diversion accounted for 0.21 MAF (the total consumptive use for the period 1921-43 was 4.8 MAF). (Table II. 34)

In general, RDO fluctuations and Delta diversions were similar to RRI (Fig II. 51B). However, the maximum water withdrawals from the Delta were half the level of upstream diversions (with the exception of December, 1921, when the highest Delta diversion of 2.9 MAF occurred -- 69% of the mean monthly). This month and this year both corresponded to the wettest seasonal category.

For the rest of the 1921-43 period, the maximum diversion of 0.6 MAF occurred in December of 1927 (the wettest year). The range of diversion of 0.01-0.6 MAF was typical for the Delta.

The average Delta consumption was 0.1 MAF (1921-43). The maximum total diversion (upstream and Delta) of 3.0 MAF occurred in 1921; the range for the period was 0.02-3.0 with an average of 0.3 MAF.

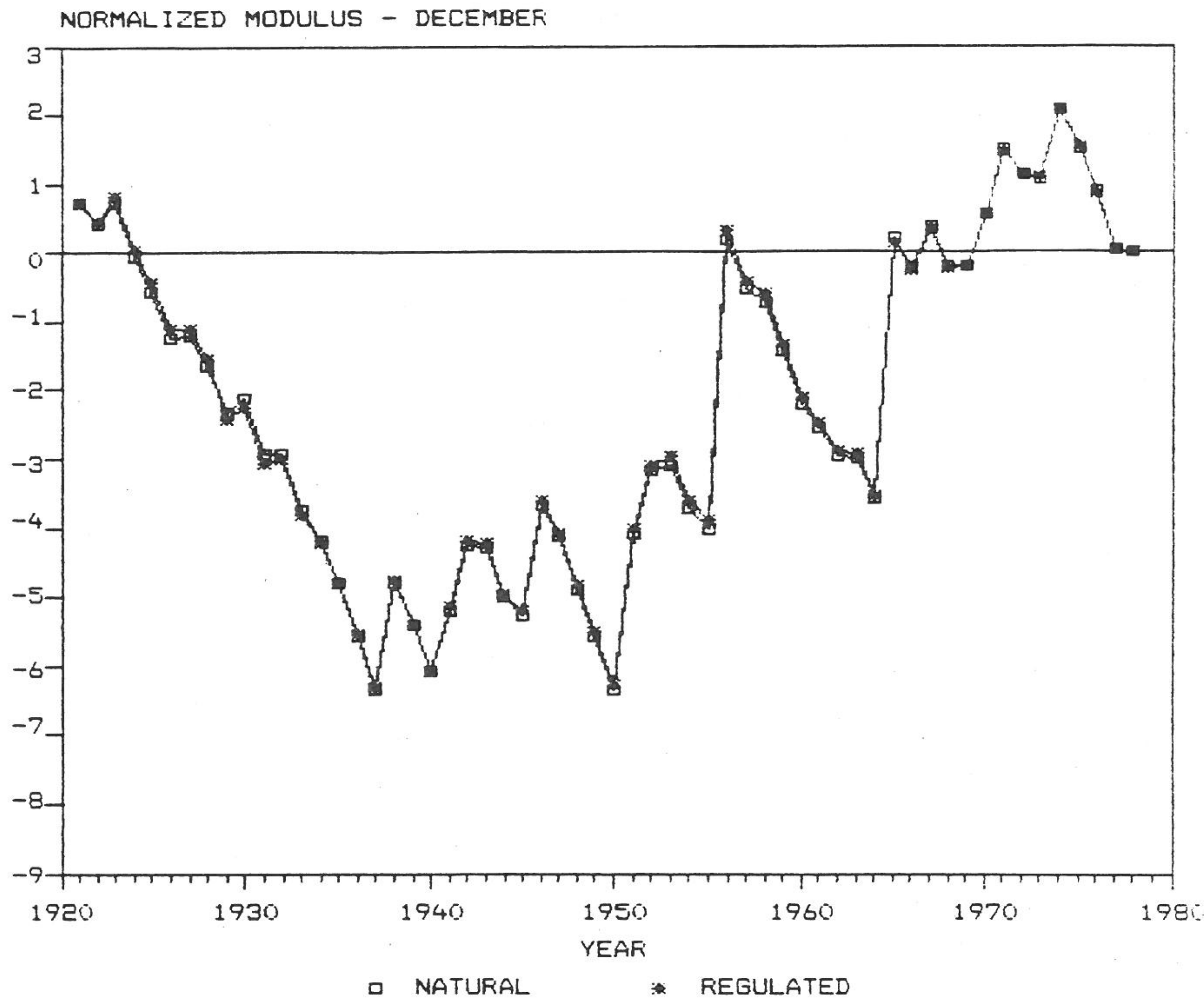


Fig. II.47. Normalized modulus for natural and regulated delta outflow.

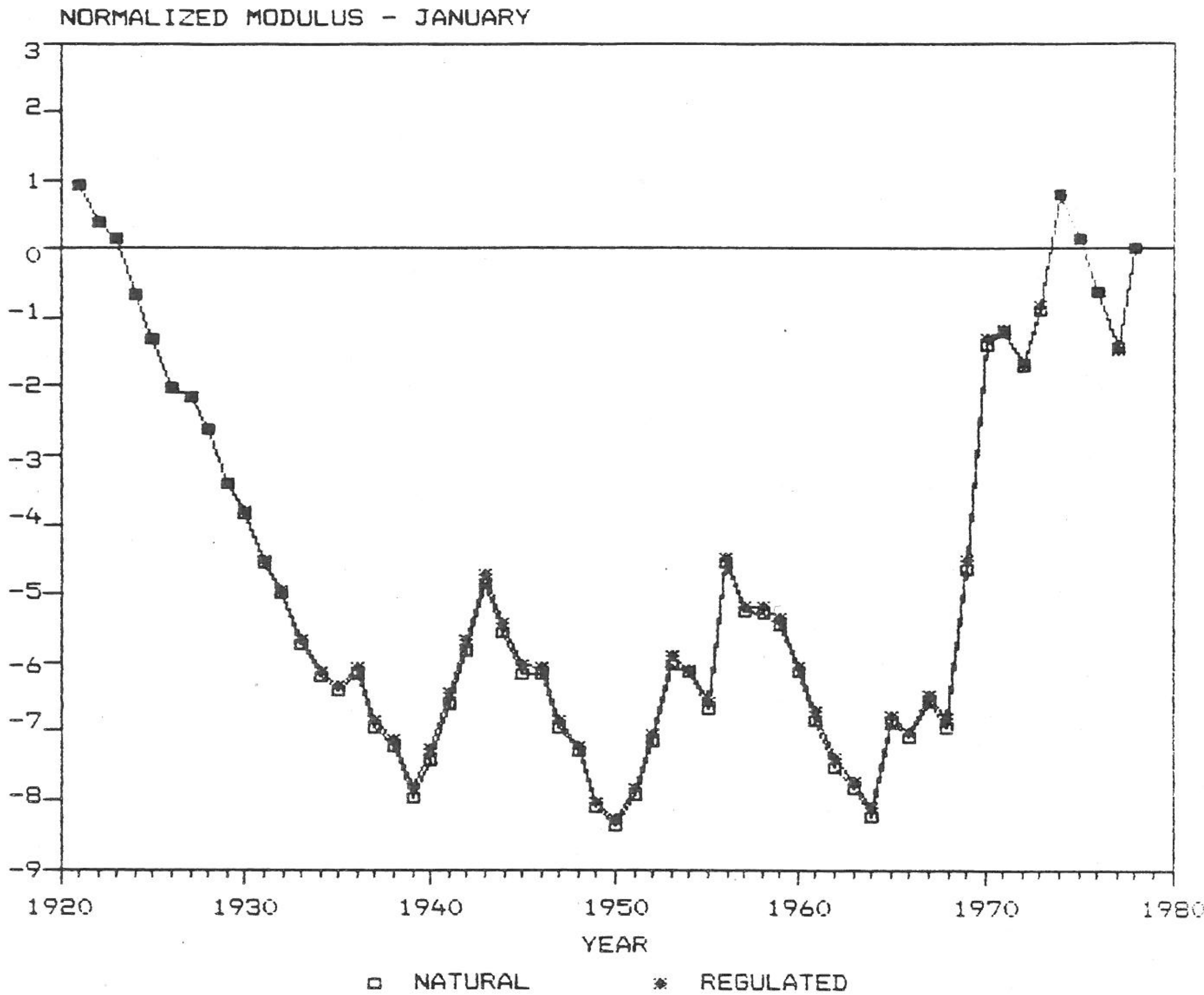


Fig.II.48. Normalized modulus for natural and regulated delta outflow.

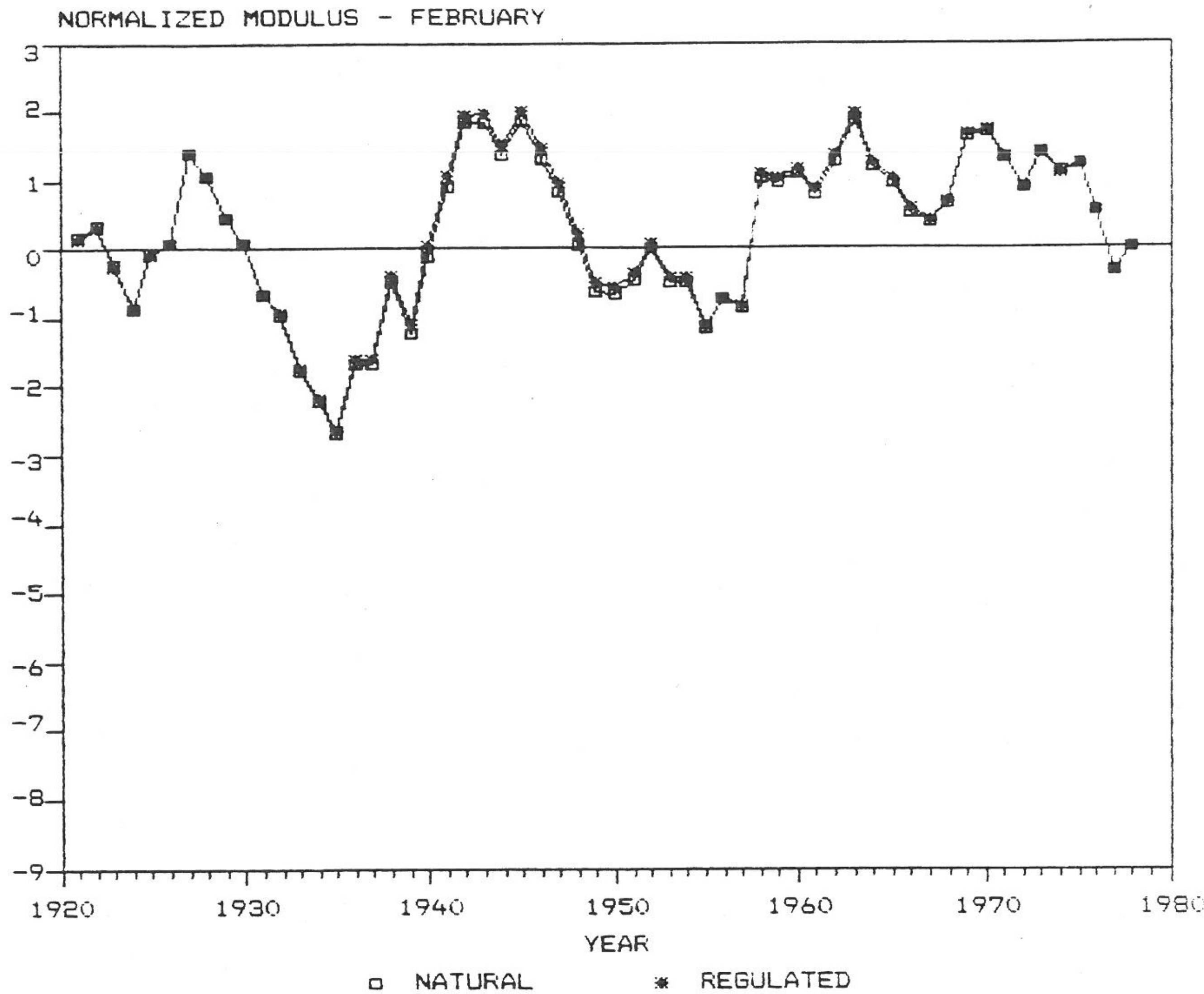


Fig.II.49. Normalized modulus for natural and regulated delta outflow.

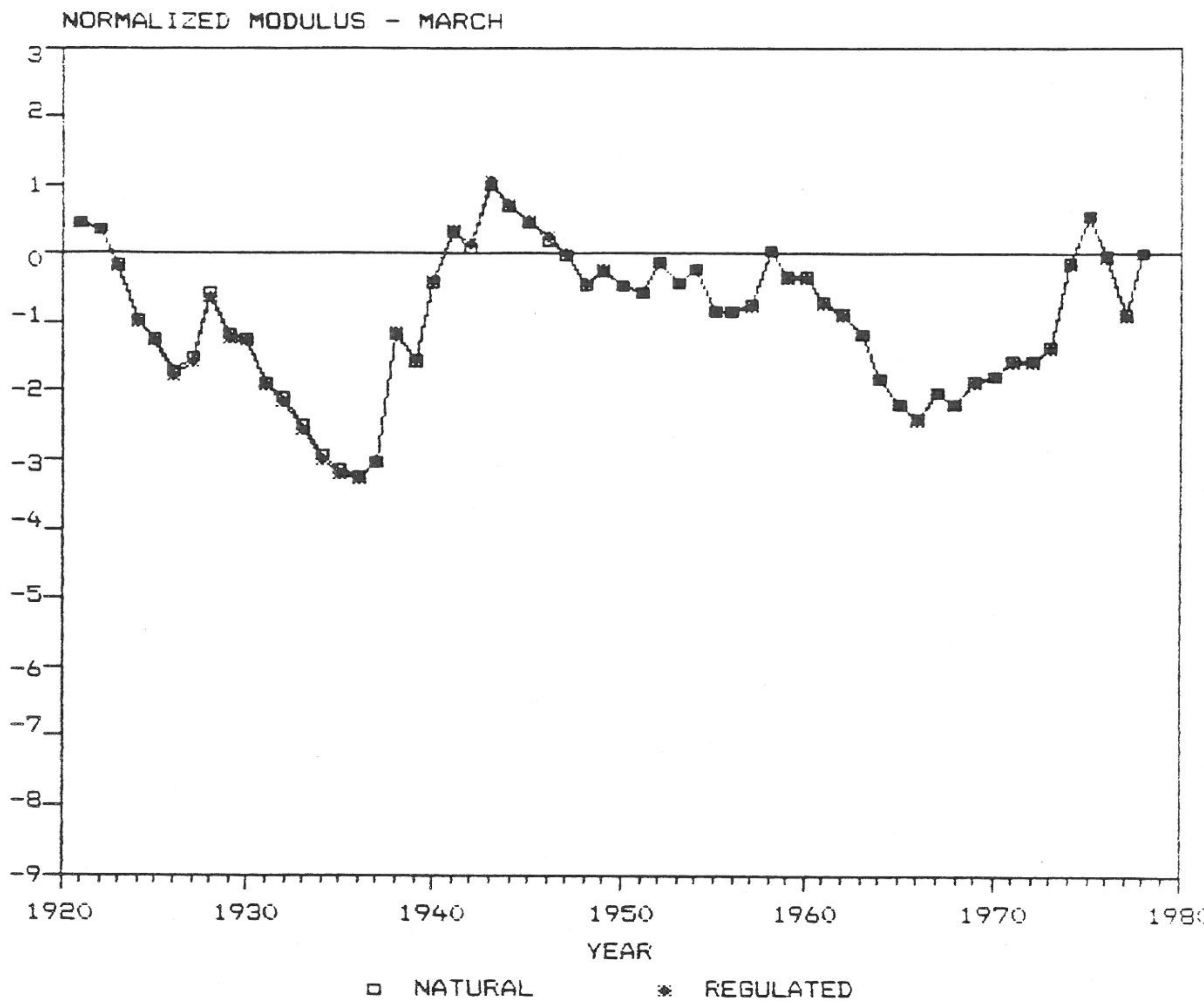


Fig.II.50. Normalized modulus for natural and regulated delta outflow.

December

Post-Project Period (1944-78)

With the increase in project operations, the upstream and downstream water withdrawals as well as Delta consumption increased.

Although the predominant upstream (0.2-0.4 MAF), inner Delta (0.01-0.2) and total diversions (0.2-0.4 MAF) were relatively small, some very high upstream withdrawals, 1.8 MAF (1946), 5.3 MAF (1956), 5.1 MAF (1965) occurred which may reflect reservoir filling (e.g., Folsom Lake, 1955-56) (Tables II. 5-10).

The maximum inner Delta diversion of 0.6 MAF took place in 1976 (NRI for this month, 0.9 MAF, corresponded to 75% probability of exceedance, i.e., sub-normal conditions, which may occur one or more times in four years).

The maximum percentage of 77.3% of total water withdrawals from NRI (2.33 MAF) took place in 1978, (1.8 MAF, of which 1.6 MAF were upstream diversions and 0.2 MAF were Delta diversions).

It should be noted that the RDO discharged to San Francisco Bay in 1977 and 1978 were record lows for this month and corresponded to a recurrence interval of not less than once in 20 years and once in more than 100 years, respectively (Fig. II. 16), while the NDO for the same years would have a recurrence interval of at least once in 93 years and once in 2 years, respectively).

The trend in water diversions can be seen from Table II. 34 which reveals that upstream and total diversion for the 1944-66 period versus 1921-43 almost doubled.

Table II. 34 Upstream, Delta and total diversions (MAF) from the Sacramento-San Joaquin River Basin (December)

Years	Upstream	Delta	Total
1921-43	-4.7	-2.4	-7.1
1944-66	-12.6	0.0	-12.6
1967-78	-2.0	-2.5	-4.5

In the following twelve years, important changes took place Delta diversion which increased up to the value of the pre-project period.

January

Pre-Project Period (1921-43)

For the majority of years of this period, the upstream and especially Delta water supply was positive. The latter means that RDO was slightly higher than the RRI. The predominant range of this surplus accounted for 0.1-0.25 MAF (Fig. II. 52).

The upstream water supply, in some years was subjected to diversions, especially in the cases when the preceding year was dry, sub-normal or critical dry. For example, 1926 and 1939 were critical dry years; in the following years, 1927 - normal and 1940 - wettest, the upstream diversions were 0.5 and 1.2 MAF, or 25 and 23% of their NRI, respectively.

Therefore, having both a Delta water surplus and predominant excess of water in the upper part of the river, the total diversions in the basin were relatively low with the exception of years like 1940 (0.9 MAF) and 1943 (1.0 MAF).

In sum, January of the pre-project period did not experience the impact of pronounced winter withdrawals given the fact that at that time there were no large storage facilities or water conveyance systems in operation.

January

Post-Project Period (1944-78)

The trend of post-project upstream diversions for this month began to change noticeably in the 1960's.

1) Significantly greater amounts of water were withdrawn above the Delta than during the pre-project period. As a result, RRI was much less than the would-be natural river inflow to the Delta.

The biggest diversion occurred in 1969 and was than 3.4 MAF (or 31.1% of NRI of the wettest January, 5% probability of exceedance). It followed a December of sub-normal wetness (1968 was a year of sub-normal wetness).

The second highest proportion of upstream diversion during this period, 4.0 MAF, was observed in 1978 (48% diversion) which followed the drought of 1977.

2) At the same time, the inner Delta diversions increased significantly and reached their maximum of 0.54 MAF in 1976 - critical dry year. This withdrawal constituted 47% of January's RRI, while in the drought year of 1977 the lower inner Delta diversion of 0.4 MAF corresponded to 60% of RRI.

3) There has been a gradual increase in total water diversions (upstream diversions plus Delta diversions) with the exception of the years in which additional water was released because of lack of water in dry years or excess of water in wet years, as 1946, 1947, 1949, 1952, 1955 and 1965.

A high level of total withdrawals (3.6 MAF) was documented in 1969 (34% of NDO). The preceding year, 1968, was a sub-normal year for NDO. The biggest total withdrawals for the period under consideration, 4.3 MAF, was observed in 1978 (53% of mean monthly NDO of that year); the two preceding years were critical dry and drought years (Table II. 7).

Therefore, if January's residual discharge (RDO) to the San Francisco Bay for 1976 and 1977 is contrasted with the would-be natural NDO for those years, the frequency of recurrence for both would be once in 100 years, or in the case of RDO for the drought year, 1977, even beyond the theoretical curve. (The latter has a recurrence of at least once in several hundred years). In this regard, it should be noted that the recurrence interval for the NDO of 1976 would be 4-5 years.

Table II. 35 Upstream, Delta and total diversions (MAF) from the Sacramento-San Joaquin River Basin (January)

Years	Upstream	Delta	Total
1921-43	-2.6	-2.8	+0.2
1944-66	-2.8	+2.1	-0.6
1967-78	-12.4	+2.2	-10.2

January for the 1967-78 period is characterized by a sharp increase of upstream and total water diversions in comparison with two other periods. At the same time, the Delta area experienced relatively small water surplus (Table II. 35).

February and March

Pre-Project Period (1921-43)

Although the amplitude of runoff for these months was slightly less than for January, the overall increase in rainy weather may have produced a more stable water supply, which is why February and March are characterized by the progressive increase of water diversions. In the majority of cases for February, (Fig. II. 53) the volume of upstream diversions was higher than for March. (Fig. II. 54).

The two highest upstream water withdrawals were: 2.3 MAF (or 28.4% of the average 8.1 MAF of one of the wettest months of February in 1940, characterized by rare occurrence, one or more times in twenty years), and 2.1 MAF (or 28% of the average of 7.5 MAF of one of the wettest months of March of 1928, recurrence of at least once in twenty years).

It should be noted that the proceeding 1938-39 hydrological year (12.8 MAF) and its February runoff (1.0 MAF) corresponded to critical dry conditions, i.e., 95% of probability of exceedance.

The maximum Delta diversion for February and March occurred in 1942 (4.8 MAF, or 65% of the average NRI) and in March 1928 (0.9 MAF, or only 12% of March NRI, but the highest volume for this month for the entire pre-project period). Both months are typified as very wet periods. It should be noted that because of the relatively small volume of the Delta, 1.27 MAF, diversions of this magnitude or any greater than 1/3 of its volume may greatly modify Delta circulation patterns, resulting in salt intrusion and salinization of the water body.

The maximum total withdrawal of 3.9 MAF was observed for February, 1927 (one of the wettest years) and 3.0 MAF in March, 1928 (also one of the wettest years).

It should be noted that the maximum volume of upstream diversions was almost equal to normal which may illustrate the scale of upstream diversions which started during the pre-project period. This trend did not change during the post-project period or for the spring, as we shall see later.

There were many cases of small releases or returning water discharges which masked the level of diversions. The greatest increase in river water balance, 1.0 MAF, occurred in February, 1938, and March, 1941.

February and March

Post-Project Period (1944-78)

During this period, these two months of winter have a majority of years with a higher volume of diverted waters than those observed for December and January.

The maximum upstream diversion for February, 2.1 MAF, was observed in 1957 after a January which had a water supply four times lower than normal and the entire year was a sub-normally wet one.

As for March, the maximum upstream diversion of 5.8 MAF was observed in 1974, one of the wettest years in the period of observations, while February was also sub-normally wet.

There were several cases in which releases influenced water balance: In February, at the beginning of this period, these releases ranged between 0.1-0.5 MAF. The highest, 2.2 MAF, occurred in 1970, which resulted in increased water supply to the Delta of about 0.3 MAF. This release followed one of the wettest January months since observations began (NRI was 14.4 MAF). (Such critical wet conditions occurred only one time during the 1919-84 period).

The highest inner Delta diversion for February (0.8 MAF) and March (1.3 MAF) occurred in 1975. These volumes constituted 28.3 and 30.3% of RRI for the same months, respectively.

It should be noted that the preceding December and January had sub-normal runoff which was 2.4 and 2.7 times less than normal (the annual runoff of 1975 corresponded to wet conditions). In general, when the preceding months of the season are characterized by low water supply, then diversions in the following months of the season may increase noticeably.

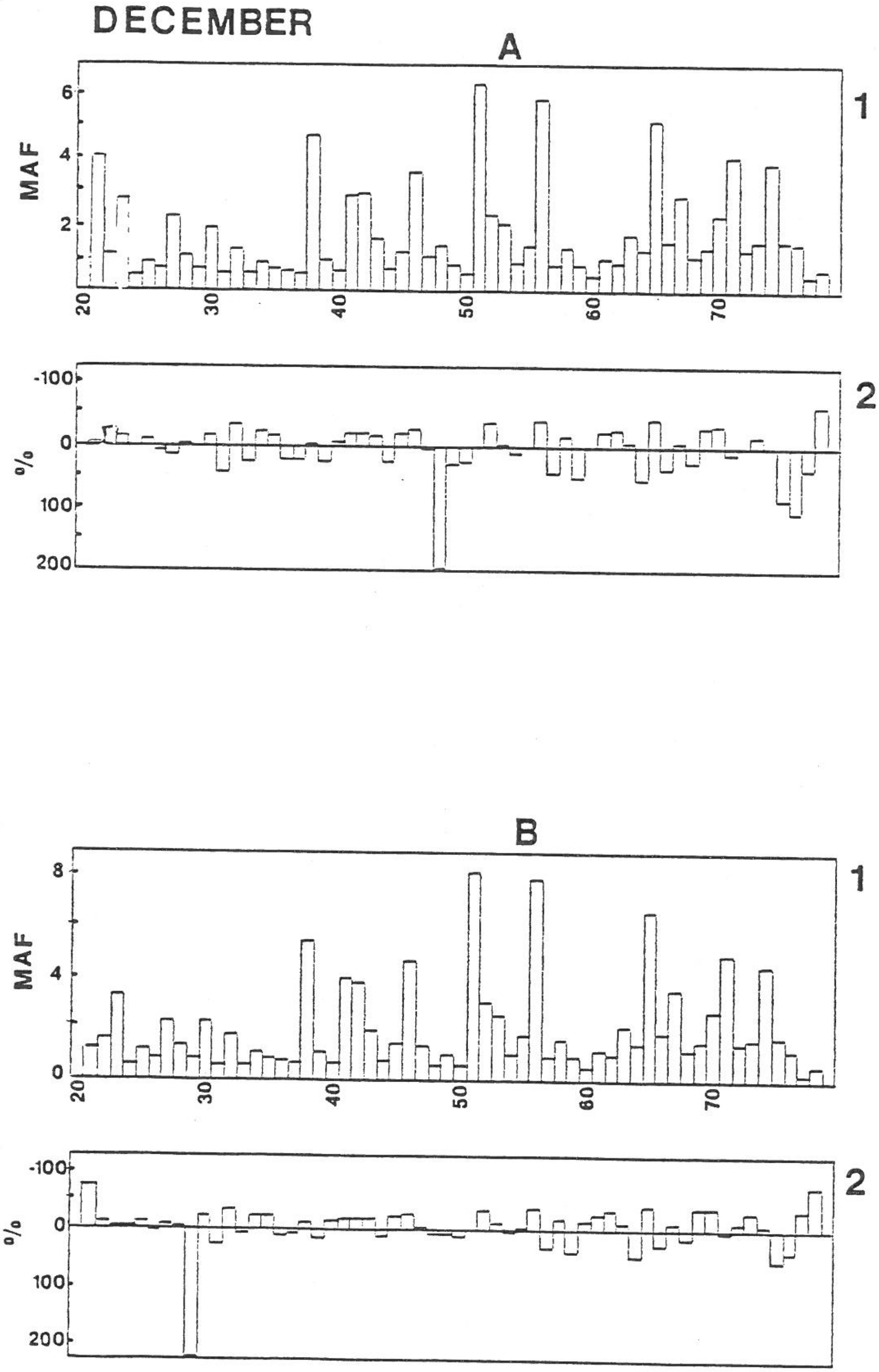
At the same time, the maximum total withdrawals of 2.5 MAF and 3.9 MAF occurred in February of 1982 and March of 1974, which corresponded to 33.3 and 45.9% from their NRI averages, or 34% and 46.4% from their NDO, respectively.

It should be noted that in the case of 1974 (one of the wettest years) NRI = 50.5 MAF; the preceding year was above normal, while annual runoff for 1982, 57 MAF, was one of the highest for the entire period of record); the preceding year was a typical lower than sub-normal one (60% of normal). However, if one analyzes the percentage of total monthly diversions typifying the sub-normal, dry and drought years like 1957, 1976 and 1977, the results may look much less optimistic.

The maximum of total diversions of 2.0 MAF (for 1944-78) in percentage occurred in February 1957 (year of sub-normal wetness). This volume corresponds to 59% of NRI and 61% of NDO for February. (NRI for the preceding December and January corresponded to the category of critical dry months with a recurrence interval of at least once in 8-12 years.)

The next highest percentage (65%) of diversion was documented for March 1977, although total volume was only 0.35 MAF.

It should be stressed that in this case, as for other similar cases, (January and February 1977), the diversion reduced RDO to such small values that probability of exceedance fell beyond the frequency curve for NDO. This may mean at least once in several hundred years RDO may be within the range of 0.2-0.3 MAF. Under these conditions the Bay and Delta were nearly out of water.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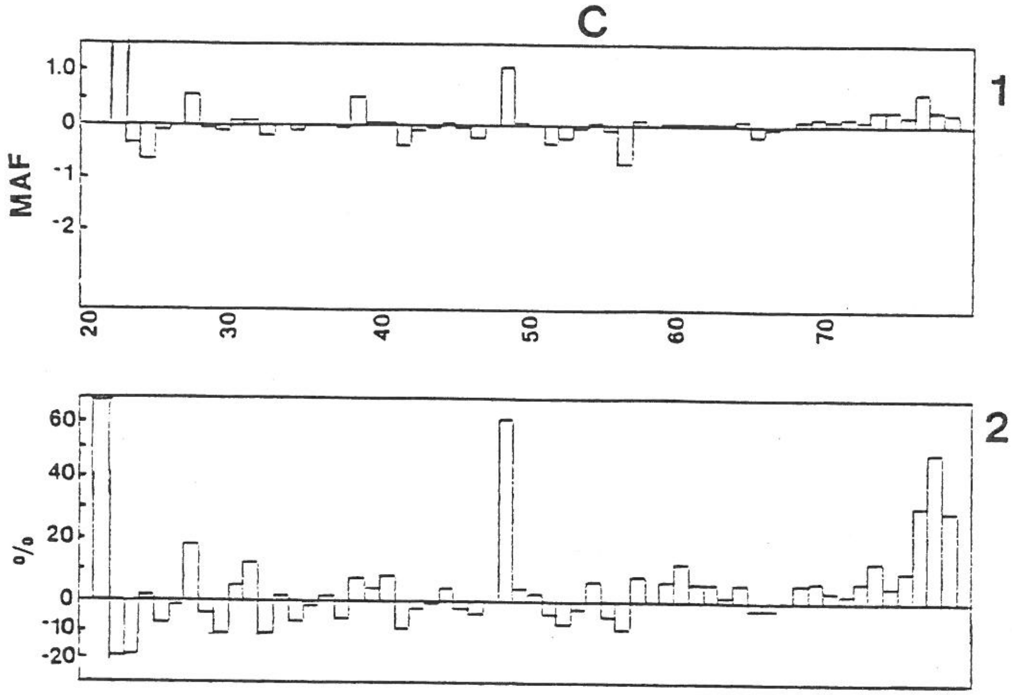


Fig.II.51 . (A,B,C)

A-1. Monthly Chronological Fluctuations of Regulated River Inflow (Qrri) to the Delta

-2. Percentage of Upstream Diversions

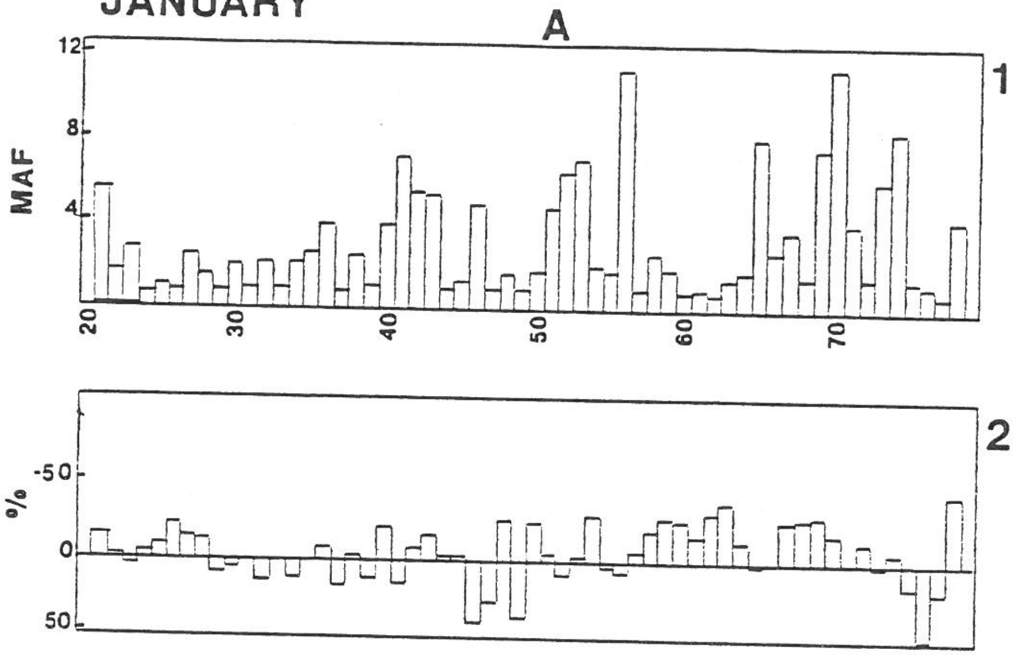
B-1. Monthly Chronological Fluctuations of Regulated Delta Outflow (Qrdo) to the San Francisco Bay

-2. Percentage of Downstream Diversions

C-1. Monthly Chronological Values of Inner Delta Diversions (Qrri-Qrdo)

-2. Inner Delta Diversions in Percentage of Regulated River Inflow.

JANUARY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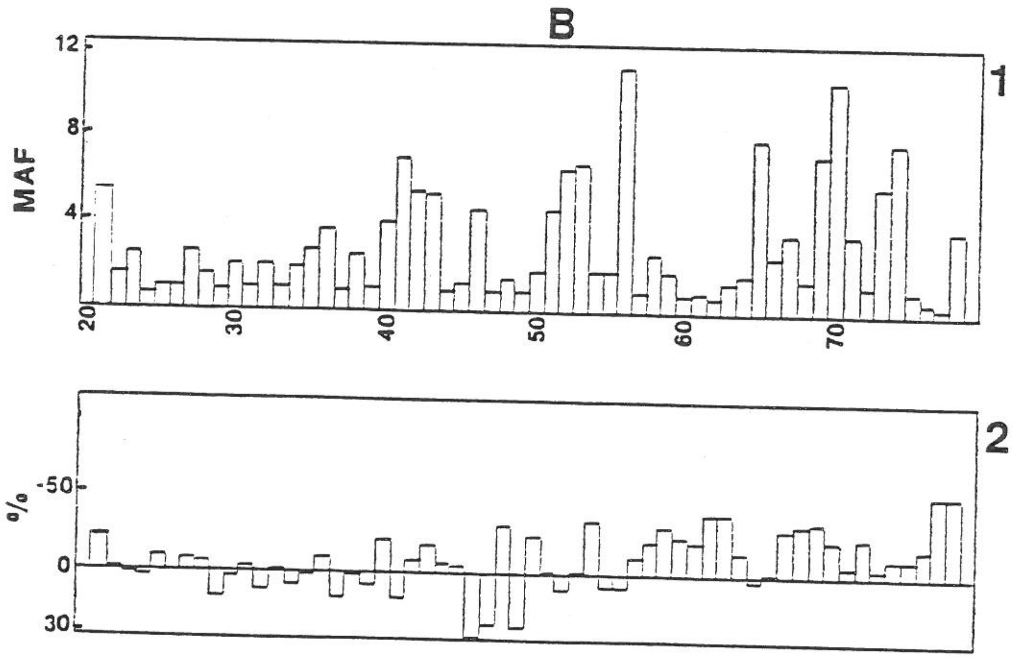
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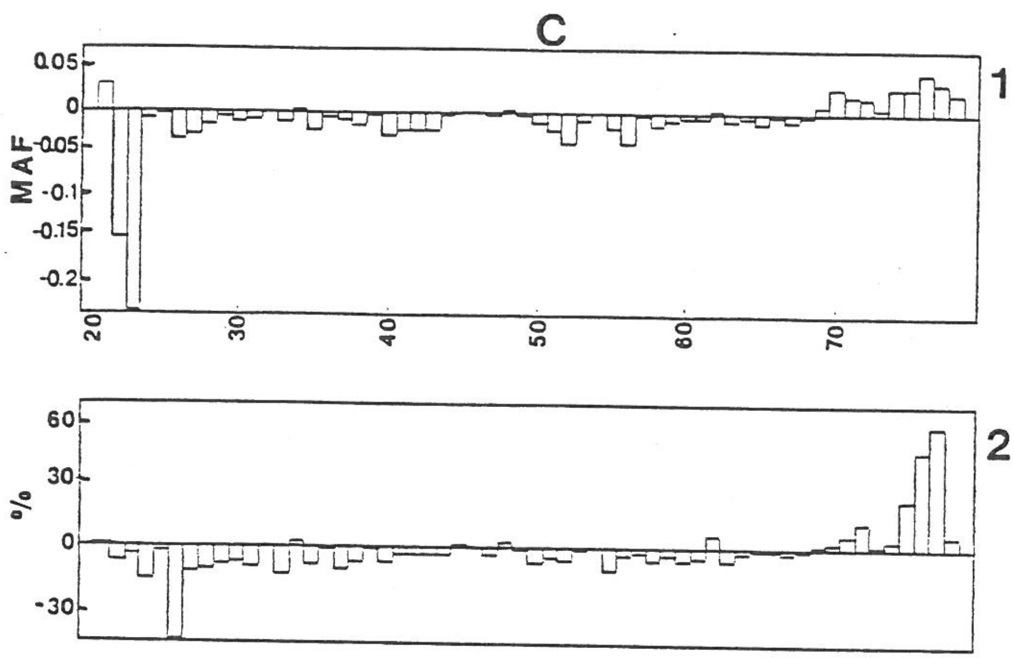


Fig.II.52 . (A,B,C)

A-1. Monthly Chronological Fluctuations of Regulated River Inflow (Qrri) to the Delta

-2. Percentage of Upstream Diversions

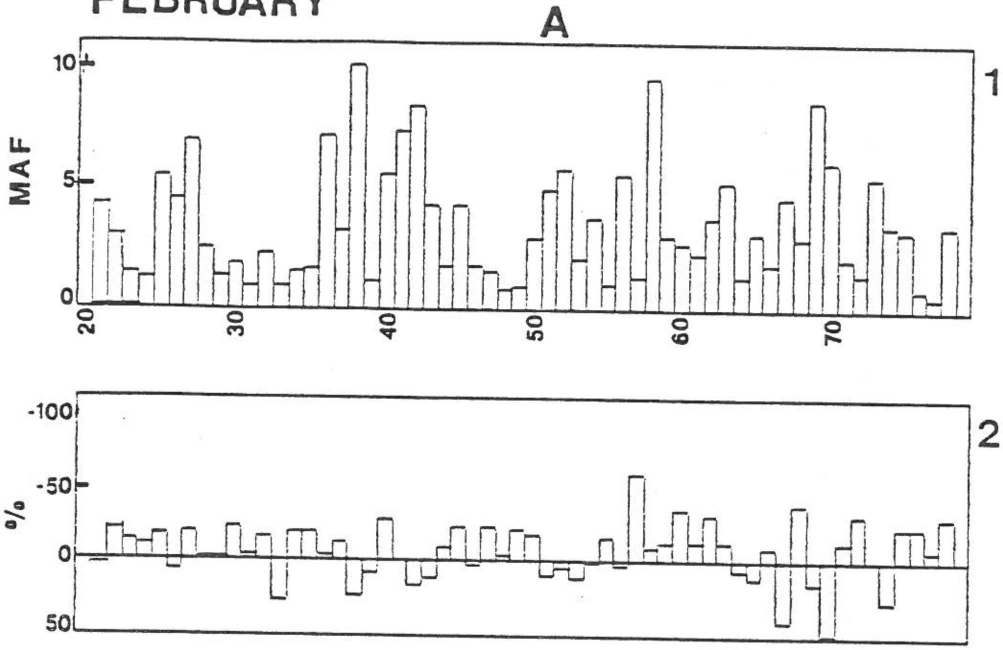
B-1. Monthly Chronological Fluctuations of Regulated Delta Outflow (Qrdo) to the San Francisco Bay

-2. Percentage of Downstream Diversions

C-1. Monthly Chronological Values of Inner Delta Diversions (Qrri-Qrdo)

-2. Inner Delta Diversions in Percentage of Regulated River Inflow.

FEBRUARY



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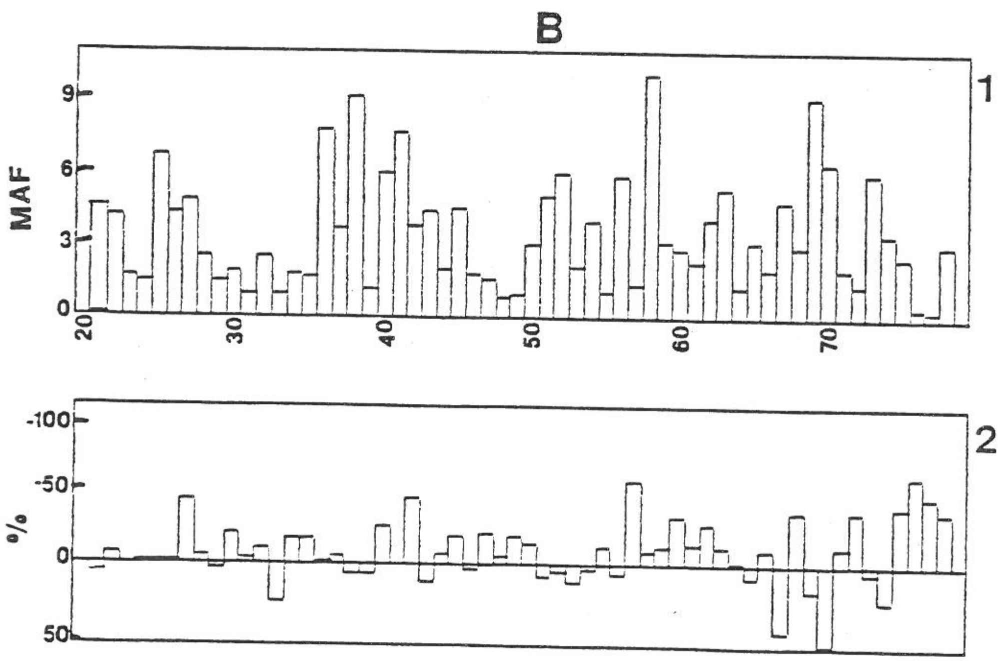

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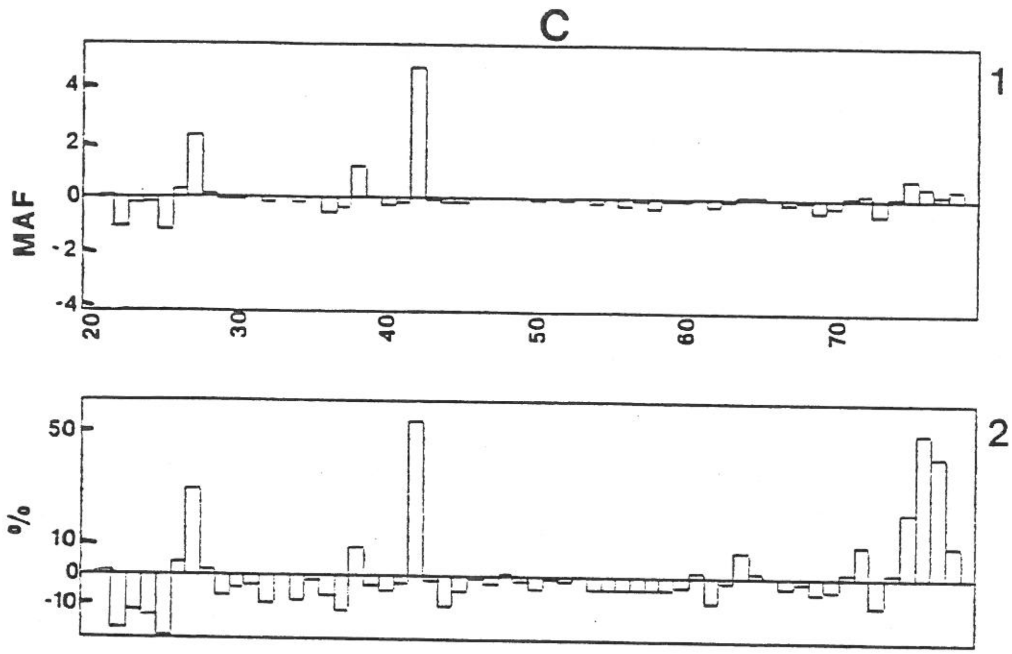


Fig.II.53 . (A,B,C)

A-1. Monthly Chronological Fluctuations of Regulated River Inflow (Qrri) to the Delta

-2. Percentage of Upstream Diversions

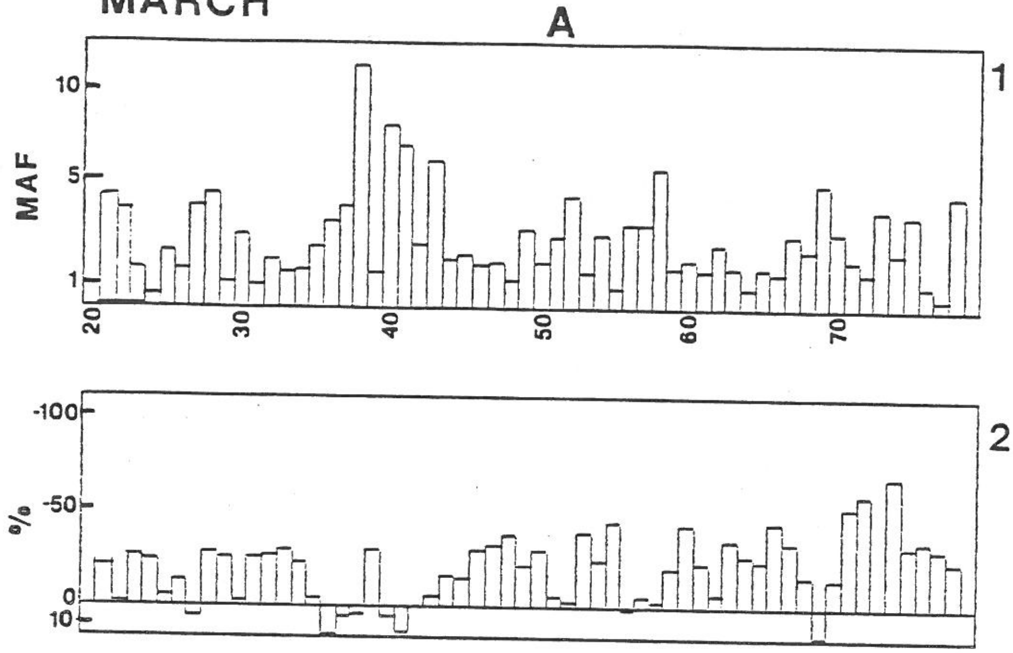
B-1. Monthly Chronological Fluctuations of Regulated Delta Outflow (Qrdo) to the San Francisco Bay

-2. Percentage of Downstream Diversions

C-1. Monthly Chronological Values of Inner Delta Diversions (Qrri-Qrdo)

-2. Inner Delta Diversions in Percentage of Regulated River Inflow.

MARCH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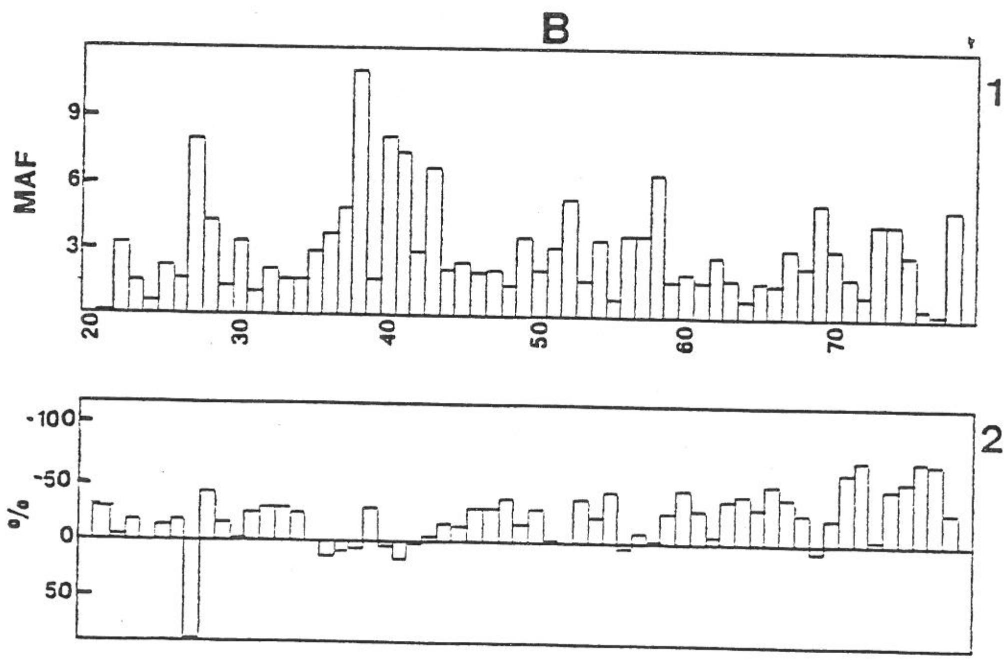
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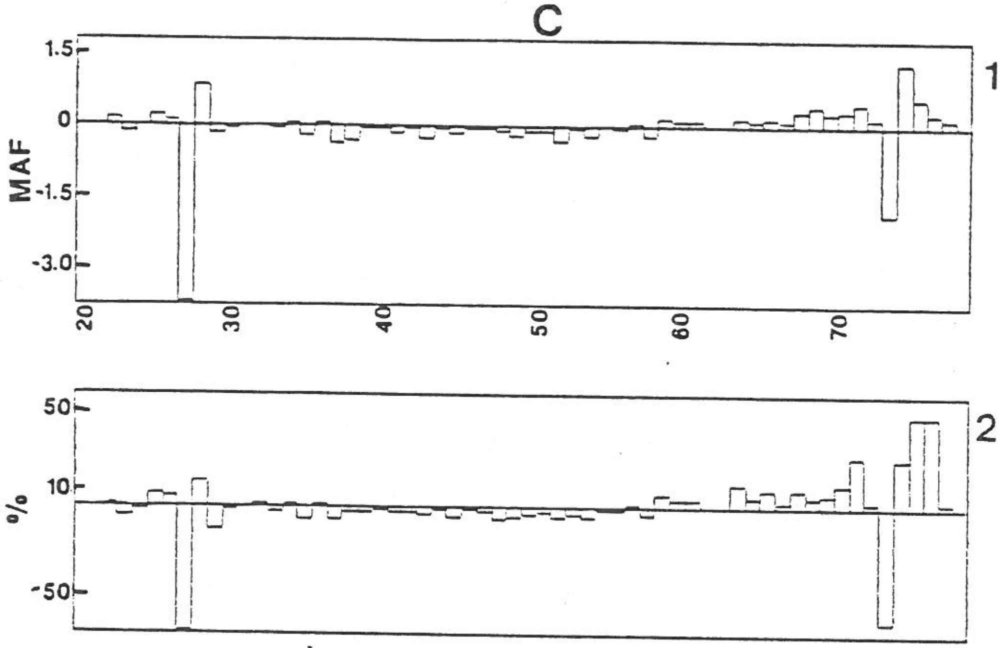


Fig.II.54 . (A,B,C)

A-1. Monthly Chronological Fluctuations of Regulated River Inflow (Qrri) to the Delta

-2. Percentage of Upstream Diversions

B-1. Monthly Chronological Fluctuations of Regulated Delta Outflow (Qrdo) to the San Francisco Bay

-2. Percentage of Downstream Diversions

C-1. Monthly Chronological Values of Inner Delta Diversions (Qrri-Qrdo)

-2. Inner Delta Diversions in Percentage of Regulated River Inflow.

The dynamics of water consumption for these months can be seen from Tables II. 36, 37.

Table II. 36 Upstream, Delta and total diversions (MAF) from the Sacramento-San Joaquin River Basin (February)

Years	Upstream	Delta	Total
1921-43	-4.2	-4.87	-9.07
1944-66	-8.1	+1.00	-7.1
1967-78	+0.2	-0.7	-0.5

Table II. 37 Upstream, Delta and total diversions (MAF) from the Sacramento-San Joaquin River Basin (March)

Years	Upstream	Delta	Total
1921-43	-3.7	+4.0	+0.5
1944-66	-15.2	+0.5	-14.7
1967-78	-17.3	-2.7	-20.0

The doubling of average upstream and total diversions for February 1944-66 compared to 1921-43 may be explained by the addition of new facilities of the SWP.

The peak of upstream, Delta and total average diversion was reached in March of the 1967-78 period, which is many times greater than for 1921-43.

II.2.6.2 Statistics of Spring Runoff and Diversions

Pre-Project Period, (1921-43)

During this period the percentage of diverted water for April, May and June varied within the predominant ranges of 10 to 35%, 20 to 40% and 25 to 45% respectively, and the ranges of their absolute values were 0.5-1.4 MAF, 0.7-1.9 MAF and 0.3 to 1.4 MAF respectively (Figs. II. 55-57).

In the majority of cases it appears that the amount of upstream diversions relied more upon entitlements for water than on water availability corresponding to the wetness of the year. This assumption is based on the fact that generally the amount of water diverted for each of the spring months, varied only ± 30% of the mean until the project operations began.

For example, in 1924 and 1931, two of the driest April months observed under natural conditions (recurrence of not less than once in 20-50 years; 95-98% probability of occurrence), diversions of 0.6 and 0.9 MAF corresponded to more than 50 and 64% of their natural monthly means of 1.2 and 1.4 MAF for those years.

It is assumed such levels of diversion might have a much greater impact on the intensity of salt intrusion into the Delta than diversions for April 1982 of almost 1.2 MAF, (38% of the mean; slightly higher than a month of sub-normal wetness, with a recurrence interval of at least once in three years).

The system experienced consistent losses in water supply during April of the pre-project period (Fig. II. 51) with the exception of 1928 and 1940, which were wet and preceded by a majority of years of high wetness.

The same regularities characterized May and June for the pre-project period.

For example, maximum diversions during May and June were 77% (1931) while their natural inflow was only 1.3 and 0.6 MAF respectively (probability of 95%, or recurrence of once in 20 years; see Figs. II. 52, 53 and Table II. 38).

It is important to emphasize that the residual inflows to the Delta for these examples of April, May and June were so low that they correspond to recurrence intervals under unimpaired conditions of at least once in 100 years which are very rare events for the natural combined inflow to the Delta. Their volumes were 2.5-10 times less than the volume of the Delta water body itself. It is likely that an essential part of this water was lost to evapotranspiration and other consumptive uses, especially for June, which had no net Delta outflow.

Spring

Post-Project Period

This period, especially since the late 1940's, was characterized by a steady increase in absolute values as well as percentage of diversions that ultimately led to significant reduction of NRI and NDO.

It is important to emphasize that the post-project period did not experience the same severe natural reduction of runoff as was the case in 1929-34 and had a relatively stable water supply to the system.

However, the steady development of major water storage facilities led to such growth of diversion of river inflow to the Delta that in many instances, the residual inflow for these months was almost equal to the runoff typical of sub-normal and critical dry periods observed during the pre-project conditions. May upstream diversions were much higher than those of April and June in absolute values and also more frequent (see Table II. 5 and Figs. II. 51-53).

The predominant range of diversions in April, May and June for this period was 40-55%, 55-65% and 45-60% respectively, but in absolute values they were 1.5-2.0 MAF, 1.6-3.0 MAF and 1.0-2.0 MAF respectively, or 1.3-2 times higher than for the pre-project conditions.

The lowest volumes of water diverted for these months (0.4-0.8 MAF) were observed in 1976 and 1977, but they corresponded to 45-54% of the unimpaired runoff which itself was critical low. For example, the runoff of April, May and June for 1976 corresponded approximately to recurrence intervals of at least once in 17, 13 and 20 years, and for 1977, once in 50, 50 and 20 years, respectively (Table II. 38).

The highest percentage of diversion was observed in April 1972-sub-normal wetness (69% of the natural river inflow of 2.9 MAF), and in May 1973-wet year (67% of 5.4 MAF).

In June of 1976, the increment of 0.063 MAF to the record low natural inflow of 0.64 MAF suggests that there was no water left to be discharged into the Delta and as such, this addition represents either a small release or reflects measurement error.

The steady increase of diversions during these months of spring in the post-project period reflects the fact that since 1966, coinciding with the overall decrease of wetness and therefore increase in years of sub-normal runoff (with the exception of the years 1967, 1969 and 1974, April), the residual inflow to the Delta-San Francisco Bay ecosystem corresponded to a low would-be natural inflow characterized by a recurrence interval not less than one time in 20-50 or even 100 years. However, for the same period the majority of values of natural inflow to the system corresponded to above normal and sub-normal years of wetness with a much higher recurrence interval (at least once in 2-4 years). Flow levels that were once rare events have become a common feature of the system.

This suggests that on an annual basis (as also will be shown for 5-year running means) the river-Delta-Bay environment currently has to cope with successive years of spring runoff which would be expected to occur only as very rare events under natural conditions.

For example, the extremely low natural inflow of 0.8 and 1.0 MAF for April and May 1977 was observed only once in the 58 year

Table II.38 Variables of the runoff probability of exceedance for spring runoff.

Probability of exceeding, %	1	5	10	25	50	75	90	95	99
Years of recurrence	100	20	10	4	2	4	10	20	100
Spring Natural River Inflow to the Delta (1921-1978)									
	7.97	6.53	5.83	3.80	3.58	2.55	1.70	1.25	0.40
Regulated River Inflow to the Delta (1921-1978)									
	6.73	5.11	4.29	3.12	2.03	1.15	0.52	0.23	0.25
Spring Natural Delta Outflow to the Bay (1921-1978)									
	7.90	6.46	5.78	4.63	3.48	2.40	1.58	1.08	0.25
Regulated Delta Outflow to the Bay (1922-1982)									
	6.50	4.88	4.12	2.96	1.86	0.95	0.29	0.04	0.60

period, but since 1966 under regulated conditions this value or even less was observed under regulated five times in April and six times in May. This would appear to be the result of diverting 50 to 77% of upstream water during these years.

Similarly, the lowest range of natural inflow for June (0.5-0.8 MAF) was observed five times in 58 years; however, for the period 1966-78, the same range was observed six times under regulated conditions.

Considering these thirteen years as well as the previous 46 (especially the period since the inception of project operations) the river system and the Delta were deprived of such large amounts of spring runoff (and chemical constituents carried by the water), it is not surprising that many changes have developed under the impact of this complex runoff transformation.

Table II. 39 Upstream, Delta and total diversions (MAF) from the Sacramento-San Joaquin River Basin (April)

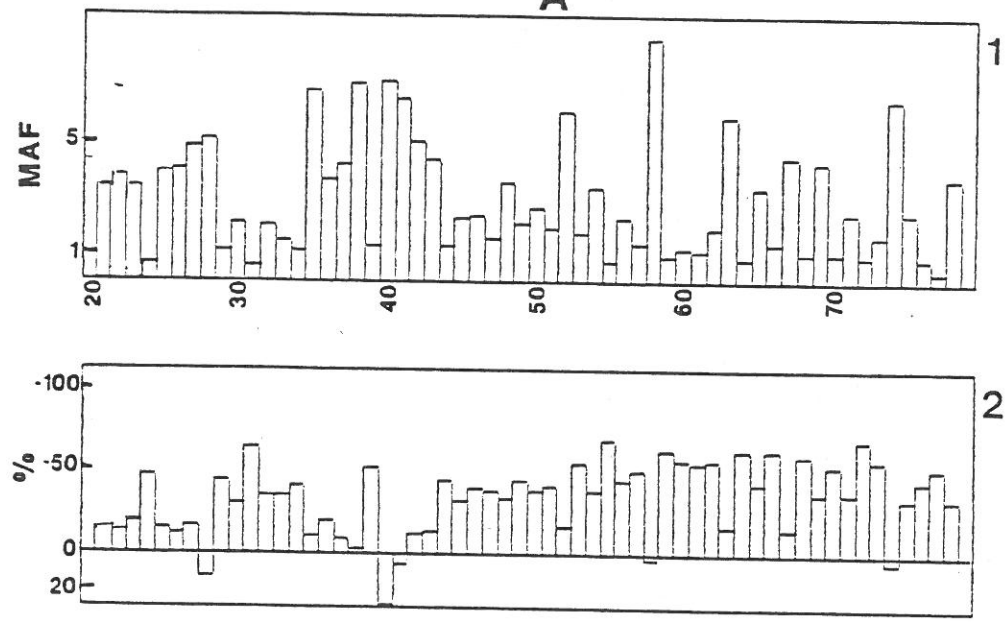
Years	Upstream	Delta	Total
1921-43	-11.4	-3.4	-14.8
1944-66	-37.0	-1.8	-38.5
1967-78	-16.2	-3.8	-20.0

Table II. 40 Upstream, Delta and total diversions (MAF) from the Sacramento-San Joaquin River Basin (May)

Years	Upstream	Delta	Total
1921-43	-27.1	-2.7	-29.1
1944-66	-43.6	-3.2	-46.5
1967-78	-39.2	-5.5	-37.6

APRIL

A


MAF
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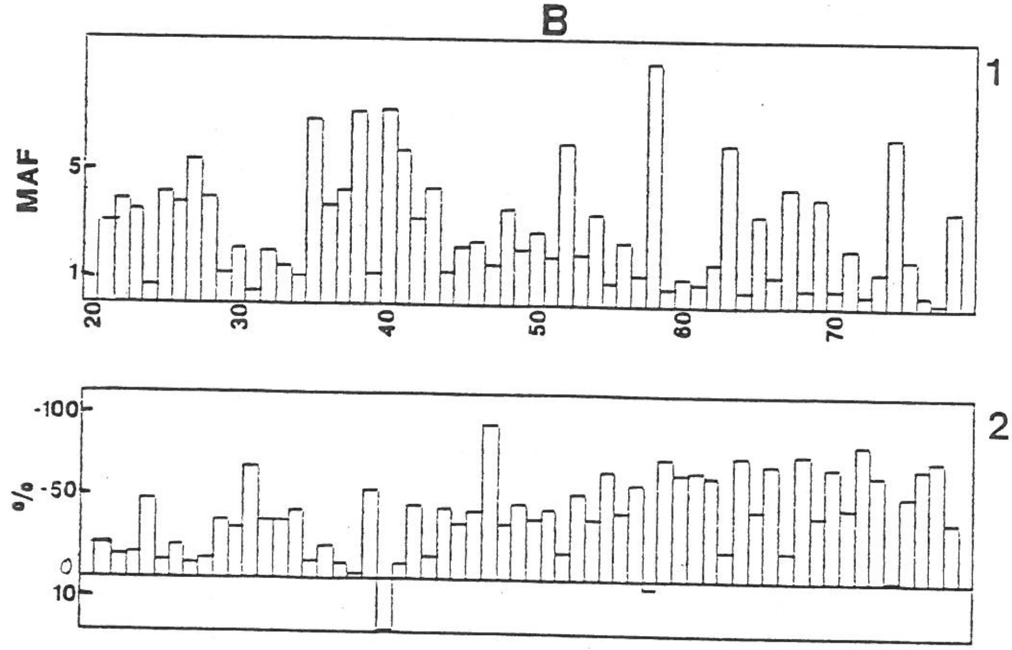
B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APR

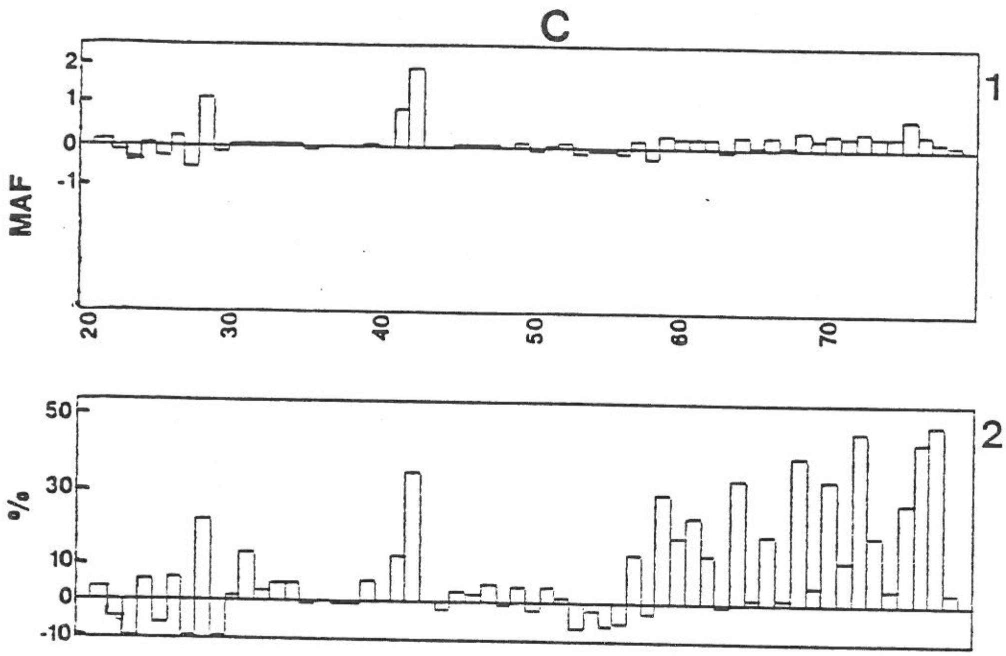


Fig. II.55 . (A,B,C)

A-1. Monthly Chronological Fluctuations of Regulated River Inflow (Qrri) to the Delta

-2. Percentage of Upstream Diversions

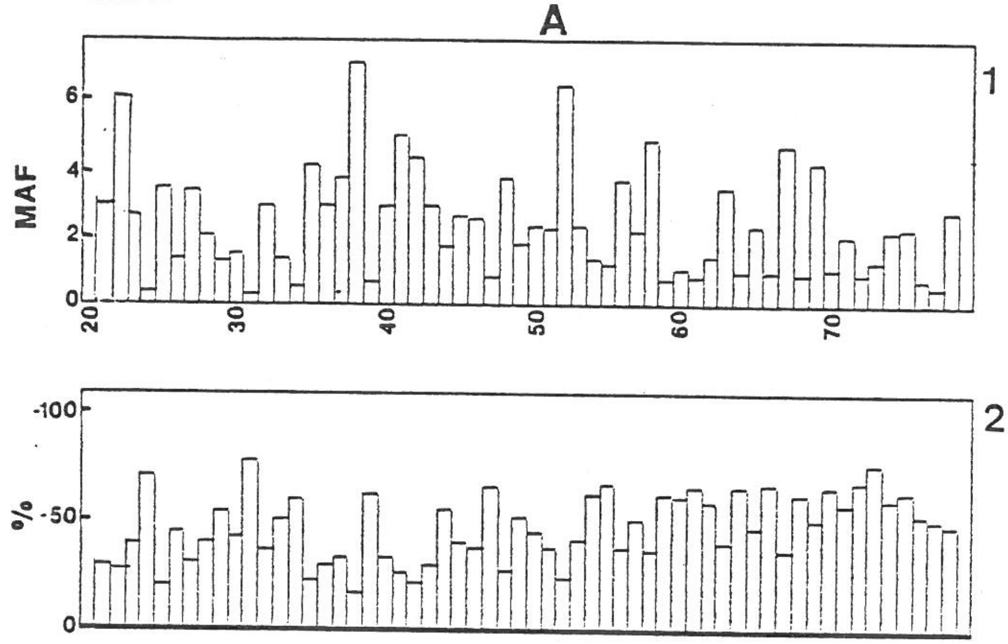
B-1. Monthly Chronological Fluctuations of Regulated Delta Outflow (Qrdo) to the San Francisco Bay

-2. Percentage of Downstream Diversions

C-1. Monthly Chronological Values of Inner Delta Diversions (Qrri–Qrdo)

-2. Inner Delta Diversions in Percentage of Regulated River Inflow.

MAY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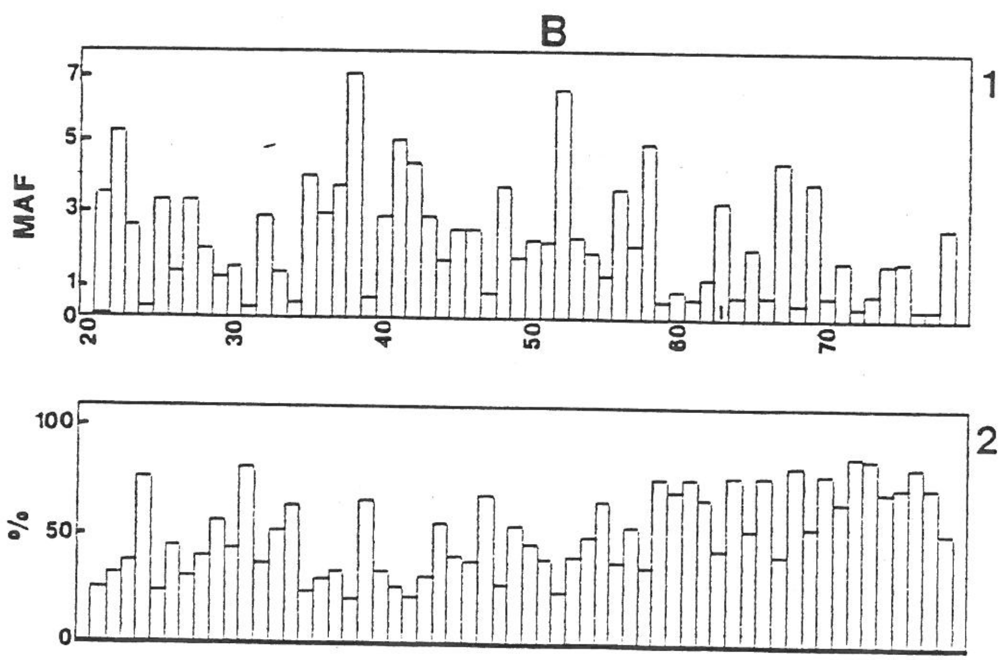
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MAY

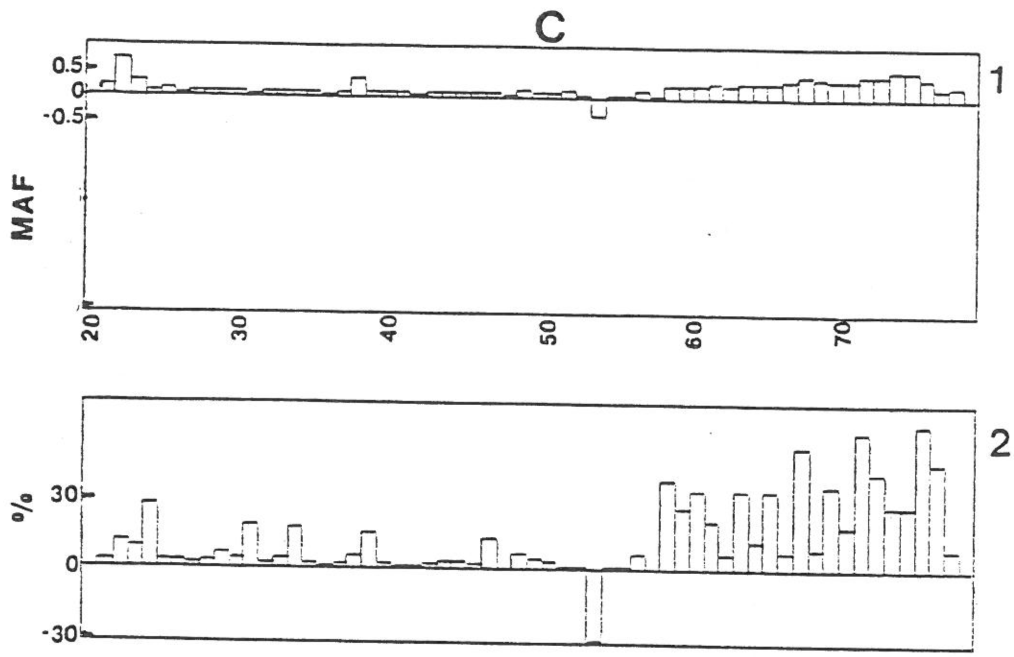


Fig. II.56 . (A,B,C)

A-1. Monthly Chronological Fluctuations of Regulated River Inflow (Qrri) to the Delta

-2. Percentage of Upstream Diversions

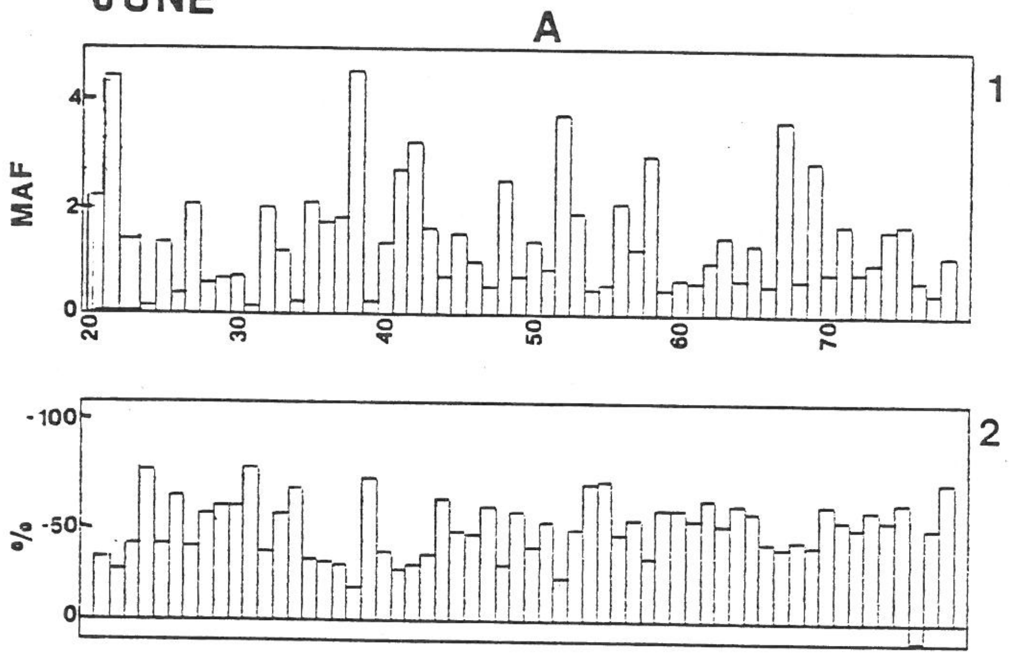
B-1. Monthly Chronological Fluctuations of Regulated Delta Outflow (Qrdo) to the San Francisco Bay

-2. Percentage of Downstream Diversions

C-1. Monthly Chronological Values of Inner Delta Diversions (Qrri-Qrdo)

-2. Inner Delta Diversions in Percentage of Regulated River Inflow.

JUNE



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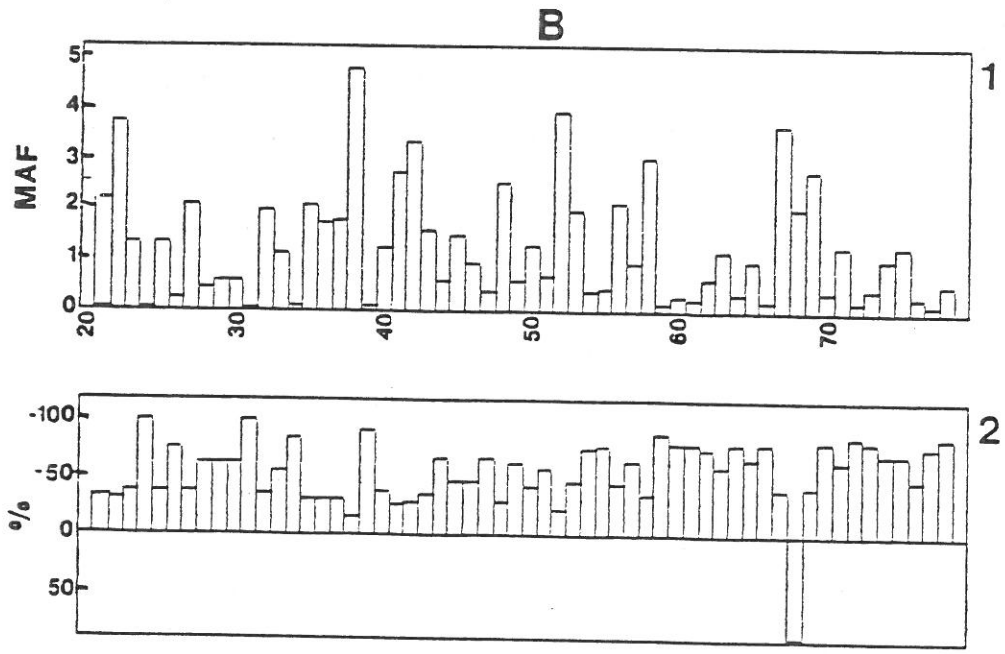

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JUN

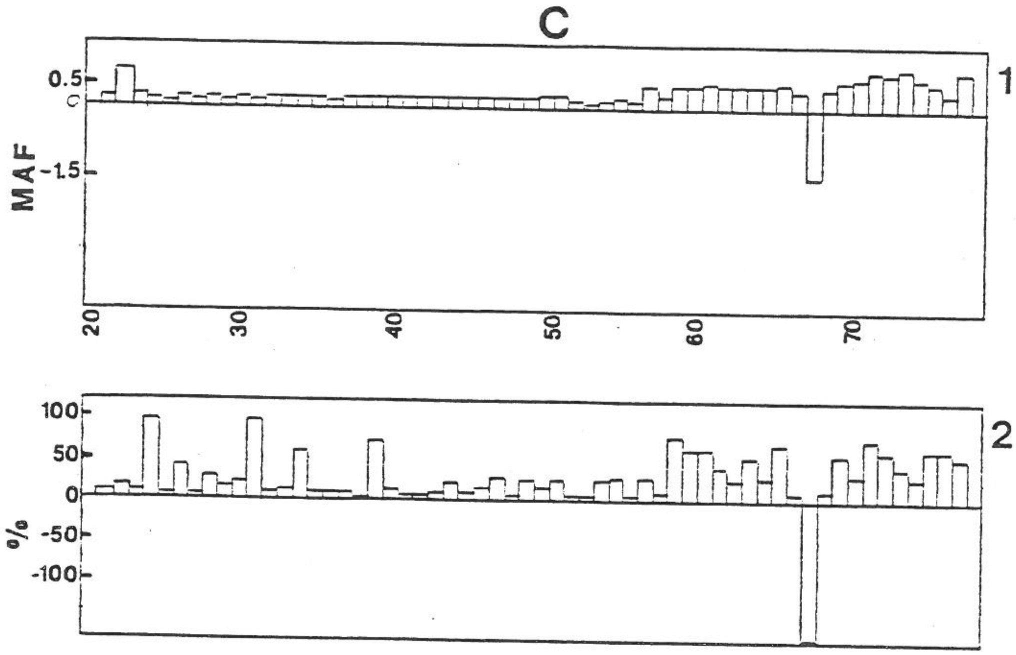


Fig.II.57 . (A,B,C)

A-1. Monthly Chronological Fluctuations of Regulated River Inflow (Qrri) to the Delta

-2. Percentage of Upstream Diversions

B-1. Monthly Chronological Fluctuations of Regulated Delta Outflow (Qrdo) to the San Francisco Bay

-2. Percentage of Downstream Diversions

C-1. Monthly Chronological Values of Inner Delta Diversions (Qrri-Qrdo)

-2. Inner Delta Diversions in Percentage of Regulated River Inflow.

Table II. 41 Upstream, Delta and total diversions (MAF) from the Sacramento-San Joaquin River Basin (June)

Years	Upstream	Delta	Total
1921-43	-18.5	-3.0	-21.5
1944-66	-25.7	-6.0	-33.7
1967-78	-16.0	-4.4	-23.4

Changes in runoff characteristics resulting from spring diversions discussed above are explained in Tables..... which demonstrate the pronounced increase in upstream, Delta and total diversion for the post-project period, the maximum of which occurred in the month of May.

The sum of the total spring average diversions corresponds to more than 55% of the annual water withdrawals.

The mean upstream water diversions for this period for the spring were 5.4 MAF, and this value is several times higher than the volume of the Delta and Suisun Bay together, and almost 2/3 of the San Francisco Bay under mean sea level.

In general, flow regulation diminished the spring monthly peak flows by nearly 50-85%.

II.2.6.3 Statistics of Summer Runoff and Diversions

July

Pre-project period (1921-43)

The predominant range of upstream diversions (% of NRI) was 45-60% with a maximum of 100% (in 1924, 1926, 1929, 1931, 1934 -- critical dry or sub-normal years) which means there was no water to be discharged to the Delta (Fig. II. 58). Salt intrusion into the Delta was pronounced at this time and exacerbated by the low RRI during the spring). Although the range of upstream diversions in absolute values was relatively small, 0.3-0.6 MAF, relative to spring monthly flows, these values were almost the same as the volumes of the average regulated river inflow to the Delta.

During the period 1921-43, the predominant range of combined upstream and Delta (downstream) diversions (RRI-RDO x 100%) was RRI as high as 65-90%, and in many cases, the San Francisco Bay ecosystem did not receive any water from the Delta, especially in critical dry years. Such critical dry periods had a very low frequency of occurrence and were observed in such succession for unimpaired runoff, only once between 1921 and 1984. On the other hand, when water regulation coincided with sub-normal and critical dry months and years, the recurrence of critically dry years increased 3-4 times in comparison with the natural river inflow fluctuations for the same period. This became a new feature of July runoff fluctuations.

The maximum total diversion was observed in July 1942 (1.0 MAF). The predominant range was 0.6-0.9 MAF with an overall trend showing a steady increase of upstream and downstream diversion during this summer month (Fig. II. 58).

July

Post-Project Period (1944-78)

The typical feature of July during this period is the increase of Delta diversion 2-4 and even more times in comparison with the pre-project period, though in some cases, the full scale of diversion was masked by returning water discharges.

At the same time, the predominant range of upstream diversion reduced several times due to returning water discharges (or releases from storage facilities).

Between 1944-59 the predominant range of upstream diversion was 0.2-0.4 MAF, with the gradual increases up to 0.6-0.9 in 1953-59. After this period, there were many cases of significant water releases, maximum of 0.35 (1976).

The highest levels of upstream water for this month were diverted in 1952 and 1967, 1.0 and 1.2 MAF respectively, (Fig. II. 8A, Tables II. 5, 8, 42; it should be noted that the preceding months and years correspond to the wettest category).

Since that time, there have been no diversions documented higher than 0.85 MAF (1978) and 0.83 (1983, critical wet year).

For this period, and with rare exceptions, the predominant range of upstream diversions was 40-50%, with a maximum in 1944 of 74% (which corresponds to only 0.7 MAF).

As a rule, for some of the sub-normal and dry years, there have been additional releases, the highest of which were 0.4 MAF (1976) and 0.53 (1981).

Between 1944-56 the predominant range of the inner Delta diversion was 0.2-0.3 MAF. Since that time, there has been a steady increase. The highest diversions, 0.9 MAF, occurred in 1974 (wet year) -- which constituted 61% of RRI -- and 1984, 0.85 MAF -- which corresponded to 58% of RRI (Tables II. 6, 9, 42).

The predominant range of inner Delta diversion between 1968-

84 was 0.6-0.7 MAF, and the range of percentage of diversion was 45-60% (% of RRI).

This level of inner Delta diversion results in sharp reduction of RDO to the Bay for low wetness months.

The maximum total diversions in absolute values took place in 1952 (1.3 MAF, or 49% of NDO), and 1967, 1.5 MAF (47% of NDO), and the last peak of total diversions, after two drought years in 1978, was 1.6 MAF (85% of NDO). The lowest value of water diverted for this period was 0.18 MAF observed in 1976 and 1977; at the same time there were additional releases from storages between 0.14 and 0.35 MAF. The relative range of inner Delta diversions of 45-70% dominated for more than forty years (Tables II. 7, 10, 42).

August

Pre-Project Period (1921-43)

The predominant range of upstream diversions in percentage during this period was 50-65%, with a maximum of 65-86% during the same years as for July (Fig. II. 59A). The river inflow at that time did not reflect any noticeable inflow from storage releases or returning water because, as was said before, there were not significant storage or drainage facilities to provide a water surplus.

The range of upstream water withdrawals in absolute values was 1.8-2 times less than that observed for July during the same period of time.

Minimal upstream diversion was typical for one of the driest periods, 1929-34, and the highest volume, 0.4 MAF, was diverted in 1942 when the NRI runoff for August would be in the "wettest" runoff category.

Combined upstream and downstream diversion reached its peak in 1942 (wet year) and was equal to 0.61 MAF (preceding July was wet). The minimum of 0.3 MAF was taken during July of 1931 (critical dry year) (Table II. 7).

Because of upstream diversions superimposed, in many instances on low NRI, there have been nine cases out of twenty-two years when there was no RDO.

As in July, with the exception of the critical dry years, there were steady increases in upstream and downstream diversions (Fig. II. 59) from 0.3 up to 0.6 MAF at the end of this period. However, in general they were 1.5-30 times less than the increases observed for July during this period.

August

Post-Project Period (1944-78)

The first year of this period was the last one with a major diversion (50.1%). After that, with the exception of the early 1950's, the amount of returning and released storage water masked entirely the water withdrawals from the upper part of the basin (which can be seen from Fig. II. 59). The cumulative gains in water supply due to water releases of different origin reached their maximum of 0.82 MAF in 1974, with a predominant range of water "surplus" of 0.3-0.5 MAF. (In the discussion of late summer and fall surpluses, the possibility that they contain pollutants in returning waters from agricultural fields should be taken into consideration. Such a "surplus" may require a dozen times that volume of water to dilute, disperse, and flush them to the ocean, and therefore this "surplus" may only exacerbate water quality conditions of the Delta.)

Such low levels of upstream diversion (Fig. II. 59A, Table II. 5) were observed during the wettest years of 1958, 1965 and 1967 (0.03-0.09 MAF) as well as in the driest year of 1977 (0.13 MAF).

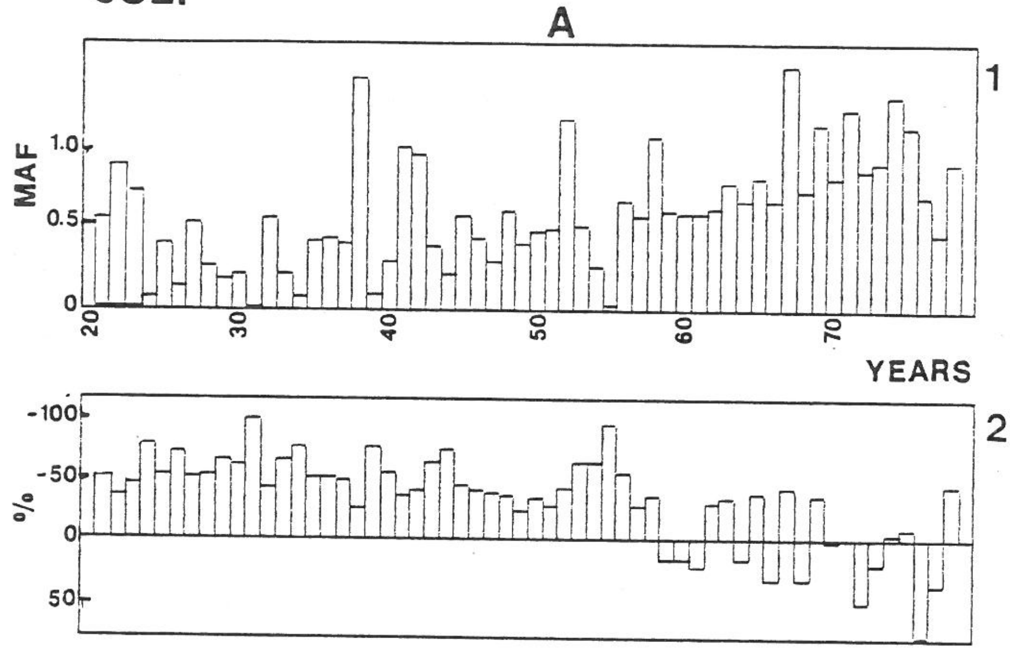
For this period the percentage, increment in relation to natural river inflow, had a prevailing range for this period between 60% and 100%, with a maximum in 1972 of 126%, which corresponded to 0.6 MAF, or 1.5 times higher than NRI observed during this time.

Therefore, the post-project period for August was characterized by an increase of water supply to the system, in some cases more than twofold. As a result, the runoff variables for this month were greatly increased compared to the would-be NRI for this month. The August NRI frequency curve cannot be of use in the evaluation of probability of exceedance because of the artificially-high values of RRI. The only similarity between this curve and that of regulated river inflow is the frequency of occurrence of runoff of very low values.

This infers that when NRI corresponds to a probability of 85-99%, there are no strong upstream diversions, and therefore there will be a low probability of incoming late summer agricultural return waters. The low values of NRI and RRI for this range of probability are almost equal. This is especially true when the year itself and the preceding June or July correspond to the category of sub-normal or critical dry.

In addition, the summer modification of runoff and water use can be seen from Tables II. 42, 43.

JULY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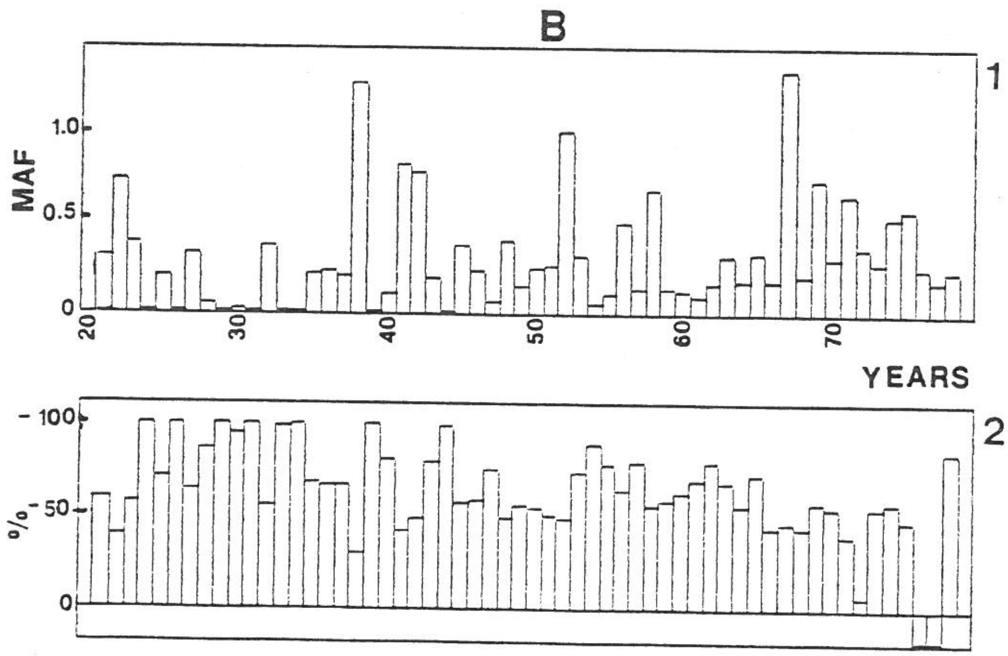
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JUL

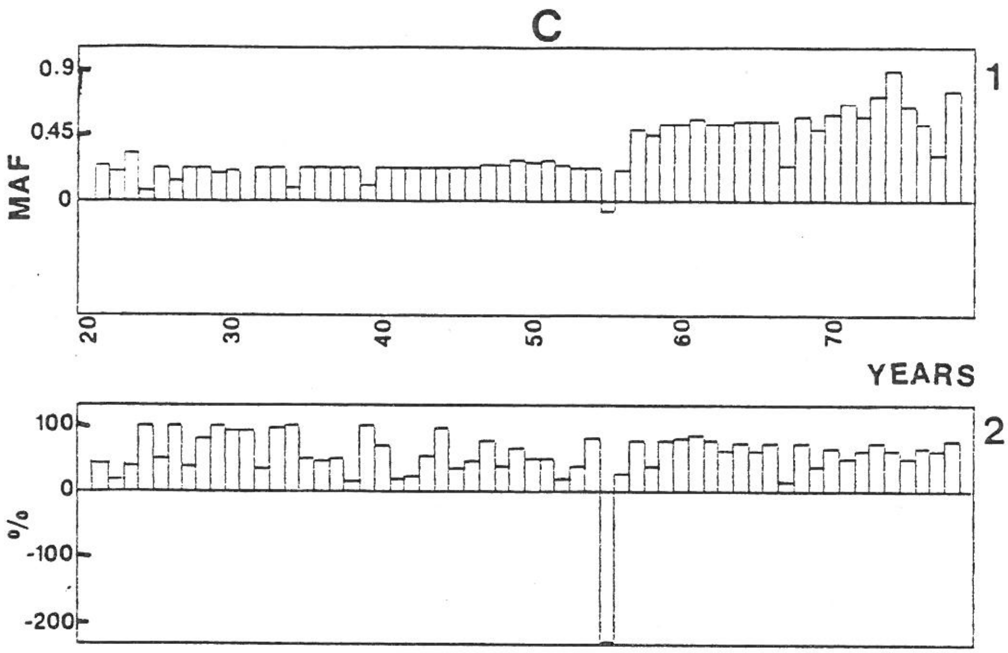


Fig.II.58 . (A,B,C)

A-1. Monthly Chronological Fluctuations of Regulated River Inflow (Qrri) to the Delta

-2. Percentage of Upstream Diversions

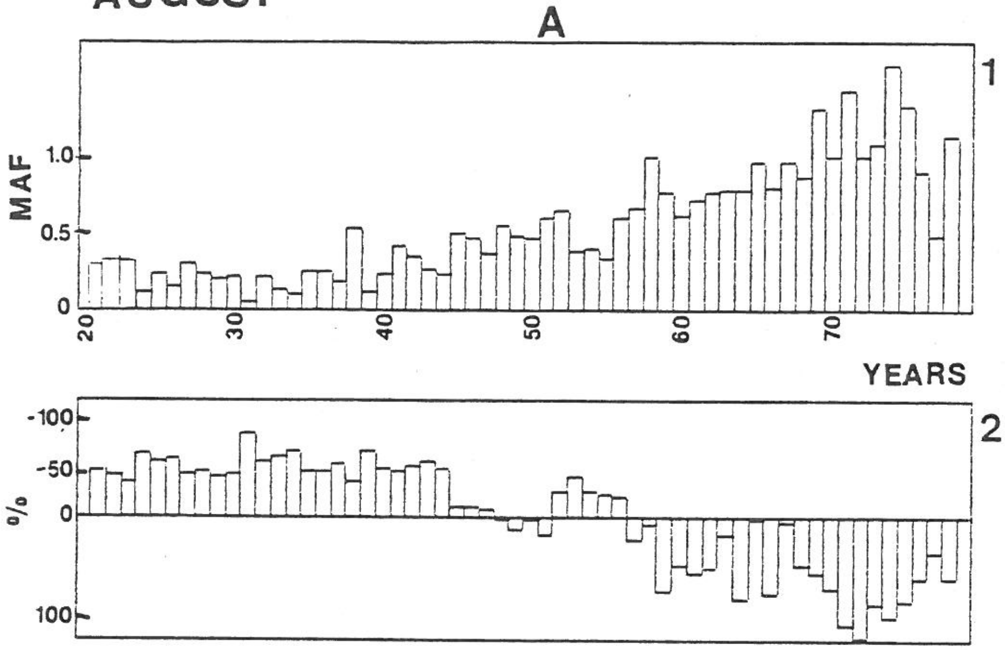
B-1. Monthly Chronological Fluctuations of Regulated Delta Outflow (Qrdo) to the San Francisco Bay

-2. Percentage of Downstream Diversions

C-1. Monthly Chronological Values of Inner Delta Diversions (Qrri-Qrdo)

-2. Inner Delta Diversions in Percentage of Regulated River Inflow.

AUGUST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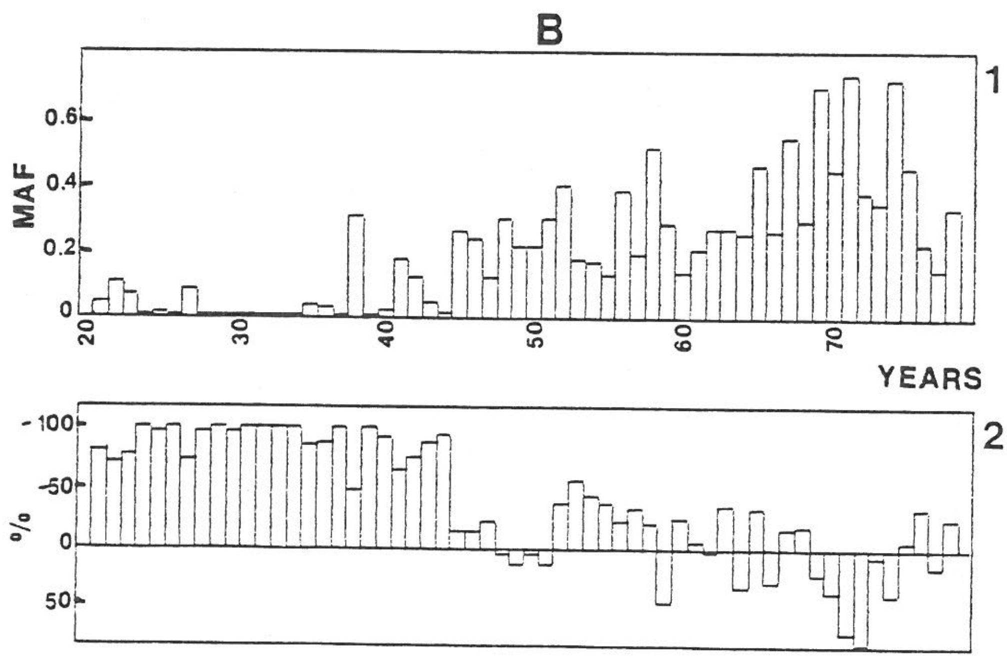
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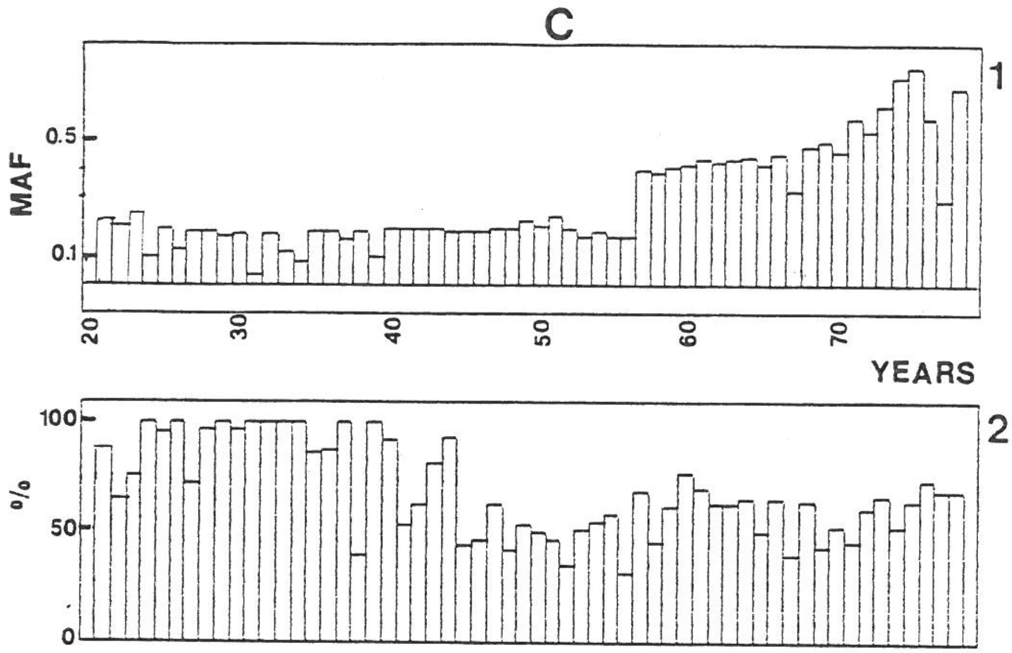


Fig.II.59 . (A,B,C)

A-1. Monthly Chronological Fluctuations of Regulated River Inflow (Qrri) to the Delta

-2. Percentage of Upstream Diversions

B-1. Monthly Chronological Fluctuations of Regulated Delta Outflow (Qrdo) to the San Francisco Bay

-2. Percentage of Downstream Diversions

C-1. Monthly Chronological Values of Inner Delta Diversions (Qrri-Qrdo)

-2. Inner Delta Diversions in Percentage of Regulated River Inflow.

Table II. 42 Upstream, Delta and total diversions (MAF) from the Sacramento-San Joaquin River Basin (July)

Years	Upstream	Delta	Total
1921-43	-10.0	-3.8	-13.8
1944-66	-8.6	-8.1	-16.7
1967-78	-2.0	-8.0	-10.0

Table II. 43 Upstream, Delta and total diversions (MAF) from the Sacramento-San Joaquin River Basin (August)

Years	Upstream	Delta	Total
1921-43	-5.4	-3.8	-9.2
1944-66	+0.6	-7.1	-6.5
1967-78	+6.6	-8.6	-2.0

As already mentioned, the returning water discharges masked and reduced the value of upstream diversions for July, and provided surplus for August.

This resulted in almost doubling Delta diversions, while average total losses in water supply to the San Francisco Bay were reduced, especially for August of the 1967-78 period. The cumulative significance of these changes will be discussed later.

II.2.6.4 Statistics of Autumn Runoff and Diversions

Autumn

Pre-Project Period (1921-43)

The predominant value of upstream diversions (Fig. II. 60A) for September had a relatively small range of 0.04-0.07 MAF, but the Delta diversion was slightly higher, 0.14-0.16 MAF. Meanwhile, for the critical dry years of 1924 and 1931, these diversions accounted for 84 and 79% of the RRI and the total diversion from the basin accounted for 77 and 63% (or 0.23-0.26 MAF).

The upstream diversions during October (Fig. II. 61A) were negligible and the majority of cases illustrate some additional water surplus, but at the same time, the predominant range of the inner Delta consumption was 0.08-0.12 MAF.

In percentage, the maximum of upstream and total diversion was about 20 and 40% respectively in 1942, and a maximum of 42% of inner Delta diversions (0.12 MAF from the RRI).

For November (Fig. II. 62A), there have not been noticeable upstream diversions (except 1927 - wet year), but on the contrary, some small releases prevailed depending upon years of wetness.

In 1927, the upstream losses which followed the months of sub-normal wetness (1926) reached more than 50% of 2. 3 MAF, but in the Delta area there was an essential surplus in water (almost 1.0 MAF) which constituted more than 70% of RRI, and there were no total losses in the system RDO>NDO.

However, in 1938, (the wettest year), the water consumption in the Delta was the highest for the pre-project period (0.42 MAF), although with a small excess of water in the upper part of the basin, and the total water losses in the system were one of the lowest (3.6%) for this period.

Post-Project Period (1944-78)

September

As was said above, the returning waters and some storage releases radically changed not only runoff patterns, but also the volumes of water diverted from the inner Delta.

From 1945 to 1978, with no exceptions, the RRI was higher than the NRI, and this difference increased almost gradually with a maximum of water surplus observed in 1974 of 1.13 MAF (which corresponds to a 96% increase of NRI for this month, 0.6 MAF), although for the critical dry year of 1977, there was no surplus at all.

The post-project maximum range in percentage that characterized this surplus was 40-200% (Fig. II. 60B, Table II. 9) Due to this water increment, the consumptive use of inner Delta water increased in comparison with the pre-project conditions, for some years more than four times, with a gradual increase during 1945-78 from 0.15 up to 0.7 MAF (for 1975 it corresponds to 48% of the regulated river inflow). Practically, this process can be described based on the data available in the following manner: First, water coming from the river basin to the Delta (RRI) was higher in volume (with the exception of 1977) than the NRI. Then, in the Delta, about 25-35% (predominant range) was consumed and the rest was discharged to the Bay. The residual RDO flow is still higher than the NDO heading to the Bay.

It should be noted that the highest artificial surplus in RDO was more or less typical for the years characterized with the highest NRI and NDO.

October

In general, the same features were typical for this month, although the scale of positive differences between RRI and NRI, and RDO and NDO were slightly smaller.

The absolute maximum of water diverted from the Delta of 0.7 MAF was observed in 1976 (or 46.3% of the RRI). But in the critical dry year of 1977, the percentage of inner diversion was 60% but corresponded to only 0.35 MAF (Fig. II. 61, Tables II. 5-10).

In this case, as in September, the amount of Delta outflow emptying into the Bay corresponded to values of would-be wet Octobers of NDO. Its probability of exceedance is 5-25% (recurrence once in 20-4 years). Therefore, since 1968 the final amount of RDO discharged to the Bay has been 1.5-2 times higher than NDO (with the exception of 1969 and 1977).

November

As it should be expected in November, when the amount of rain increases and consumptive use decreases, the relationship between the regulated runoff characteristics and the would-be natural are in most cases different from those observed for September and October.

For this period, we observe an alternation of significant surplus and upstream water diversion which may have a different impact on the Delta outflow because it took place over a succession of years of different wetness. The common feature in this case is that the highest diversion took place when NRI was in wet, above the normal or normal categories of wetness, and correspondingly, the lowest diversions, or even releases, took place when the NRI would be characterized as sub-normal or critical dry for this month. For example, in 1951, when the NRI of more than 6.0 MAF was as much as 5.3 times normal, the upstream diversion was 1.9 MAF (31%). However, when the second maximum occurred in 1981-82 (5.3 MAF, 1% probability of exceedance, at least once in 100 years), the projects upstream diversion was 3.0 MAF (57% of NRI). (The preceding months and 1981 are characterized by lower than sub-normal wetness and total withdrawals of about 3.2 MAF (60% of NDO.)

However, for the critical dry year of 1977, the upstream diversion was relatively low, only 0.085 MAF (19.1% of the NRI), while the inner Delta losses were equal to 0.14 MAF which constitute 40% of the RRI, and the total diversions accounted for more than 48% (0.23 MAF). In this case, as in 1978 when the total diversions were more than 58%, the Delta was practically deprived of water. During this month, the discharges of RDO constituted no more than 1/6 of the Delta volume (Fig. II. 62, Tables II. 5-10).

The changes brought about by returning water discharges during autumn can be seen from Tables II. 44-46.

Table II. 44 Upstream, Delta and total diversions (MAF) from the Sacramento-San Joaquin River Basin (September)

Years	Upstream	Delta	Total
1921-43	-1.0	-2.9	-3.9
1944-66	+5.5	-5.0	-0.5
1967-78	+7.7	-4.2	-3.5

Table II. 45 Upstream, Delta and total diversions (MAF) from the Sacramento-San Joaquin River Basin (October)

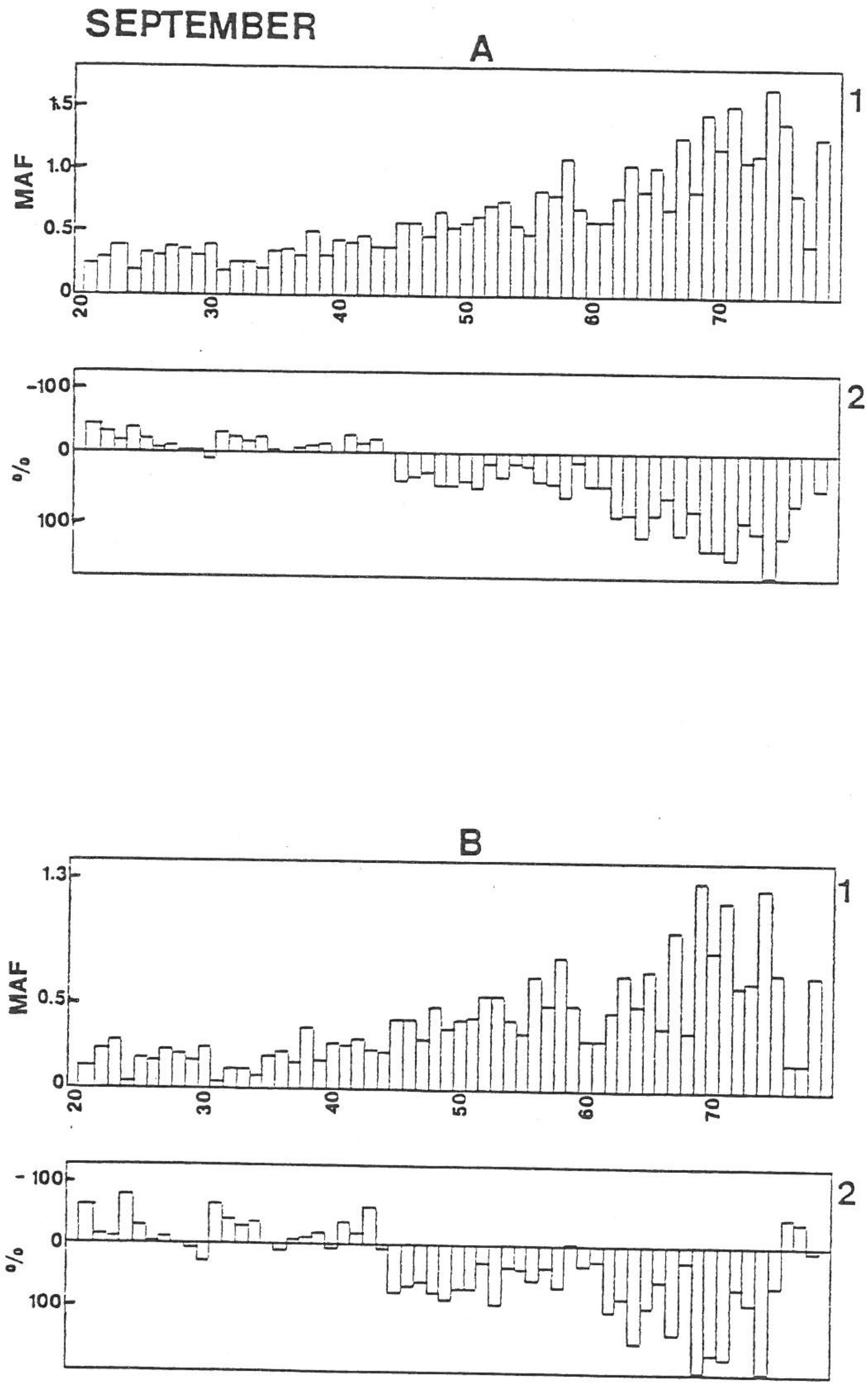
Years	Upstream	Delta	Total
1921-43	+0.82	-2.2	-1.3
1944-66	+2.9	-3.4	-0.5
1967-78	+5.1	-4.1	+1.0

Table II. 46 Upstream, Delta and total diversions (MAF) from the Sacramento-San Joaquin River Basin (November)

Years	Upstream	Delta	Total
1921-43	-1.10	-0.20	-1.30
1944-66	+1.1	-1.1	-2.3
1967-78	-1.0	-1.8	-2.8

The typical feature for September and October of the 1944-66 and 1967-78 periods was the strong increase in upstream water surplus, and owing to this development, overall reduction of total diversion.

<u>November</u> water losses demonstrated neither very strong increases of water diversions nor gains due to releases for the 1944-66 and 1967-78 periods, though both showed the growth of Delta and total losses in comparison with 1921-43.



SEPTEMBER
A
1
MAF
1.5
1.0
0.5
0
20
30
40
50
60
70
2
-100
0
%
100
B
1
MAF
1.3
0.5
0
20
30
40
50
60
70
2
- 100
0
%
100

SEP

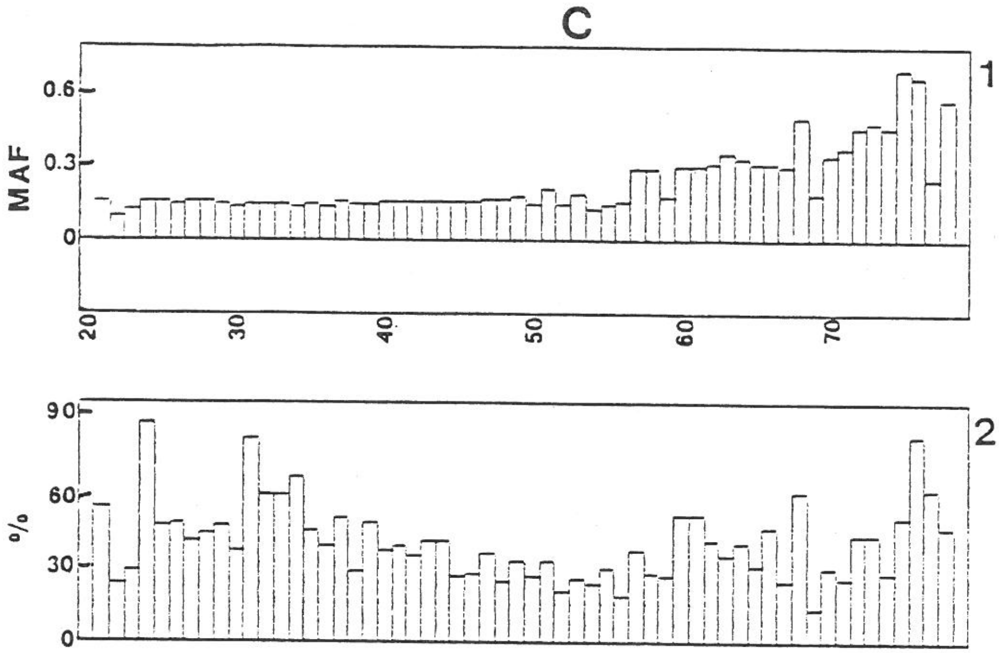


Fig.II.60 . (A,B,C)

A-1. Monthly Chronological Fluctuations of Regulated River Inflow (Qrri) to the Delta

-2. Percentage of Upstream Diversions

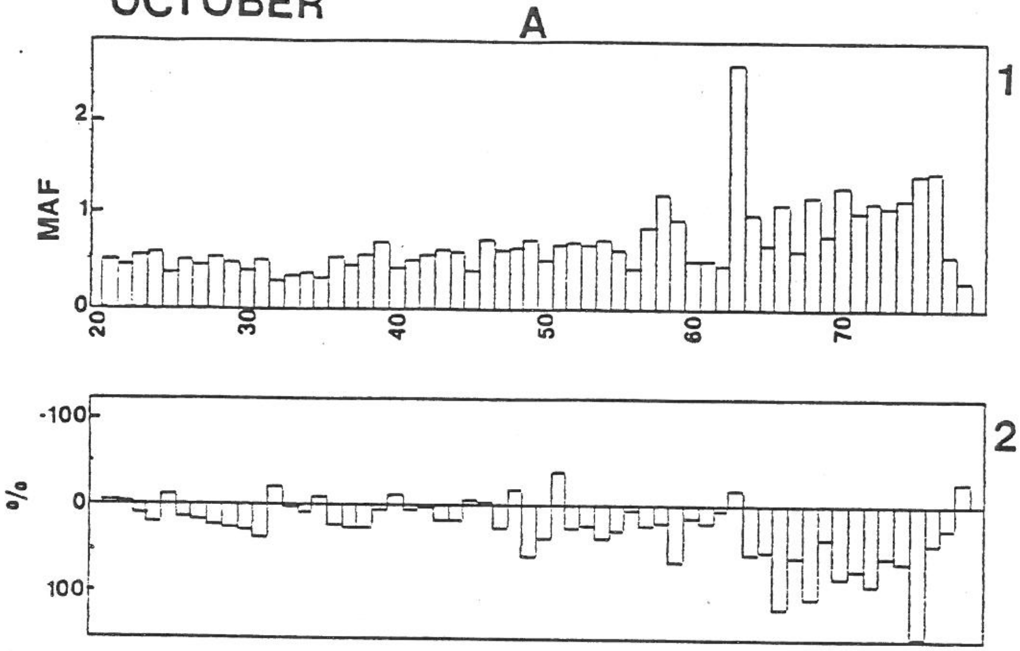
B-1. Monthly Chronological Fluctuations of Regulated Delta Outflow (Qrdo) to the San Francisco Bay

-2. Percentage of Downstream Diversions

C-1. Monthly Chronological Values of Inner Delta Diversions (Qrri-Qrdo)

-2. Inner Delta Diversions in Percentage of Regulated River Inflow.

OCTOBER


A
1
MAF
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1
2
20
30
40
50
60
70
2
%
-100
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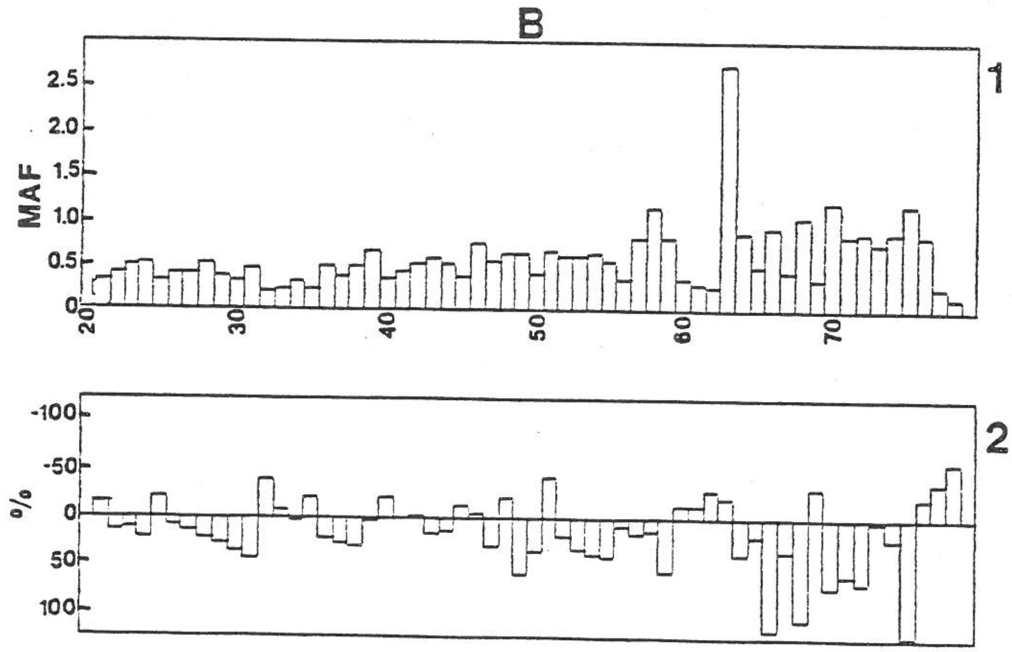
100


B
1
MAF
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0.5
1.0
1.5
2.0
2.5
20
30
40
50
60
70
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%
-100
-50
0
50
100

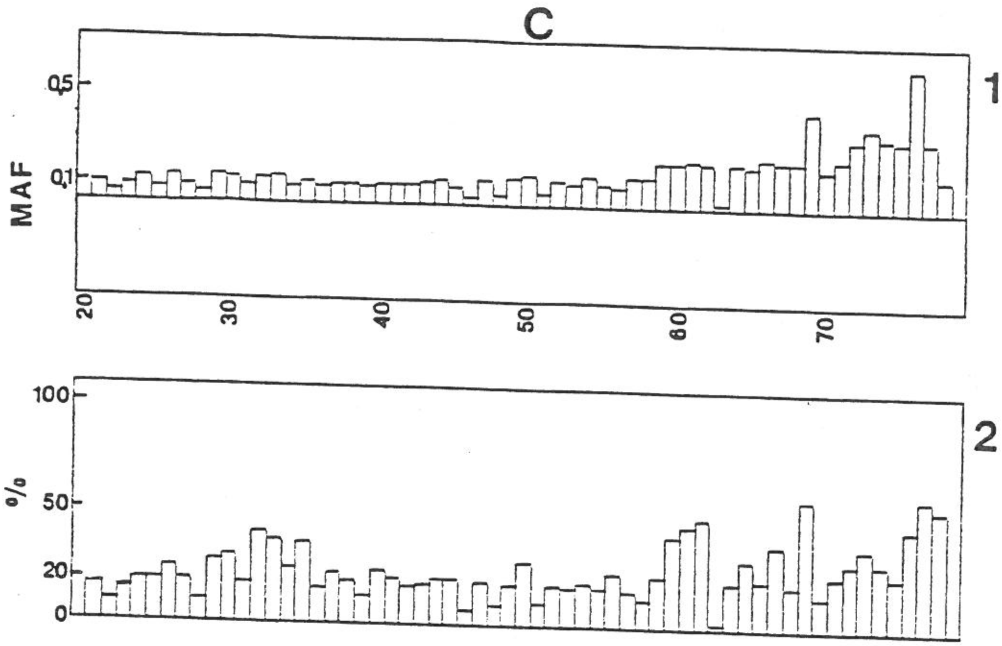


Fig.II.61 . (A,B,C)

A-1. Monthly Chronological Fluctuations of Regulated River Inflow (Qrri) to the Delta

-2. Percentage of Upstream Diversions

B-1. Monthly Chronological Fluctuations of Regulated Delta Outflow (Qrdo) to the San Francisco Bay

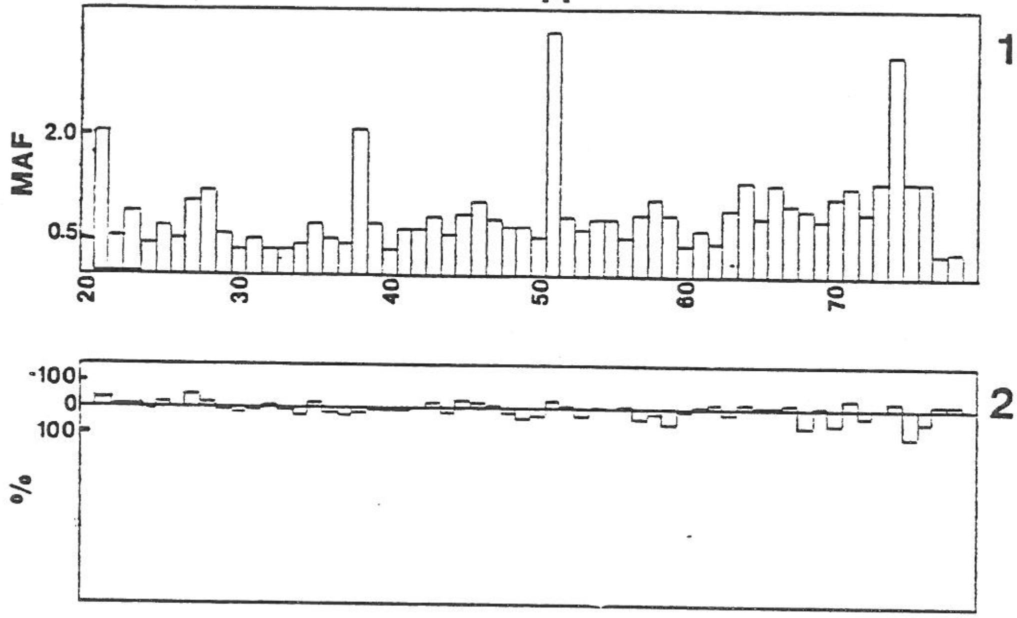
-2. Percentage of Downstream Diversions

C-1. Monthly Chronological Values of Inner Delta Diversions (Qrri-Qrdo)

-2. Inner Delta Diversions in Percentage of Regulated River Inflow.

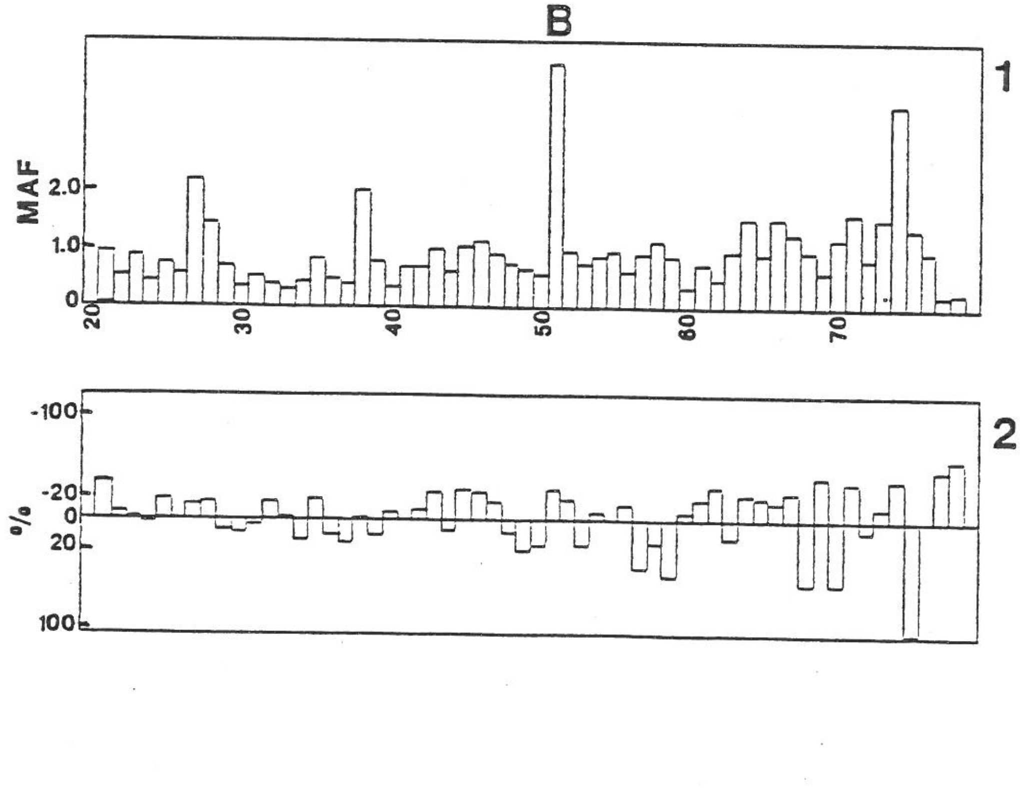
NOVEMBER

A



1
MAF
2.0
0.5
20
30
40
50
60
70
2
-100
0
100
%

B



1
MAF
2.0
1.0
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70
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-20
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NOV

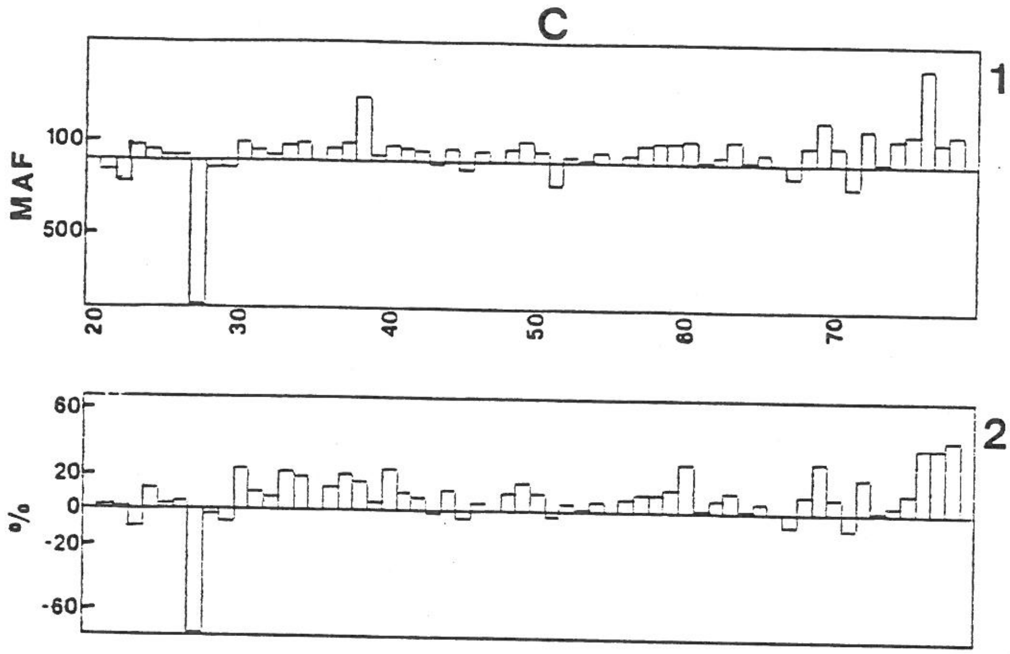


Fig. II.62 . (A,B,C)

A-1. Monthly Chronological Fluctuations of Regulated River Inflow (Qrri) to the Delta
-2. Percentage of Upstream Diversions

B-1. Monthly Chronological Fluctuations of Regulated Delta Outflow (Qrdo) to the San Francisco Bay
-2. Percentage of Downstream Diversions

C-1. Monthly Chronological Values of Inner Delta Diversions (Qrri-Qrdo)
-2. Inner Delta Diversions in Percentage of Regulated River Inflow.

II. 2. 7 Summary of Seasonal Diversion Statistics

WINTER

Winter upstream, Delta and total average diversions before (1921-1943) and after (1944-78) CVP and SWP operations revealed the following:

Table II. 47 Winter Monthly Average Upstream, Inner Delta and Total Diversions (MAF) from the Sacramento-San Joaquin River System (1921-78)

	Upstream	Delta	Total
1921-43			
December	-0.2	-0.1	-0.3
January	-0.1	+0.14	+0.04
February	-0.18	-0.21	-0.39
March	-0.16	+0.17	-0.01
1944-66			
December	-0.55	-0.0	-0.55
January	-0.18	+0.09	-0.09
February	-0.35	+0.04	-0.31
March	-0.66	-0.02	-0.64
1967-78			
December	-0.2	-0.25	-0.45
January	1.0	-0.02	-1.3
February	-0.02	-0.06	-0.04
March	-1.44	+0.22	-1.67

Table II. 48 Average Total Winter Withdrawals (MAF) from the Sacramento-San Joaquin System (1921-78)

Years	Dec	Jan	Feb	Mar	Total
1921-43	-0.30	0.04	-0.36	-0.01	-0.63
1944-66	-0.55	-0.09	-0.31	-0.61	-1.56
1967-78	-0.45	-1.30	-0.04	-1.67	-3.46

1. Maximum absolute values of upstream and total diversions occurred if some of the preceding months of the winter season or the entire preceding year was subnormal or critical dry, or drought, but the following winter season was wet or normal, for example, winter water withdrawals in 1978 (9.95 MAF) versus 1977 drought year (1.14 MAF).

2. Normal, subnormal, dry and critical dry years are characterized by the highest percentage of upstream and total diversions when the amount of water withdrawn compares with NRI and NDO for a given month or winter season. In these cases it is logical to expect that even small winter diversions which occurred in periods of low wetness, particularly when followed by a spring of subnormal wetness, may have much stronger impact on the river-estuary environment than the highest diversions occurring in wet or normal years.

3. Since the beginning of CVP and SWP operation, January and March have been characterized by the highest average values of upstream and total diversions.

4. Average upstream diversions between 1921-43 and 1944-66 and between 1921-43 and 1967-78 have increased 1.8 and 10 times for January and 4.1 and 9 times for March.

5. The total average water withdrawals for the same periods (between 1921-43 and both 1944-66 and 1967-78) increased 1.8 and 1.5 for December, 2.0 and more than two orders of magnitude for January, and 61 and over two orders of magnitude for March.

6. Total <u>average</u> winter diversions between 1921-43 and both 1944-66 and 1967 and 1978 increased 2.5 and 5.5 times, respectively.

7. Total seasonal <u>average</u> winter diversion of 3.5 MAF (1967-78) corresponds to 26% of the normal winter water supply of 13.5 MAF (NRI) to the Delta-Bay ecosystem.

Therefore, under average regulated conditions the total RRI value equals 10.0 MAF, or 74% of the normal water supply (NRI = 13.5 MAF) to the system. Consequently, if the average (for the 1921-78 period) distribution of normal winter supply per month (%) is: Dec. = 18.1%, Jan. = 21.81%, Feb. =28.44% and Mar. = 28.52%, then these percentages of RRI (10.0 MAF) are: Dec. = 1.81 MAF, Jan. = 2.48 MAF, Feb.= 2.84 MAF and Mar. = 2.85. However. these seasonally redistributed values of RRI correspond to 74% of their normal values.

8. Therefore, for the most recent period (1967-78), monthly regulated flow (RRI) for winter, modified by major monthly upstream diversions, corresponds to seasons of subnormal wetness while NRI for the winter months reflects the above-normal conditions of combined Sacramento-San Joaquin system discharges for the same period. Almost the same redistribution characterized the subnormal years of wetness for the 1979-84

period.

In summary, winter runoff regulation appears to be a prelude to the more serious reduction of water supply to the Delta-Bay system which occurs during the spring months.

SPRING

The seasonal runoff redistribution due to diversions intensified, particularly from 1959 to the present, and resulted in changes of flow variables between the seasons on a scale that has not been observed since record-keeping for the system began in 1878.

1. Under unregulated conditions, NRI and NDO for each month of spring for normal (and even sub-normal or wet years) may be 2-5 times higher than NRI and NDO for summer (July and August) and autumn (September, October and November). For example, in 9 years out of 28 cases (1959, 61, 64, 66, 68, 70, 72, 79 & 81), when annual runoff was subnormal, this ratio occurred between spring and summer.

2. However, since the development of the increased capacity of water facilities for diversions, this natural seasonal distribution of runoff no longer exists.

In most years RRI in July was almost equal to, or slightly less than, RRI of April.

Meanwhile, the RRI of August and September were generally equal to that of May and June. Often the values for September were up to two times higher than those of May and June.

3. Almost the same regularities are seen for RDO in the comparison of spring and summer. RRI for September in particular had pronounced increases in water supply which could be equal to any of the RDO for the three spring months. But it could also be 1.3-2.5 times higher than the June RDO.

4. Such atypical distribution of seasonal runoff, especially during years of sub-normal wetness, may have a profound effect on physical and biological properties of the Delta-Bay ecosystem, especially on salinization of the basin, residence time, fish migration and spawning.

Comparison of dynamics of spring diversions before and after the beginning of project operations reveals (Tables II. 49, 50):

Table II. 49 Spring Monthly Average Upstream, Inner Delta and Total Diversions (MAF) from the Sacramento-San Joaquin River System (1921-78)

	Upstream	Delta	Total
1921-43			
April	-0.50	-0.16	-0.68
May	-1.10	-0.20	-2.04
June	-0.81	-0.13	-0.94
1944-66			
April	-1.60	-0.08	-1.68
May	-1.90	-0.14	-2.04
June	-1.10	-0.40	1.50
1967-78			
April	-1.35	-0.35	-1.70
May	-2.70	-0.46	-3.16
June	-1.30	-0.70	-2.00

Table II. 50 Average Total Spring Withdrawals (MAF) from the Sacramento-San Joaquin System (1921-78)

Years	April	May	June	Total
1921-43	0.66	1.3	0.94	2.8
1944-66	1.68	2.04	1.50	5.22
1967-78	1.70	3.16	2.01	6.86

1. Total spring (April, May and June) diversions have increased 2-6 times.

2. As a rule, the highest volume of diversions (in absolute values, i.e., MAF) took place in wet and normal (and occasional sub-normal) years if these years were preceded by sub-normal or drier years (dry, critical dry or drought years, events with 60-99% probabilities of exceedance, or which would occur at least once every 3, 4 or 10, 20 or 100 years). For example, the diversions of 1978 (the wettest spring, 10% probability of exceedance, or years of recurrence at least once in ten years) which followed the critical dry year 1976 and drought year 1977, were the highest observed for the entire 1921-78 period of record. Conversely, the lowest volumes of diversion occurred in wet and normal spring months which followed wet or normal years. Unfortunately, these practices appear to have exacerbated environmental problems by minimizing flows to the Delta and Bay

in dry periods, when water is needed, and enhancing flows in wet periods, when the needs of the resources are lower.

3. As a rule, the relative values of diversions (percentage of NRI or NDO) are highest during years of low or critical low wetness. Therefore, in order to adequately describe the levels of diversions, and to fully appreciate their impact on the ecosystem, it is imperative to evaluate both their absolute and relative values.

4. For the spring months since the beginning of project operations, the average values of upstream water withdrawals have increased significantly. Comparing the 1921-43 period with both 1944-66 and 1967-78 the increases have been: April - 1.7 and 3.0 times: May - 1.7 and 2.5 times; June - 1.4 and 1.6 times, respectively.

5. The average values of Delta (downstream) diversion for June of the same periods increased 3.7 and 5.4 times, while there was a slight reduction for April and May between the 1921-43 and 1944-66 periods. However, comparison of the 1921-43 and 1967-78 periods reveals a marked increase for April (2.0 times) and May (2.3).

6. Total (upstream plus Delta) average diversions for the same periods increased 2.5 and 2.6 times for April, 1.6 and 2.4 times for May and 1.6 and 2.2 times for June, respectively.

7. The total average diversions for the spring months combined for the same periods increased 1.9 and 2.5 times, respectively.

8. On an absolute basis, total average spring diversions (6.9 MAF) for the 1967-78 period equal 62% of the normal water supply to the Delta (NRI = 11.05 MAF) or 64% of the average outflow to San Francisco Bay (NDO = 10.76 MAF). Therefore, under average conditions the Delta-Bay ecosystem receives (NDO-RDO) only 3.9 MAF (1.3 MAF per month), or 36% of the total normal runoff for spring.

9. However 1.3 MAF of the total RDO corresponds to a 92-94% probability of occurrence or once every 13-16 years. Therefore, the estuarine system has been subjected to average regulated conditions of river discharge that occurred only rarely with natural Delta outflow (only 4 times in the 65-year period of 1919-1983 - 1924, 1931, 1934 and 1977). It must be noted that these years demonstrated one of the strongest cases of salinization of the Delta water body.

SUMMER

There are two distinct features of summer redistribution of RRI and RDO in comparison with NRI and NDO since the beginning of CVP and SWP operation.

1. Due to returning agricultural water discharges and small releases from storage facilities, the negative average upstream water balance which occurred regularly during July in the pre-project period was reduced (Tables II. 51, 52) by half in the two post-project periods (1944-66 and 1967-78).

Table II. 51 Summer Monthly Average Upstream, Inner Delta and Total Diversions (MAF) from the Sacramento-San Joaquin River System (1921-78)

	Upstream	Delta	Total
1921-43			
July	-0.43	-0.17	-0.6
August	-0.23	-0.16	-0.39
1944-66			
July	-0.37	-0.36	-0.73
August	+0.07	-0.35	-0.28
1967-78			
July	-0.20	-0.62	-0.82
August	+0.53	-0.69	-0.16

Table II. 52 Average Total Summer Withdrawals (MAF) from the Sacramento-San Joaquin System (1921-78)

Years	July	August	Total
1921-43	-0.6	-0.39	-0.45
1944-66	-0.73	-0.28	-1.01
1967-78	-0.82	-0.16	-0.98

For August the difference in average upstream water deficit observed during the 1921-43 period was eliminated for the 1944-66 period and, due to returning flows, reached the level of average normal runoff (0.54 MAF) for the 1921-78 period of record.

2. Average Delta consumption increased for 1944-66 and 1967-78 (compared to 1921-43) 2.2 and 3.7 times for July and 2.2 and 4.3 times for August, respectively.

3. As a result of inner Delta diversions, average total water withdrawals for July increased 1.2 and 1.4 times. However, primarily as a result of returning agricultural drainage water, the August deficit in water supply was reduced 2.4 and 1.7 times

(same comparisons as above). Although flows for July demonstrate gradual increases in water diversion, overall increases in RRI (most likely resulting from returning flows) masked the effect of diversions for August.

4. Average RRI values for August may be more than twice as large as NRI and correspond to probabilities of exceedance (for natural inflow) between 5 and 30% (rare events). This difference may occur only when the preceding months are normal or above normal wetness. Therefore, in the most typical case of limited natural water supply during summer, there will be no such differences. This suggests that storage facilities are not capable of providing adequate runoff in sub-normal, dry or critical dry years.

5. In summary, during the last summer month, the combined Sacramento-San Joaquin runoff is the result of water regulation and returning water discharges and, as such, is unlike the natural runoff distribution which is characterized by declining flows and water deficits.

AUTUMN

Several major changes in September runoff fluctuations and discharges to the Delta-Bay system have occurred since the beginning of project operations (Tables II. 53, 54).

Table II. 53 Autumn Monthly Average Upstream, Inner Delta and Total Diversions (MAF) from the Sacramento-San Joaquin River System (1921-78)

	Upstream	Delta	Total
1921-43			
September	-0.04	-0.13	-0.17
October	+0.04	-0.10	0.06
November	-0.06	-0.01	-0.07
1944-66			
September	+0.15	-0.21	-0.02
October	+0.13	-0.15	0.02
November	-0.06	-0.06	-0.12
1967-78			
September	+0.64	-0.44	+0.22
October	+0.04	-0.34	+0.06
November	-0.08	-0.15	-0.23

Table II. 54 Average Total Autumn Withdrawals (MAF) from the Sacramento-San Joaquin System (1921-78)

Years	September	October	November	Total
1921-43	-0.17	-0.06	-0.07	-0.30
1944-66	-0.02	-0.02	-0.12	-0.14
1967-78	+0.22	+0.06	-0.23	+0.05

1. Since 1944 there has been no upstream water supply deficit for September, i.e., regulated flows exceed those of the natural water supply (RRI>NRI). In fact, for the 1967-78 period, this surplus is 4 times higher than it was in the 1944-66 period.

2. Inner Delta consumption also increased (3.4 times) over this period.

3. As a result of increases in returning water, total average RDO increased 8.5 times between the 1921-43 and 1944-66 periods, but increased up to 0.22 MAF during the 1967-78 interval. Therefore, during this latter period, and through 1983, RDO was higher than NDO and average RDO values (and their monthly maximums) correspond to probabilities of exceedance of 10-30%, placing RDO in the range of above normal or wet years.

4. Although there were no significant changes in upstream water supply for <u>October</u>, inner Delta consumption increased several times for the post-project period. However, October flows reflect the impact of regulation to a much lesser degree than did September.

5. <u>November</u> runoff changes in upstream water supply are insignificant, although there is a slight increase in inner Delta and total water deficits. These data indicate that of the fall months, November is the least affected by regulation.

6. In summary, the average total water deficit for the fall season was reduced more than 50% between 1921-43 and 1944-66, and even slightly more during the past 15 years, primarily from return flows.

The apparent average annual surplus or net increase in flows in the Delta of 0.05 MAF during the late summer and fall should be viewed in the context of the winter and spring seasons when nearly 9-11 MAF of water are diverted from the riverine-estuarine system each year. This net gain represents only 0.45% of the amount lost and therefore can hardly be expected to compensate for the changes in NRI and NDO resulting from year-to year basis and the cumulative losses of water.

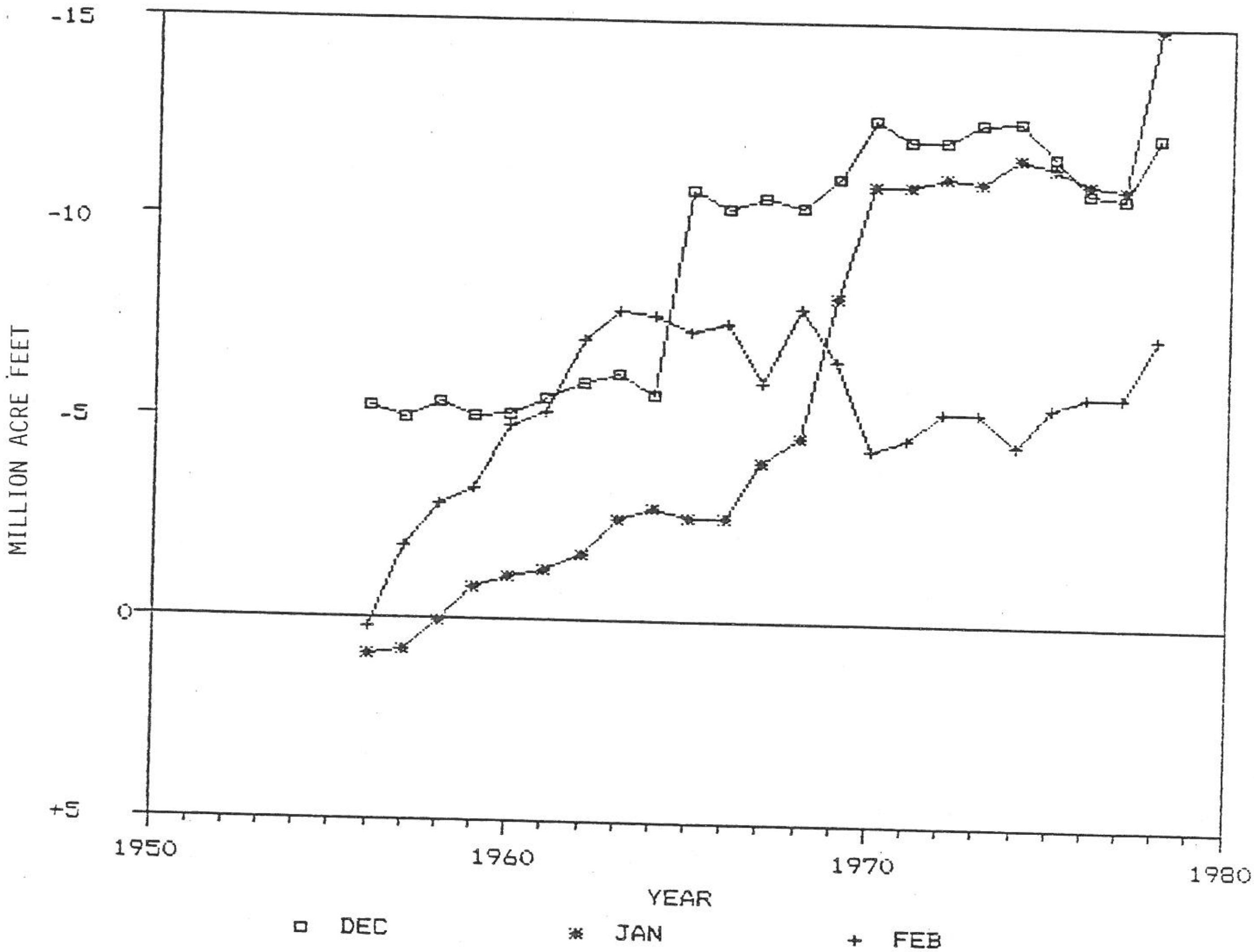


Fig.II.63. Cumulative river losses of freshwater due to diversions and withdrawals.

Note: The positive values denote net gain.

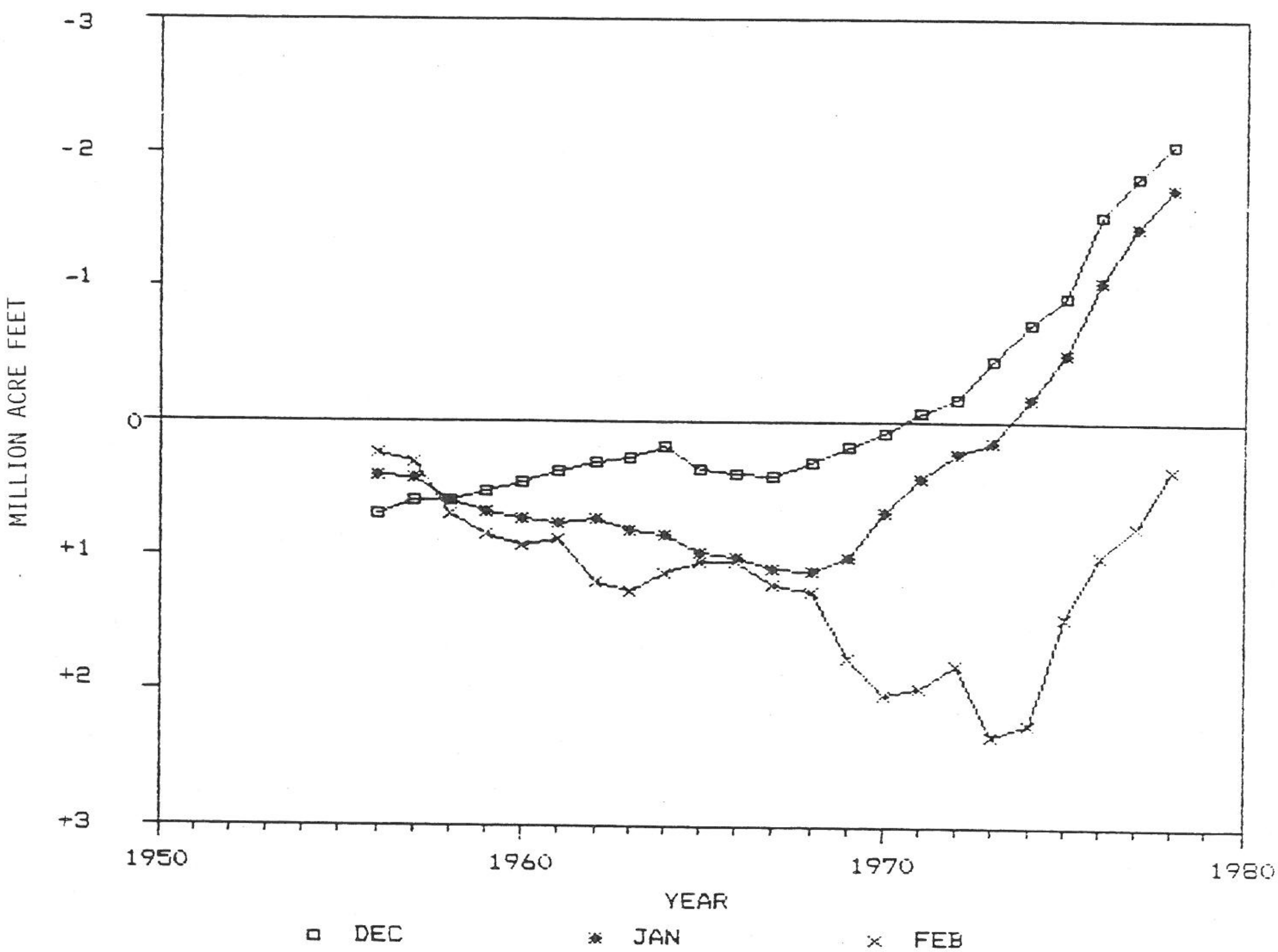


Fig.II.64. Cumulative delta losses of freshwater due to diversions and withdrawals.

Note: The positive values denote net gain.

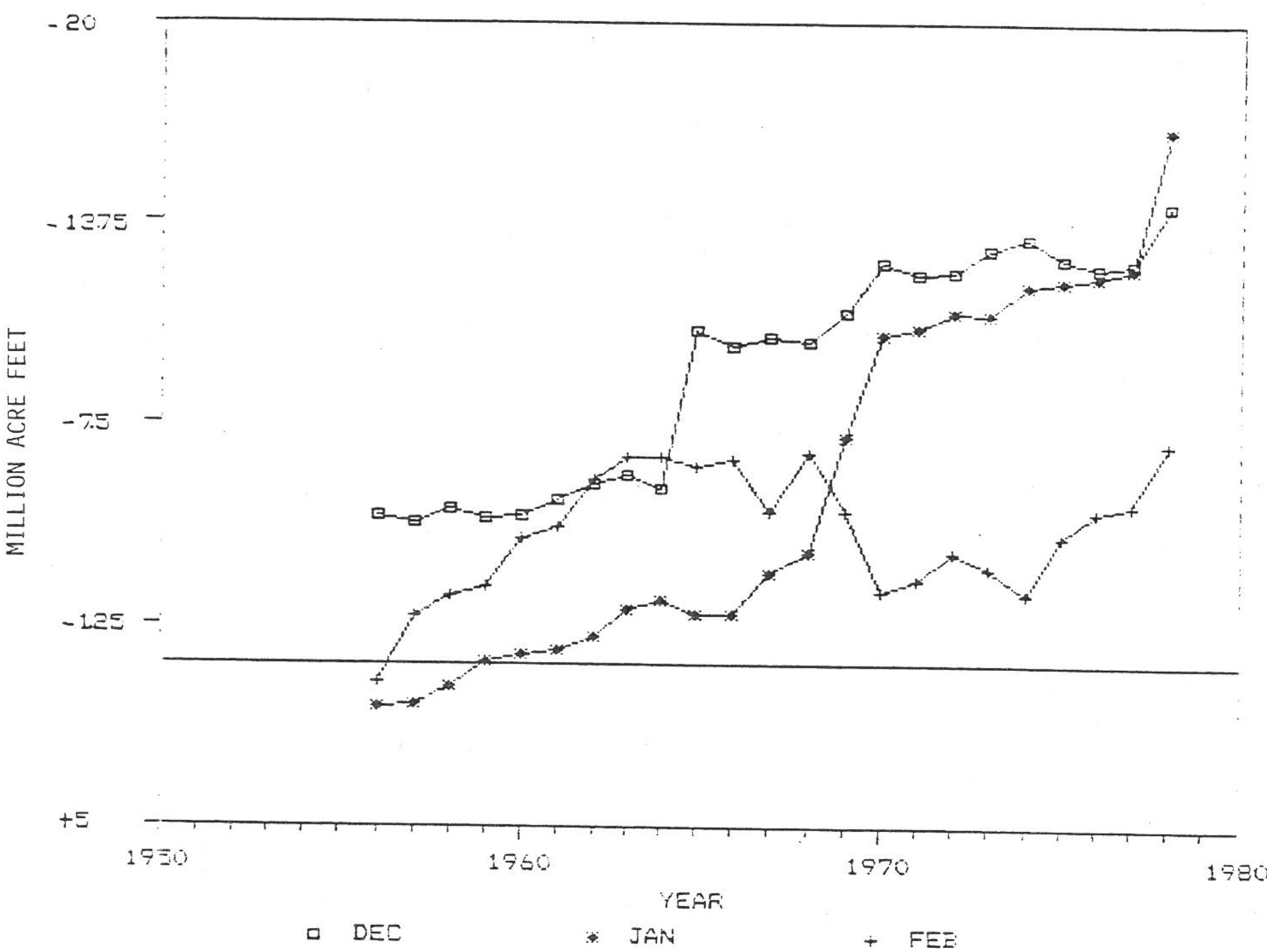


Fig. II.65. Cumulative gross delta losses of freshwater due to diversions and withdrawals.

Note: The positive values denote net gain.

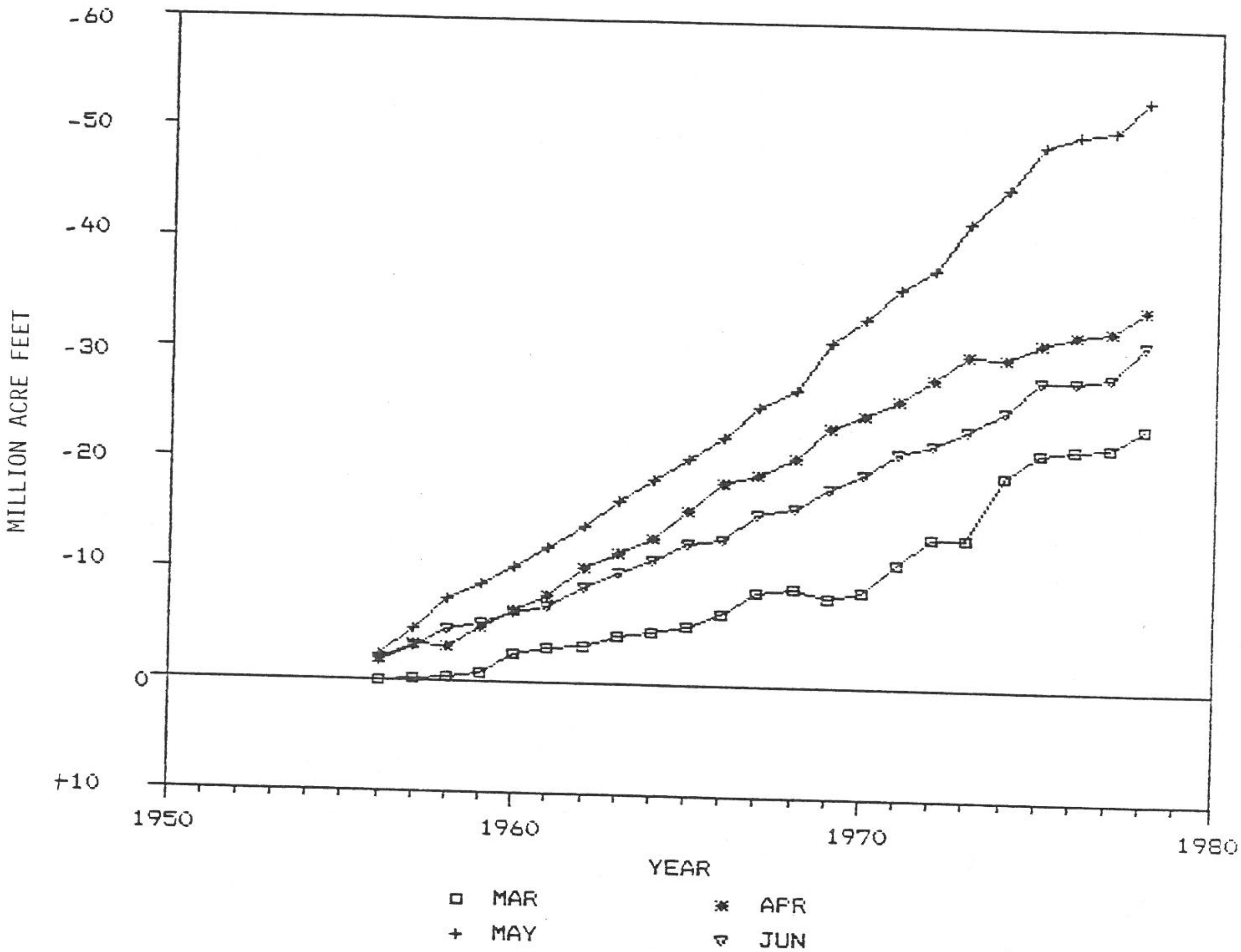


Fig.II.66. Cumulative river losses of freshwater due to diversions and withdrawals.

Note: The positive values denote net gain.

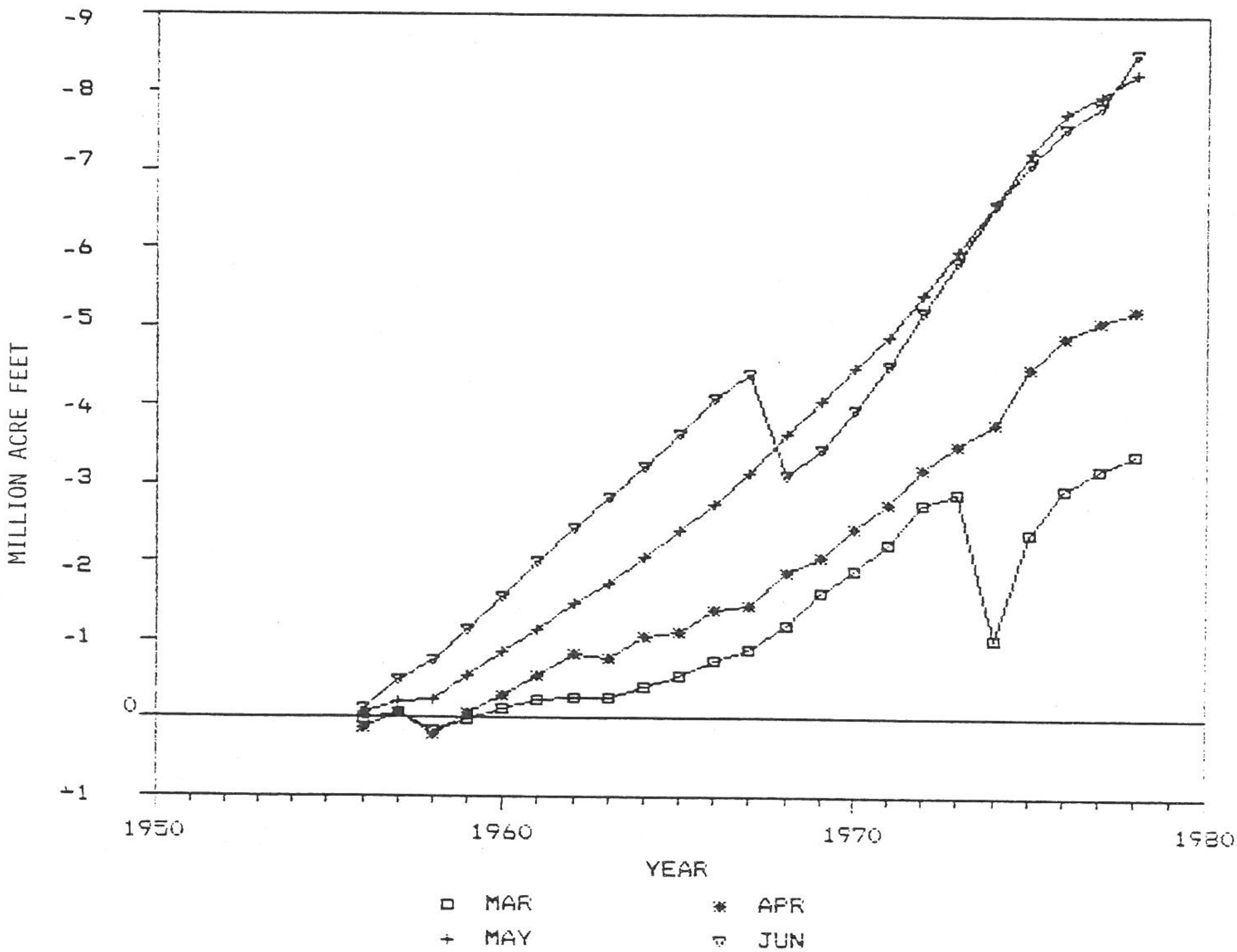


Fig.II.67. Cumulative delta losses of freshwater due to diversions and withdrawals.

Note: The positive values denote net gain.

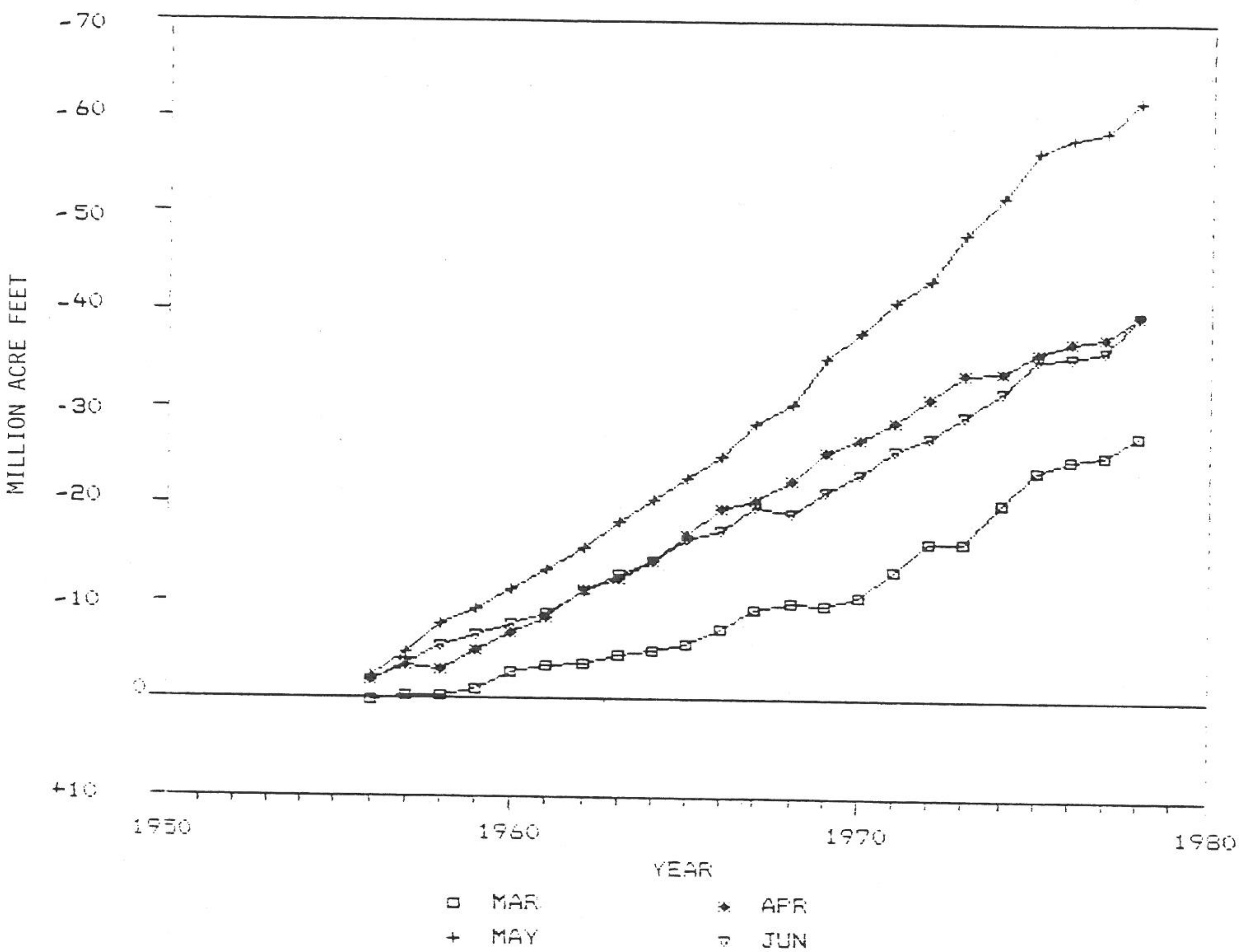


Fig.II.68. Cumulative gross delta losses of freshwater due to diversions and withdrawals.

Note: The positive values denote net gain.

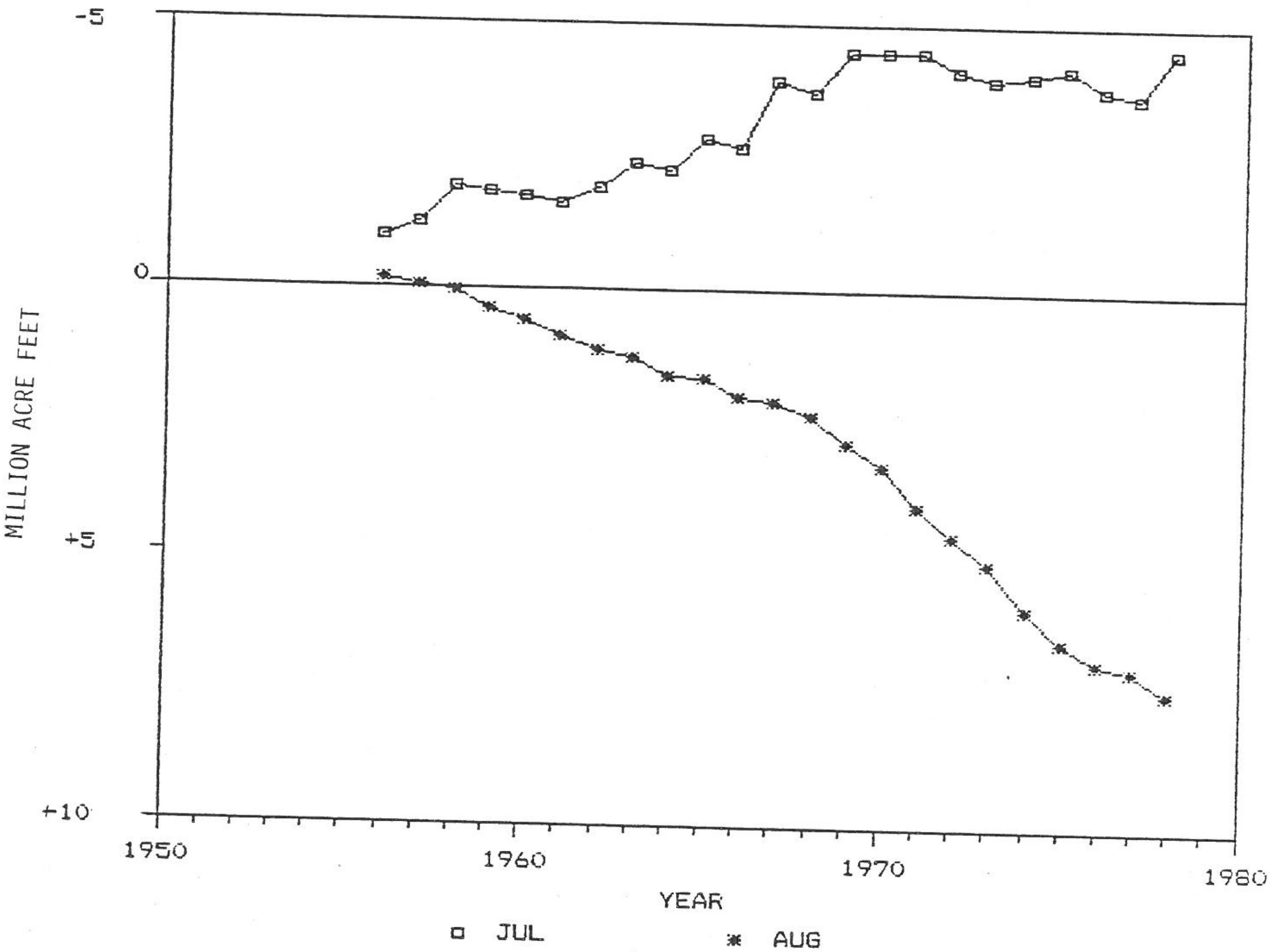


Fig. II.69. Cumulative river losses of freshwater due to diversions and withdrawals.

Note: The positive values denote net gain.

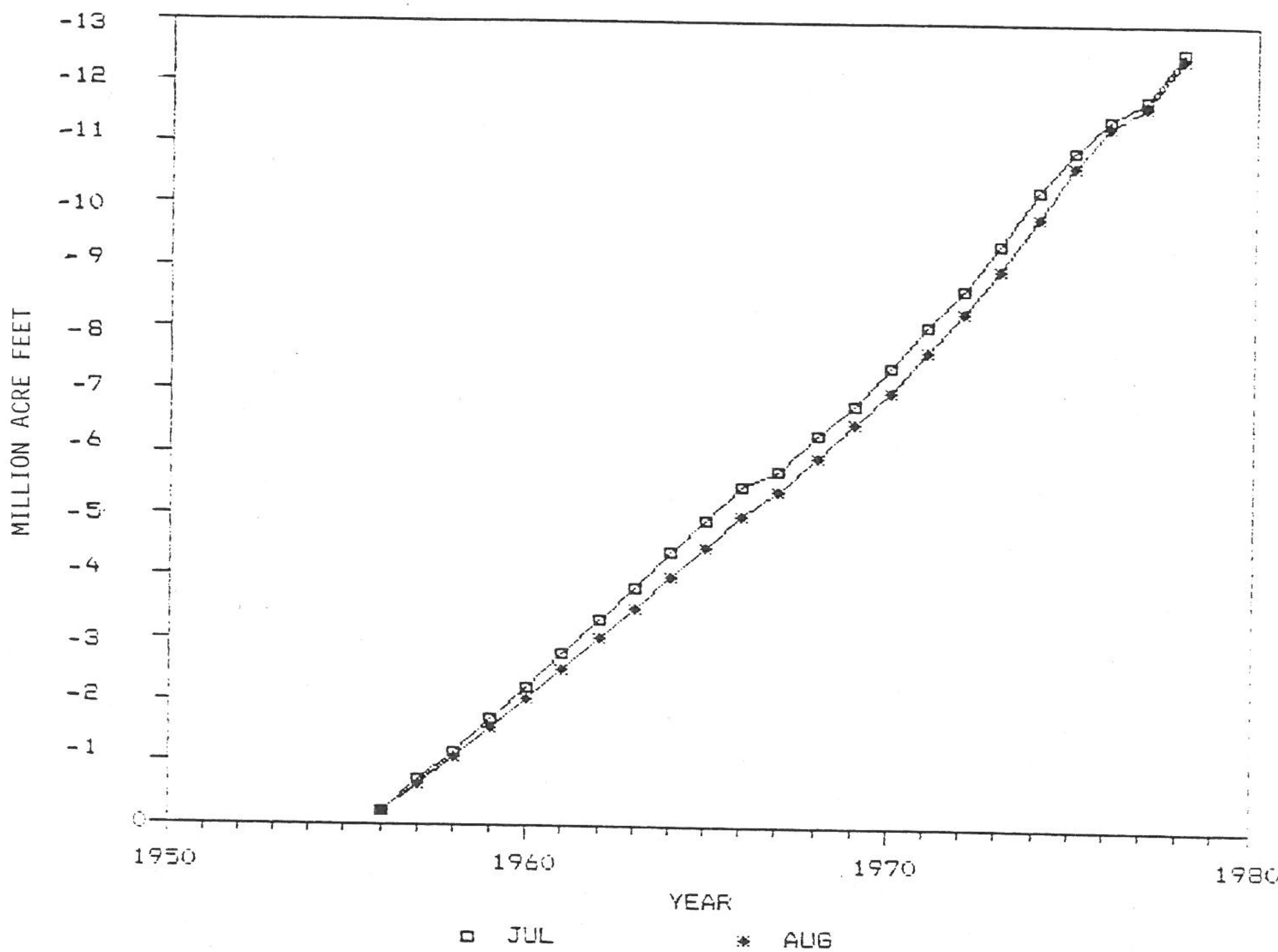


Fig.II.70. Cumulative delta losses of freshwater due to diversions and withdrawals.

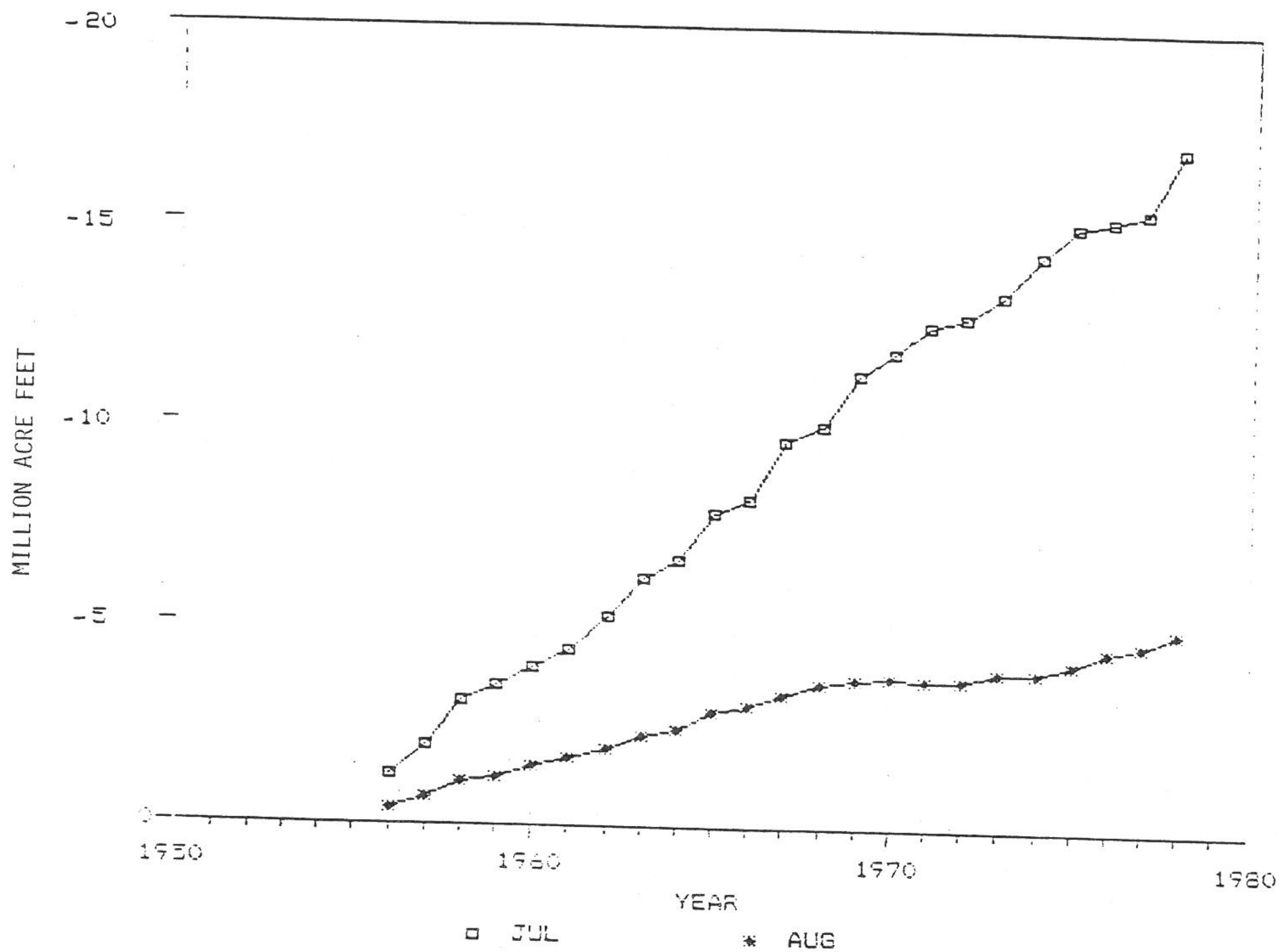
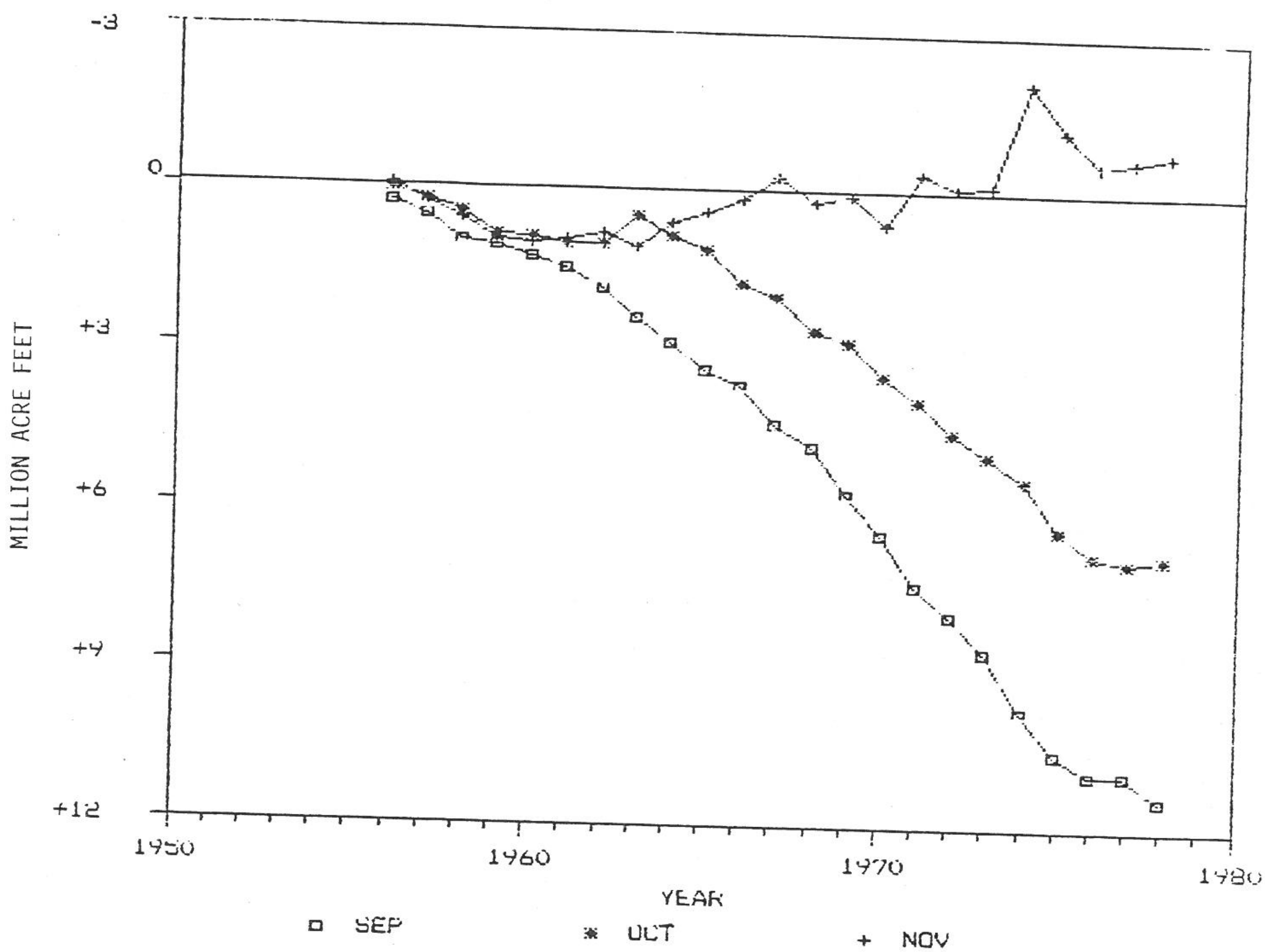


Fig.II.71. Cumulative gross delta losses of freshwater due to diversions and withdrawals.



FigII.72 . Cumulative river losses of freshwater due to diversions and withdrawals.

Note: The positive values denote net gain.

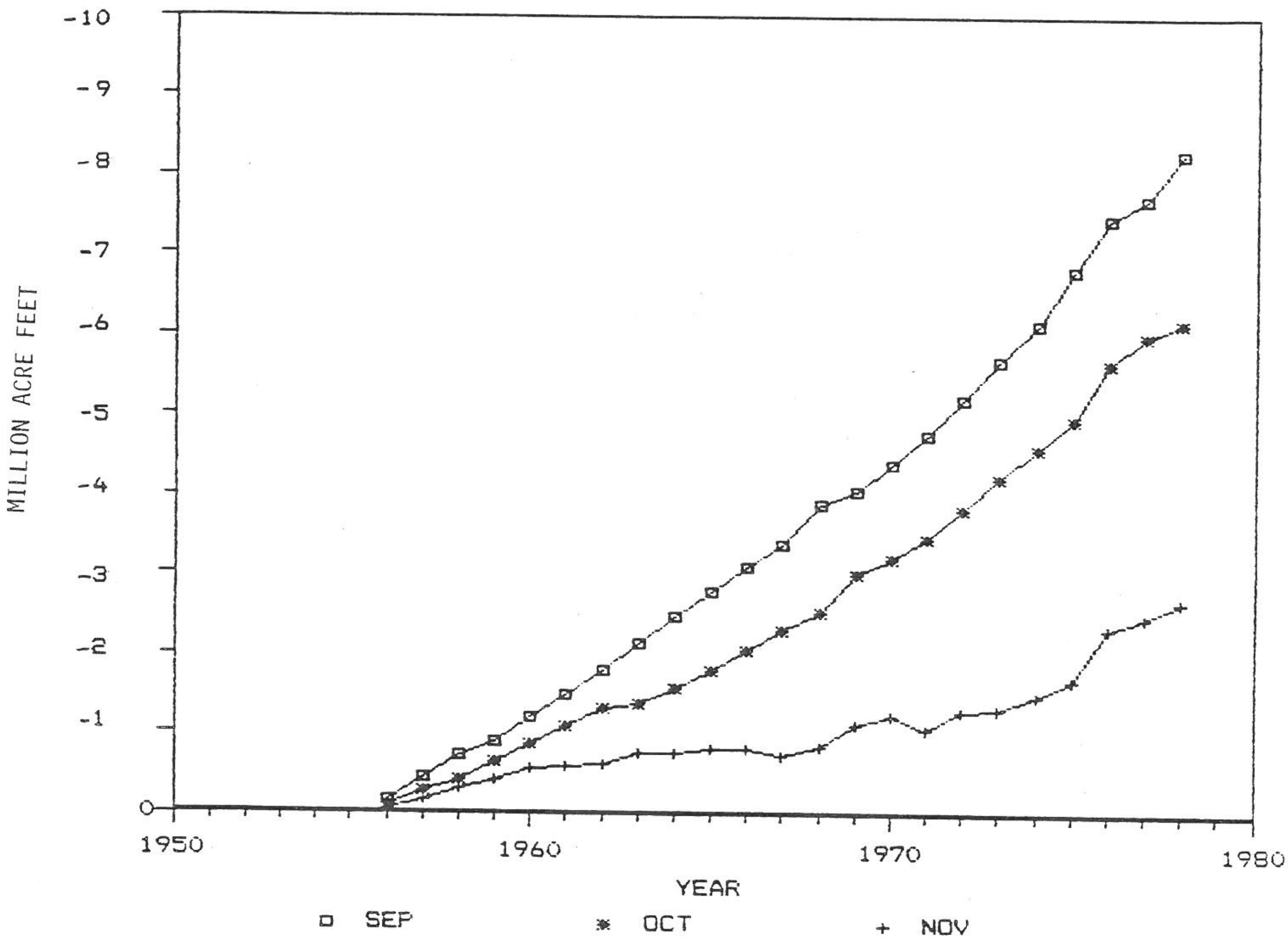


Fig.II.73. Cumulative delta losses of freshwater due to diversions and withdrawals.

II. 3 Cumulative Monthly and Annual Losses of the Sacramento-San Joaquin River Water Supply to the Delta-San Francisco Bay System

The experience of the last several decades in regard to water development in river basins has shown that rivers are very sensitive to changes in annual and, especially, seasonal discharges and to the impact of man-made effluents of various wastes, especially agricultural constituents of runoff. It is said that rivers and Deltas, in particular, react almost immediately to external influences exerted upon them.

In the river-sea ecosystem the only conservative components characterized by very strong inner resilience to the impacts of human activities (with some lag time) are the estuaries and adjacent coastal zones. Estuaries are a very specific link between riverine and marine environments and are therefore sensitive to annual and especially longer-term modifications of runoff. Riverine-estuarine systems can absorb small-scale modification in runoff but develop serious environmental problems when the variability of runoff is beyond the natural range.

Thus, changes of estuarine conditions for the most part reflect the cumulative effects of human activities in the river basin. This is the fundamental reason for our approach to the evaluation of cumulative upstream, inner Delta and total water losses resulting from diversions and withdrawals.

Figures II. 63-73 (based on the methods described in Part I,2) illustrate cumulative water losses for the period 1956-78 (during which the CVP facilities were put into operation and the first stage of the SWP was completed). This makes it possible to evaluate the net losses (or gains) during the latter period and to trace the gradual increase of water diversions since 1921.

Figures II. 63, 66, 69, 72 describe the combined cumulative losses of fresh water from the Sacramento-San Joaquin River system, primarily due to replenishment of storage facilities.

Figures II. 64, 67, 70, 73 describe the cumulative losses of fresh water from the Delta because of inner Delta consumptive natural losses and human uses.

Figures II. 65, 68, 71 show the total cumulative losses (or, as it was called in the past, the gross Delta losses) which include upstream plus inner Delta losses. Therefore, these three sets of figures describe different dynamics of water diversions, namely, above the Delta, in the Delta and in the entire Sacramento-San Joaquin River watershed (gross Delta losses).

It should be stressed that the word 'losses' used in this report means only that despite the positive application of diverted water resources for different needs of human society, this water must be considered as lost from the estuarine system in terms of its ecological value.

Winter (1956-78)

Among the winter months, as was shown earlier, January and March are characterized by the highest volumes of upstream diversions. The cumulative losses for these months accounted for 15 MAF and 24 MAF, respectively. For December, the cumulative upstream water losses were 12 MAF and for February 7 MAF.

Inner Delta Water Losses

The highest inner Delta cumulative losses are typical for March (3.4 MAF), while for February, there were no losses (Figs. II. 64, 67).

It should be noted that January and February experienced small increases in water supply.

Total Upstream and Inner Delta Water Losses

The highest total losses of 27 MAF were observed in March, and the lowest, 7 MAF, in February.

In sum, during all the winter months of this 23-year period, about 63 MAF of fresh water did not reach the system, of which almost 80% was due to upstream diversions. These cumulative losses are almost 2.2 times the annual NDO.

Spring (1956-78)

As it is logical to expect, the diversions during the spring months are the highest among all months of the hydrological year (Figs. II. 66, 67, 68).

The spring cumulative upstream, downstream and total water losses have two distinct features:

1) No gains were observed. That means that during these months, the cumulative losses increased steadily from year to year, with the rare exception of spring corresponding to a wet year.

2) The upstream diversions accounted for more than two thirds of the total losses.

Upstream Diversions

The maximum upstream diversions were observed in May (56

MAF--II. 66). The total upstream diversions for spring accounted for 125 MAF (check this number) which are almost 50% the annual losses sustained by the system (as will be seen later). This volume is 4.5 times the annual NRI.

The mean spring upstream diversion for 1956-78 was 5.4 MAF which is almost two thirds of the volume of the San Francisco Bay.

Inner Delta Diversions (1956-78)

The maximum inner Delta diversions took place in June (10.3 MAF), the minimum in April (7.4). The total inner diversion for this period added up to 26 MAF.

Total Diversions

The total diversion for May was 62 MAF, while April and June had both diversions around 40 MAF, although the normal runoff of June is half of the runoff in April. Such diversions in June, the last month of spring, may exacerbate the negative effect of the overall high water withdrawals for this season.

The total water withdrawals for spring (1956-78) were 142 MAF, or 6.2 MAF per spring on the average, which equals roughly 60% of the normal spring runoff, and 87% of which is due to upstream diversions.

In sum, this level of spring diversions between 1970 and 1984, (with the exception of 1974, 1978 and 1982 for April, and 1982 for May), corresponded to the probability of occurrence of the would-be natural Delta outflow of 90 and 95-99%. This implies that these values would be observed under natural conditions only once per 10-20 or 100 years. Needless to say, for the same period of time, the natural values of Delta outflow corresponded in the majority of cases to 60-80% probability of occurrence.

That is why the cumulative losses for the Delta outflow during the spring cannot be easily compensated for in the course of the following months or years, even if above normal wetness is observed. We do not consider that returning waters, which are much lower in volume than the losses, and which contain agricultural wastes, can be considered a positive substitute for river-Delta-Bay ecosystem water balance.

Summer (1956-78)

In this season (Figs. II. 69, 71) for twenty-three years only July had relatively small cumulative losses. The upstream and inner Delta and total water losses for July accounted for 4.5, 12.5 and 17.0 MAF, respectively. During this month on the

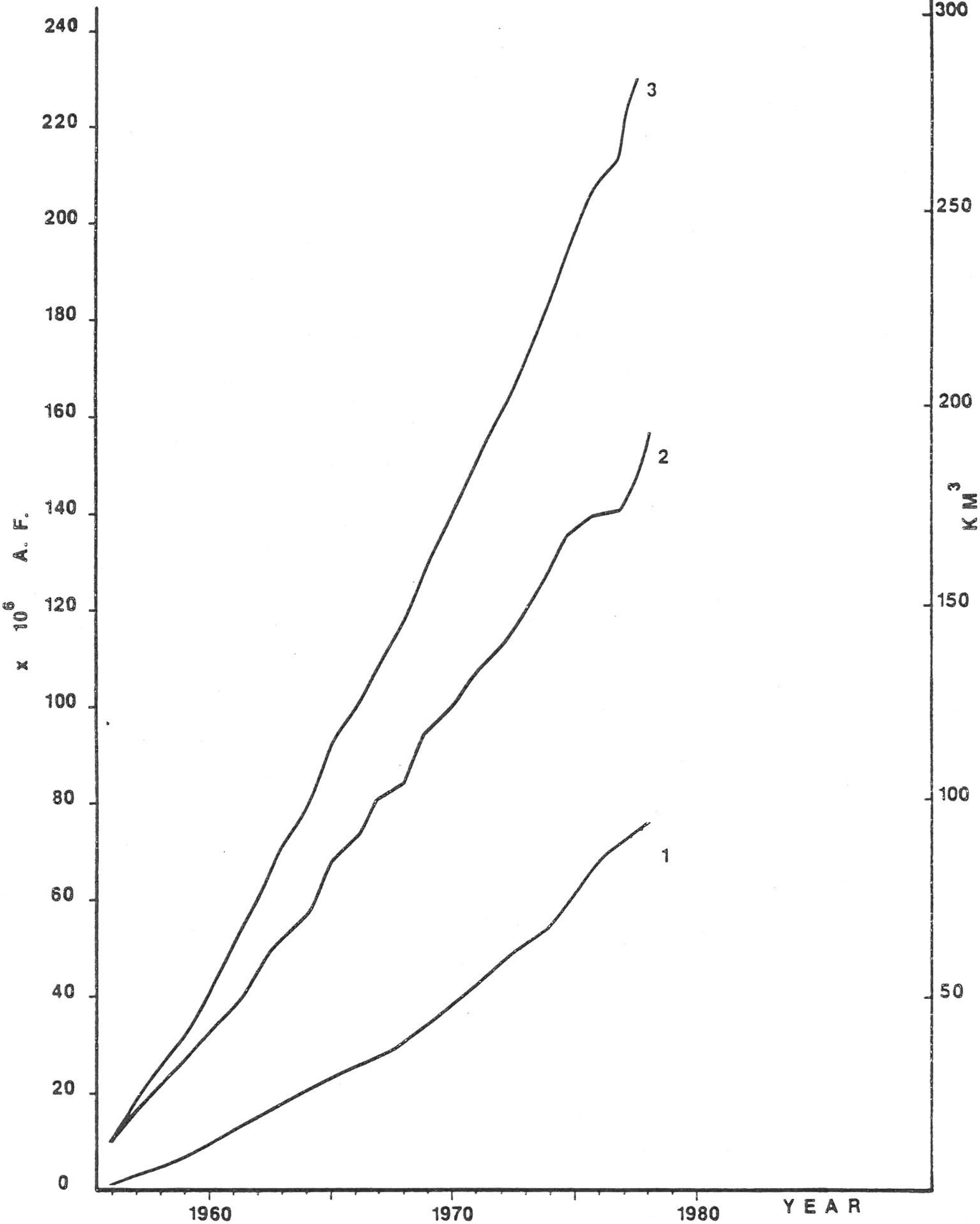


Fig. II.74 Cummulative curves of freshwater losses sustained through diversions and storages by the (1) delta, (2) river inflow to the delta, and (3) delta outflow to San Francisco Bay in comparison with natural runoff, 1956-1978.

average, inner Delta consumption was higher than upstream diversions.

In August, returning waters discharged to the system were higher than upstream losses and sometimes reached as high as 1.0 MAF. At the same time, the water diverted from the Delta increased significantly and, in sum, for this period was equal to 12.2 MAF. As a result, the net changes in the total value of upstream and Delta losses, the total value of diversions for August was only 4.7 MAF. The total volume of cumulative losses for July was only 5.0 MAF.

Autumn (1956-78)

From Figures II. 72, 73 for the period 1956-78, returning water discharges exceeded September diversions: for the upper part of the Delta, gains of 11.4 MAF; inner Delta water losses were 8.3 MAF; and the cumulative gains for the entire system were 3.2 MAF. Therefore, in spite of the changes for September, the mean monthly total water balance surplus was only 0.14 MAF per year, while the mean surplus for the upper part of the basin was 0.5 MAF and the downstream losses were 0.36 MAF.

The same categories for October and November, i.e., cumulative upstream, downstream and combined losses, show even smaller net values than for September (except the combined losses for November), although it is possible that those differences are beyond the precision of data available for calculation. It should be stressed, however, that the net increases in water supply seen during some autumn months are significantly smaller than the irretrievable losses sustained by the system during winter and spring.

In conclusion, water losses represent only the most visible impacts resulting from artificial regulation which include changes in sediment, organic and inorganic matter loadings, temperature, oxygen content, chemical constituents of various kinds leached from the soil to the river, light penetration, etc., i.e., all of the parameters which make an estuary an estuary. Therefore, the statement that the annual cumulative losses between 1956 and 1978 (a period when both major projects were in operation) in the upstream part of the river basins were 164 MAF, as much as 25 times the volume of the Bay itself, or 126 times the volume of the Delta, implies that the Delta was deprived of millions of tons of different constituents vital to the maintenance, reproduction and enrichment of the Delta ecosystem, including the sediment load necessary for in the maintenance of the levees. Delta water losses themselves accounted for 76 MAF, or almost 58 times the volume of the Delta itself. This means that in addition to the upstream losses, the Delta may have experienced even greater losses of incoming organic and inorganic matter from the rivers, not to mention such important physical characteristics as circulation patterns, the Delta's own biochemistry, nursery grounds, etc. Knowing that

San Francisco Bay and the adjoining coastal zone, both of which are vital for the migration, spawning, recruitment in stock of recreational and commercial fish, lost 240 MAF for the period 1955-78 (or 40 times the Bay's volume), makes it possible to appreciate the full scale of changes which took place from the mountains to the ocean within the entire river-Delta-Bay ecosystem.

But annual diversions are only part of the more complicated problem related to the seasonal flow redistribution and consequent reduction of significant volumes of water during spring, which, as we saw in previous chapters, is the most critical period of the year for providing adequate hydrological, chemical and biochemical conditions necessary for living resources. These spring flows also appear to be necessary for maintenance of sanitary conditions -- flushing intensity, dilution of wastes and self-purification of the estuary.

PART III

CONCEPTS AND PECULIARITIES OF THE 5-YEAR RUNNING MEAN RUNOFF FLUCTUATIONS

INTRODUCTION

In much of the literature published over the last several decades, there is strong evidence to support the hypothesis that flow fluctuation in river basins follow the same general perennial patterns of rainfall, snowmelt, or both, upon which the freshwater supply depends. The correlation between 5-year running means of precipitation and runoff is considered the best way to show these similarities (Panofsky and Brier, 1958; Chow, 1964; Kostignitsin, 1964; Kisiel, 1969; Chebotarev, 1975; Luchsheva, 1976; Baydin, 1980). That is why it is interesting to compare such correlations for rivers in different geographical areas with Sacramento-San Joaquin runoff.

Cycles of Variability

For example, a detailed analysis of long-period temperature and precipitation fluctuations in the Northern Hemisphere illustrates some typical climatological features governing the flow variability (Drozdov and Grigoriyeva, 1979). From their investigations, "these fluctuations can be divided into ultra-secular (more than 100 years), secular (50-100 years), and intra-secular (20-45 years). They are unequal in amplitude and in frequency of occurrence in various parts of the Northern Hemisphere." According to these scientists, the best described precipitation fluctuations in North America are 25- to 40-year and 60- to 70-year fluctuations; in Western Europe 25- to 40-year ("Bruckner") and 4- to 5-year fluctuations; in East Asia 7- to 8-year and 50- to 60-year fluctuations; in the USSR 14-year (in the steppe belt) and secular, 60- to 100-year, fluctuations (in the sub-polar region), in southern Asia 14- to 15- and 5- to 6-year (arid zone) and 20- to 21- and 4- to 5-year (pre-equatorial regions) fluctuations, in North Africa (to the equator) 7- and 10- to 11-year fluctuations, and in Central and South America (to the equator) 5- to 6-year and 25- to 40-year fluctuations.

They state that cyclic components of temperature and precipitation fluctuations are much better defined in winter than in summer in most temperate regions outside the tropics. However, the contribution of cyclic components becomes significant when averaged over time, for 5-year seasonal intervals.

That is why many other rivers of the Northern Hemisphere (floodplain and mountainous types whose characteristics are formed under moderate or semi-arid climate), show more or less the same typical fluctuations of water supply in their systems as the Apalachicola (Gulf of Mexico, USA), Dniester and Dnieper (the Black Sea), Don (Azov Sea), Volga (Caspian Sea) or sub-tropical rivers such as and many others (Meeter et al, 1979; Rozengurt, 1969, 1971, 1974; Rozengurt et al., 1986; Baydin, 1980).

The spectral analysis of the Apalachicola River discharges (Fig.III.1) based on data for 1920-76 shows the presence of cycles on the order of 6-7 years (Meeter et al, 1979) and that "these patterns closely resemble the cycles of Georgia rainfall since 89% of the drainage basin for this river is in that state." The same type of correlation was found for the Volga and Danube Rivers (Baydin, 1980).

Such similarities in the runoff-precipitation relationship in widely separated geographical areas can be explained by the combined effect of an array of climatological factors over the large areas. They reflect the interaction between the land the atmospheric circulation patterns. But the latter depend upon solar activities, measured by the 'Wolf' number which represents the number of sunspots observed on the sun's surface (Maksimov et al, 1970). Their fluctuations have different periods, one of which, 11 years, (Yevjevich, 1972) is considered as the most acceptable in any attempt to correlate climatological characteristics with perennial lake elevations, runoff changes etc., especially when the watersheds are large enough to reflect the impact of solar activity (Fig. III.2). Although this is not the subject of our present discussion, it should be emphasized that the drought period of the late 1920's, as well as many others observed over the last 100-150 years, coincided with an increase in sunspot activity, as did severe droughts in Europe and the USA, dust storms and warming of the Arctic Basin air and water, resulting in the retreat of the southern boundaries of ice fields several degrees to the north (Budyko, 1971).

For example, Figure II.2 demonstrates a relationship between runoff fluctuations and overall climatological conditions reflecting sunspot activity. The presence of inverse trends between river inflow and sunspot numbers (1970-1978) could be the result of a variety of factors including deforestation and urbanization of the river basin (excluding storages or conveyance facilities from consideration).

A. V. Shnitnikov (1968) described the present recurrence of cycles of wetness and demonstrated with a number of figures covering at least the last 1,000 years, that at the present time, the total wetness of the continents is declining (Fig. I.9). An analysis of the patterns of the rhythmic variations of wetness made it possible for Shnitnikov to project the trend in the state of water resources up to the end of this century and in the 21st century. Over that period he expects a depletion of the water balance of the continents to the advantage of the water balance of the ocean. For example, the analysis of deviation of natural wetness for the last 50-60 years in European parts of the

USSR illustrates the overall reduction of wetness (Lupachev, 1980, Fig. III.3; Baydin, 1980, Fig. III.4).

From this one may infer that climatological periodicity (temperature, precipitation) ought to be considered as one of the most important factors governing the water supply over large areas (Gleick, 1986). Long-term planning of withdrawals requires a rough approximation of the correspondence of precipitation limits and runoff limits, or knowledge of the relationship between precipitation fluctuations and runoff fluctuations.

The results of a Metropolitan Water District (MWD) report (1979) illustrate the importance of such trends in water balance analysis and evaluation.

The basis for their data, as can be seen from Figs. III.5-9, is the long-term record of precipitation in the most representative stations in the Sacramento River basin and the record of the annual runoff of the major rivers of this watershed: Sacramento River (Shasta Reservoir), Feather River (Oroville Reservoir), Yuba River (New Bullard's Bar and Anglebright Reservoir) and American River (Folsom Reservoir). These rivers are responsible for about 75% of the runoff originating in the Sacramento River system. The discharge of these four rivers (DWR's 4-River Index) has been used as the basis for their water-year type classification system (Decision 1485) and as the criteria for allocating water supply to the Delta-Suisun Bay system. Their analysis of the relationship between annual runoff and precipitation fluctuations (Figs. III.5-8) shows the following:

1) There are very strong similarities between the trends of rainfall and runoff variables.

2) The periods of maximum and minimum rainfall in general coincided with the periods of maximum and minimum runoff for all four rivers.

3) The 6-year running mean fluctuations best described the presence of long-term cyclicity in runoff fluctuations which more often than not coincides with the 13-15-year period cycles of combined rainfall fluctuation within the river watershed.

4) Between 1850 and 1978, the rainfall fluctuations indicate the presence of five dry or relatively dry, and six wet or relatively wet cycles, each of them consisting of two phases: rise and decline in rainfall. The approximate duration of the cycles of different wetness for these rivers is 13-17 years, with a 5-8 year-duration of the rising phase, and 5-13 years for the declining phase. For example, the record for the Redding station (Sacramento River) show an exceptional maximum duration of rainfall decline accounting for 18 years (1902-20).

5) In many instances the duration of sub-normal runoff is longer than the duration of above-normal runoff. For example,

the period from 1912 until 1934 (Mt. Shasta, Redding and Red Bluff for the Sacramento River; Sacramento-Feather River; all stations for Yuba River; Placerville-American River).

The longest above normal period was observed between 1882 and 1897, but the majority of periods of above-normal wetness had a 5-9 year-duration.

6) Within the cycles, the range in amplitude between maximum and minimum rainfall differs for each station and varies between 5-38 inches, i.e., extreme means for 6-years running for all periods of observation.

Here it is important to emphasize that this range may reveal the natural boundaries of available water supply over the river watershed and therefore its limitations if the 5-6-year running means of precipitation and corresponding values of runoff to the watershed are used as a basis for long-term water development (instead of the current year-to-year practice of river basin wetness evaluation). In this case, water availability for different users would be put on a more reliable basis for planning water withdrawals and diversions or for construction of new water conveyance and storage facilities.

In other words, water diversion planning for each year should be based, in our opinion, not only on snowpack and amount of rainfall for a given year, but each estimate should be refined by the evaluation of water supply to the river for the previous 3,4, or 5 years to arrive at recommendations for balanced water development acceptable to different water users and which can be tolerated by the environment of the entire river-estuarine system. Thus, if water project operation facilities were based on the natural patterns of runoff supply limitations, there would be more flexibility for the seasonal accumulation of water, especially during wet years, and, at least to some extent, mitigate the growing discrepancies between demands for more water by users and the environmental requirements of the San Francisco Bay. The results of MWD's report thus underscore our hypothesis that the periodicity of rainfall on the watershed determines the natural limits in water supply of the Sacramento-San Joaquin River.

However, it is also important to emphasize and describe the temporal changes in water supply resulting from human intervention and water regulation, and that estuarine regime characteristics are cumulative in nature (like solar radiation, air temperature, etc.). This is done for 5-year running mean runoff by calculating (see "Methods...I.2") the deviations of river inflow/Delta outflow from the mean runoff for the period of record (1921-78). The trends of runoff modification and tables of their numerical characteristics are presented for mean annual and seasonal flow fluctuations under natural and impaired conditions of runoff formation.

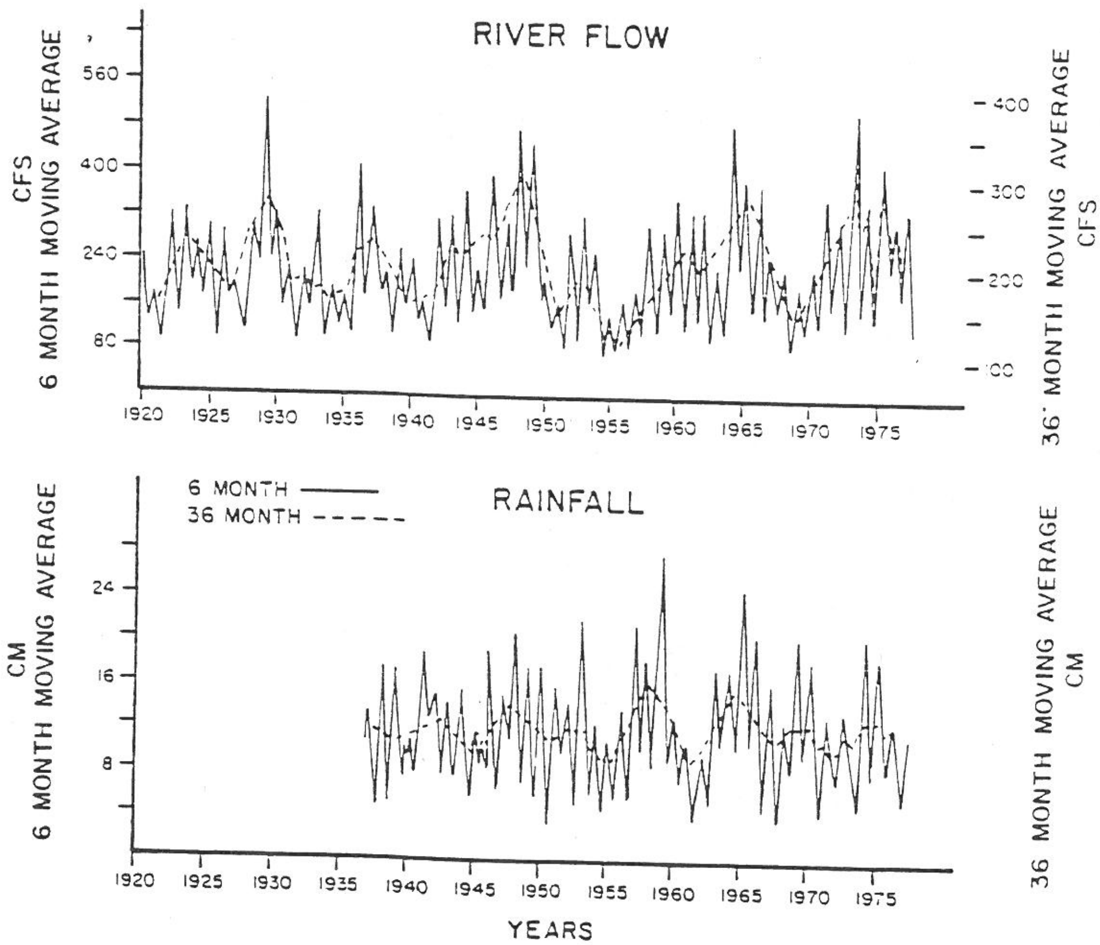


Fig. III.1 Six-month and 36-month moving averages of Apalachicola River flow (cfs; 1920-1977) and Apalachicola rainfall (1937-1977). Data are taken from Meeter et al. (1979).

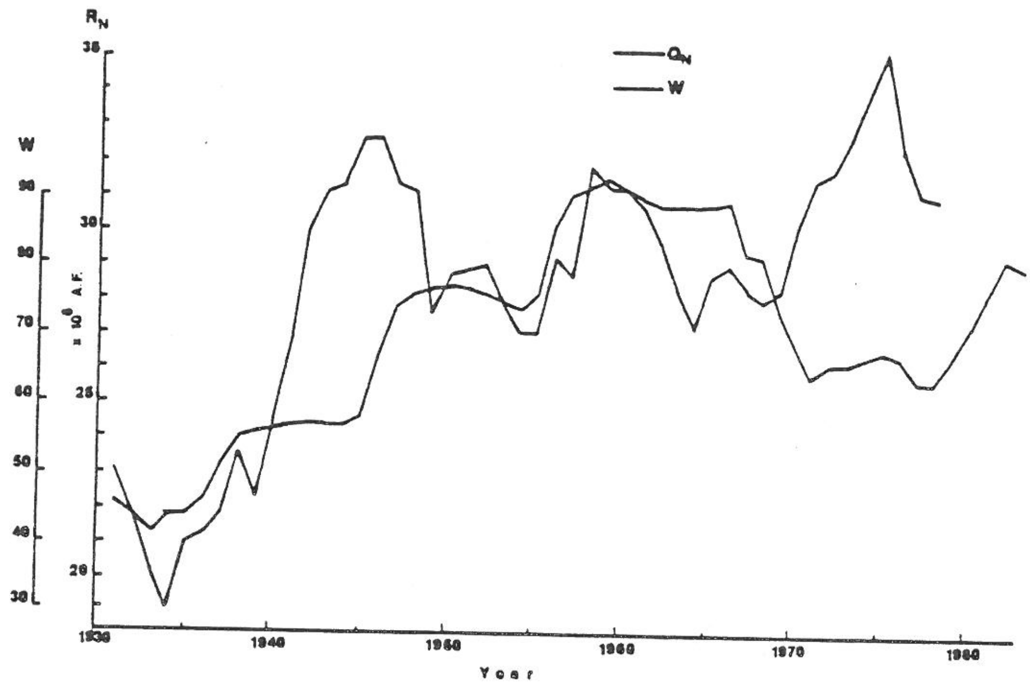


Fig.III.2 Fluctuation of natural river inflow to the Delta (Q_N) and solar activity (W - sunspot number) averaged over 11 moving years.
(Data on solar activity from records of the Wilson Observatory, Pasadena, California. Personal communication John M. Adkins, 1984.)

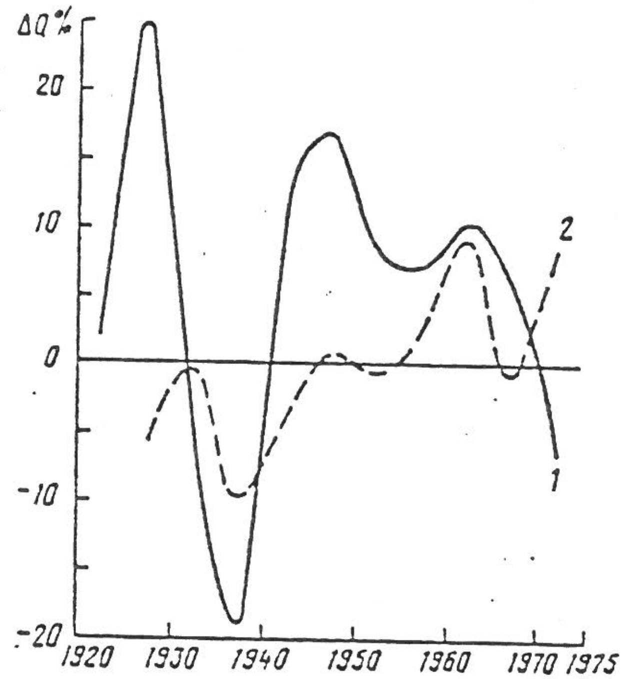


Fig. III.3. Long-period variations of the Volga (1) and Pechora (2) runoff, computed by taking 5-year moving averages (From Lupachev, 1980).

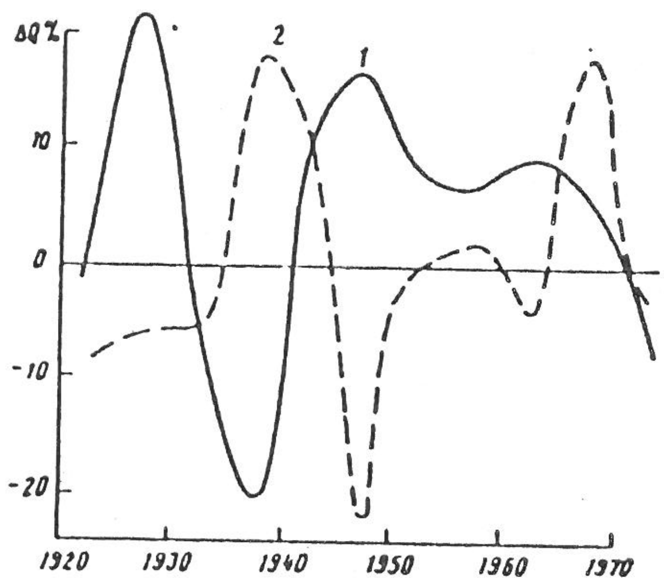


Fig.III.4a **Five-year average discharges (in % of normal) of the Volga (1) and Danube (2).** (after Baydin 1980).

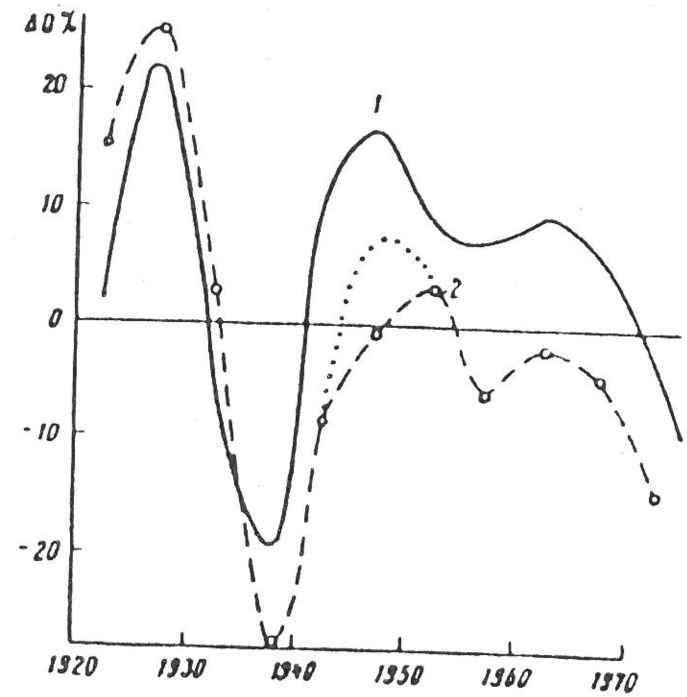


Fig.III.4b **Five-year average discharges (in % of normal) of the Volga at Verkhniy Lebyazhiy (1) and of the Northern Dvina at Ust'-Pinega (2)** (after Baydin 1980).

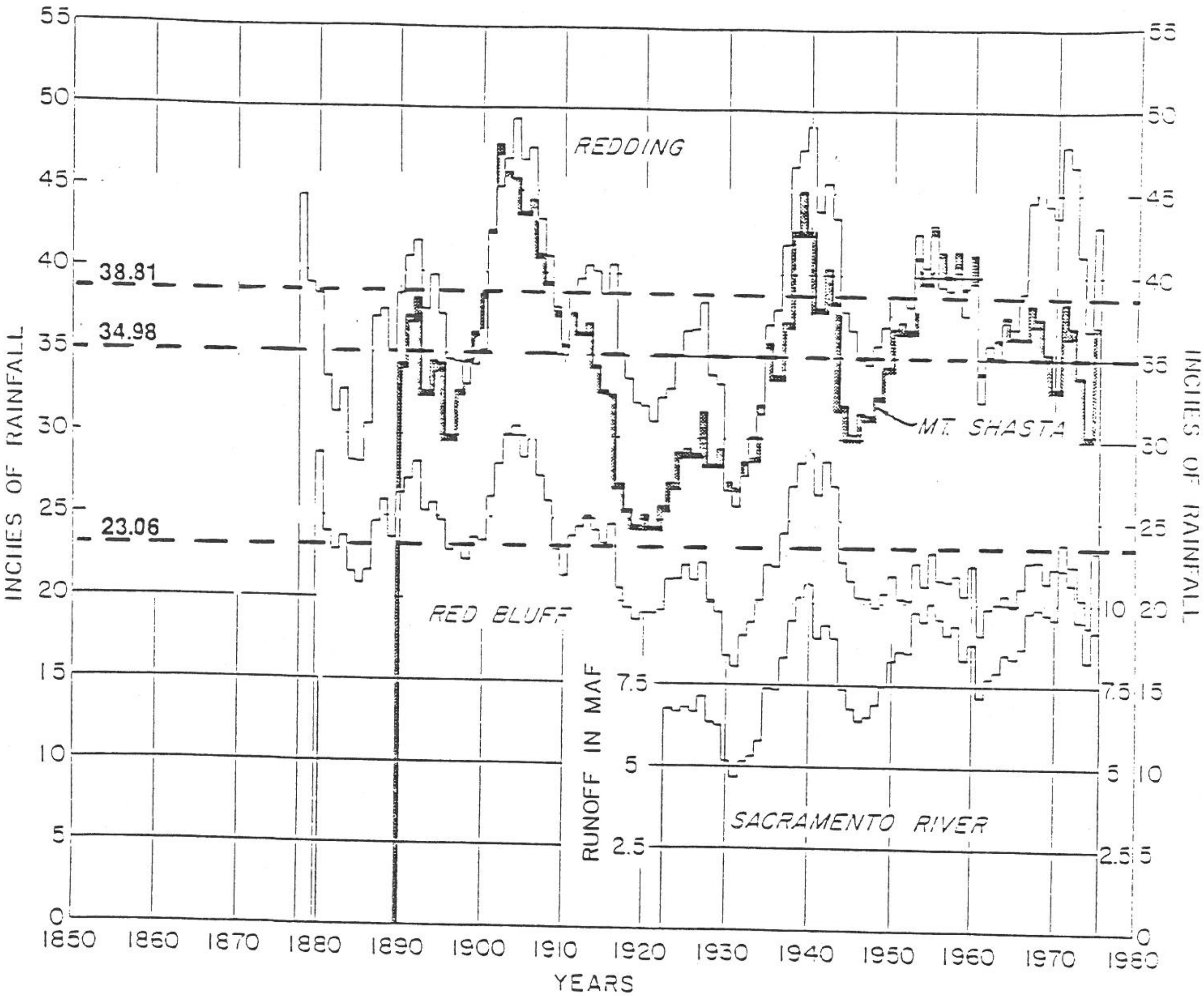


Fig. III.5 .Six-Year Moving Average of Rainfall and Runoff in Sacramento River Basin (taken from MWD, 1979)

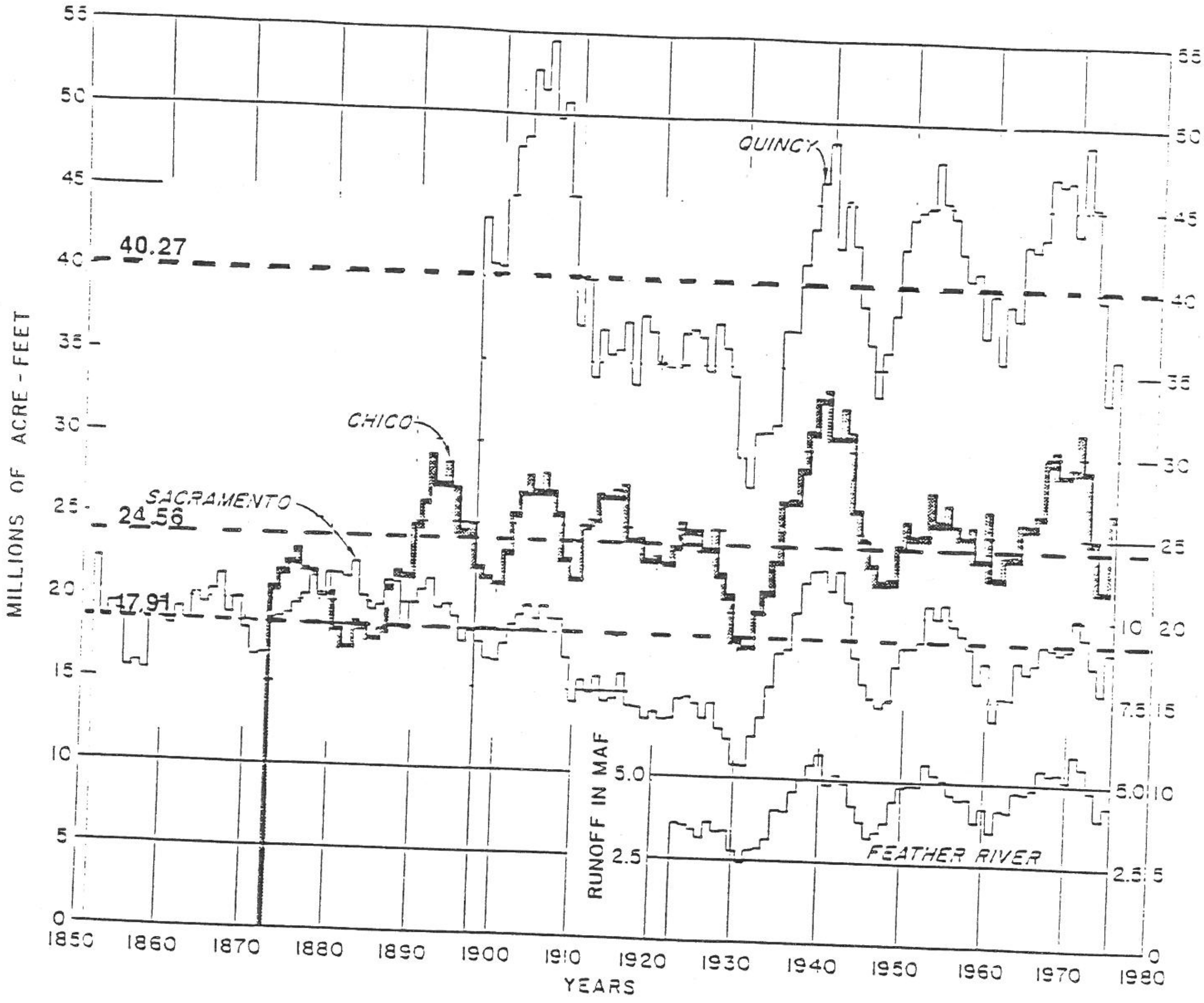


Fig.III.6 .Six-Year Moving Average of Rainfall and Runoff in Feather River Basin (taken from MWD,1979)

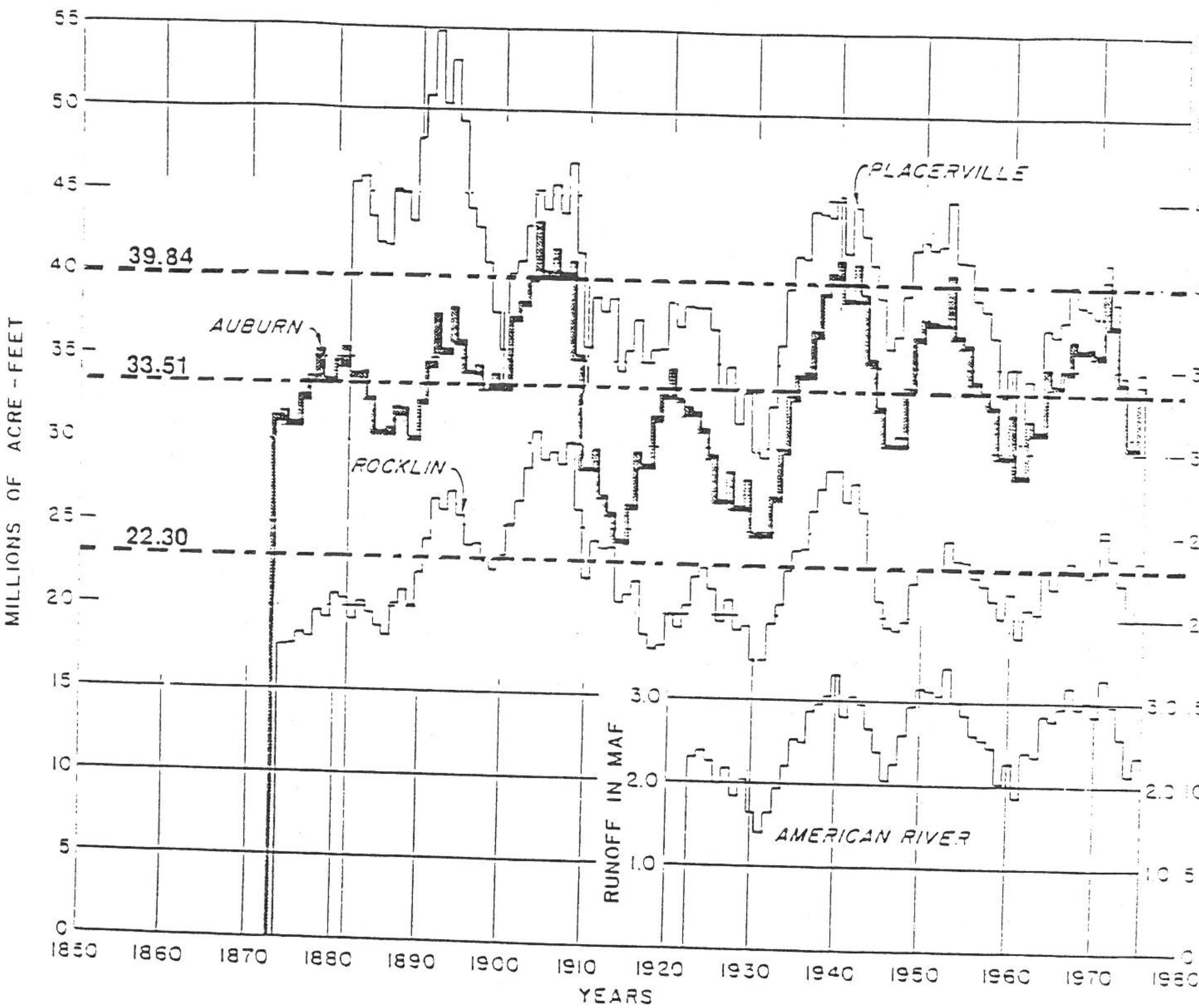


Fig. III.7 .Six-Year Moving Average of Rainfall and Runoff in American River Basin (taken from MWD,1979)

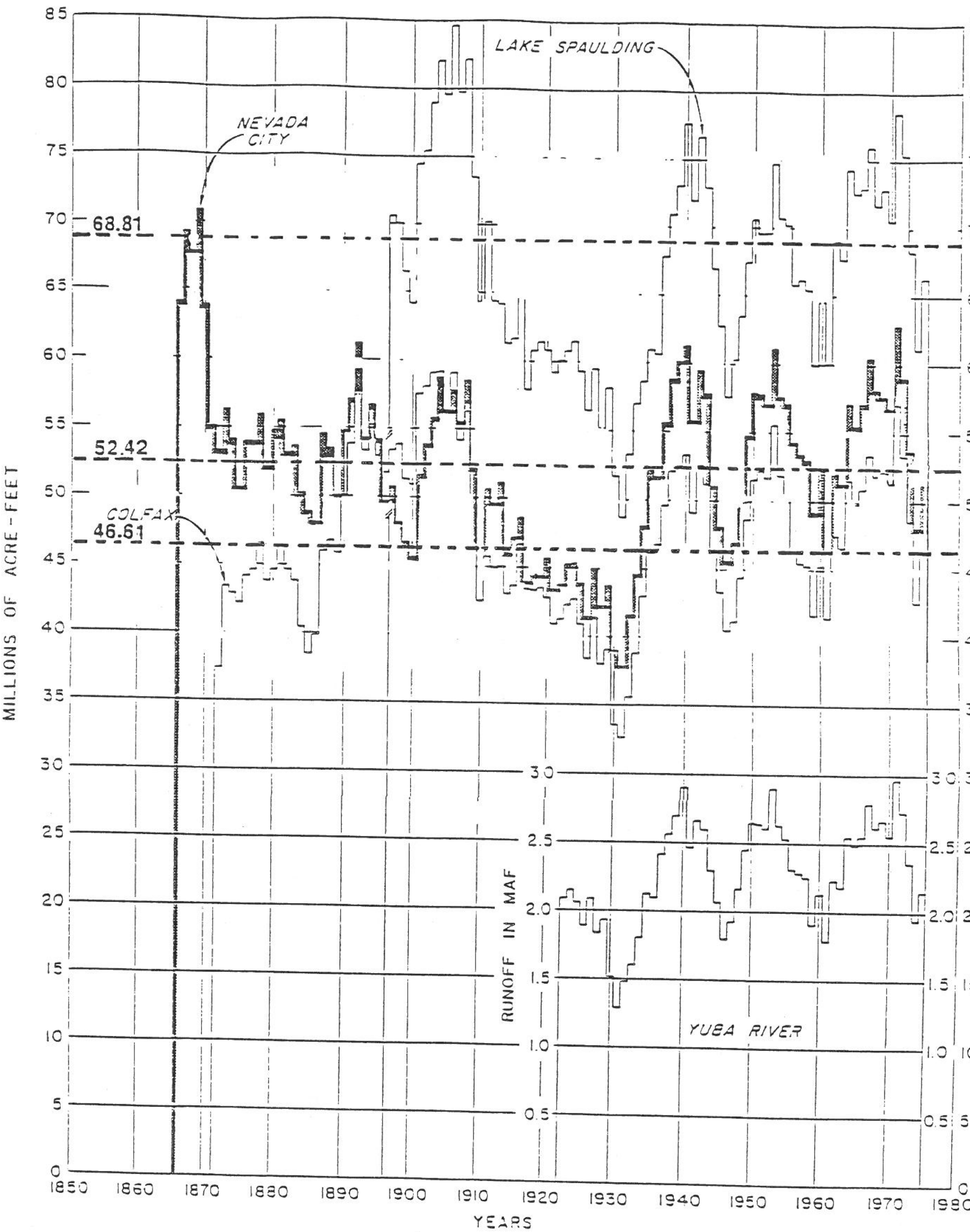


Fig. III.8 .Six-Year Moving Average of Rainfall and Runoff in Yuba River Basin (taken from MWD,1979)

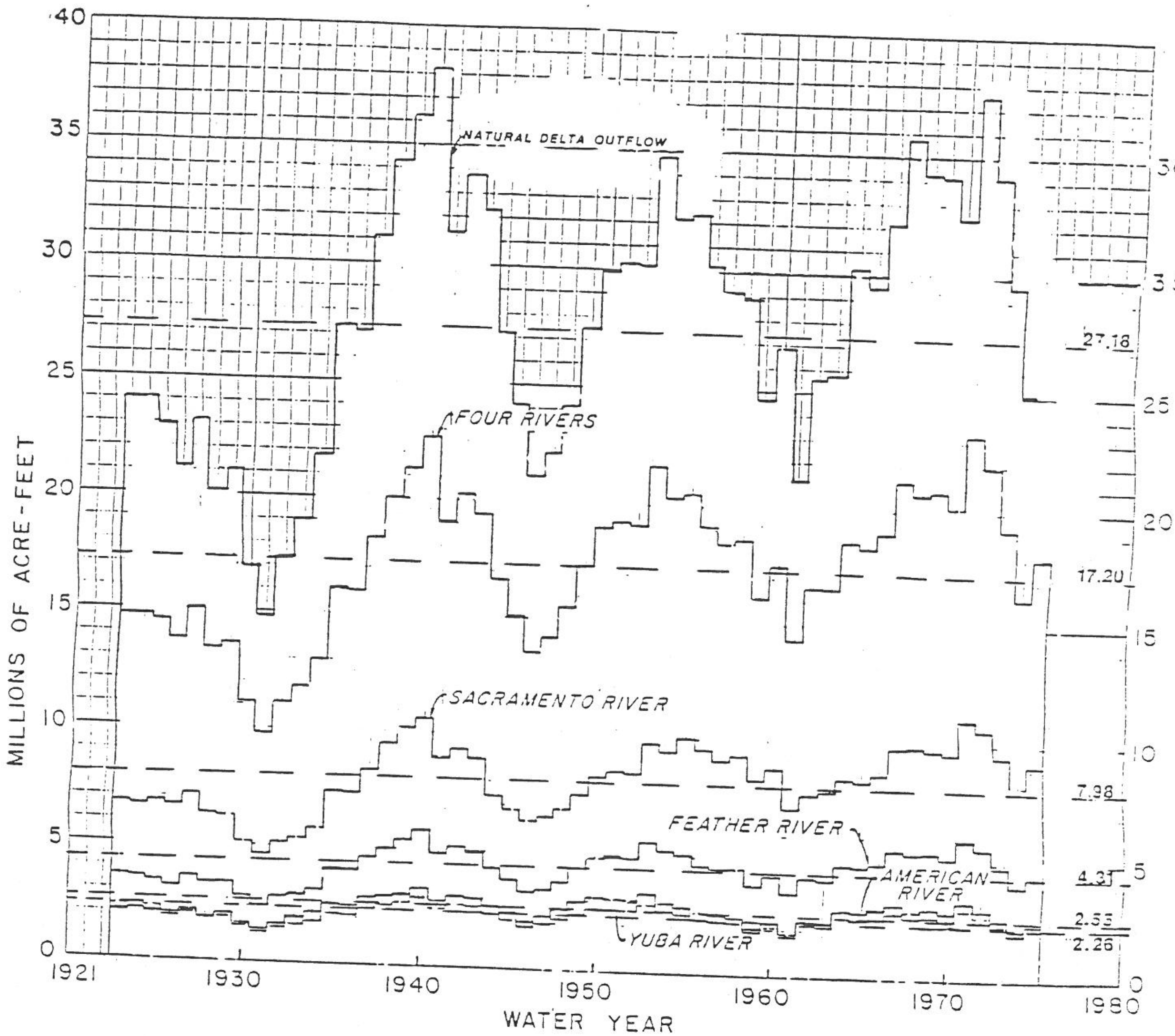


Fig.III.9. Six-Year Moving means of Natural Delta Outflow and Runoff Values of River in Four River Index (modified after MWD, 1979)

III.1 Dynamics of Wetness, Annual and Seasonal Deviations of 5-Year Running Mean Natural and Regulated Runoff

General Remarks

The analysis of the trend of fluctuations of 5-year running mean natural river inflow (NRI_5)* and regulated river inflow (RRI_5)* to the Delta and natural Delta outflow (NDO_5) and regulated Delta outflow (RDO_5) to the Bay, reveals the following patterns (Fig. III.10).

1. In more than 60% of the years, the deviations of natural water supply were ± 25-30% of the mean for the period (except for the very dry periods of the late 1920's which were documented as highly exceptional world-wide and which were attributed to high levels of sunspot activity and reductions of the albedo of the Earth-Budyko, 1972). There is strong evidence for periodicity of different cycles of wetness, (above normal, normal and sub-normal).

However, the cycles of deviation were not an exclusive phenomenon of the combined runoff to the San Francisco Bay. Other rivers located in different climatological zones elsewhere in the United States and in the USSR, demonstrate the same phenomenon (Figs. III, 1,4,10-14). This supports our earlier hypothesis that the predominant range of flow supply fluctuations of 25-30% above and below the mean flow for at least 50-60-year periods is the typical feature of many major estuaries. This leads to the conclusion that estuarine characteristics, adjusted to this range of natural fluctuations over many decades, can tolerate deviations in water supply to the system resulting from artificial management, if they do not exceed this range of natural deviations (Rozengurt and Herz, 1981; Rozengurt et al., 1987; Hedgpeth and Rozengurt, 1987).

2. For the Sacramento-San Joaquin system, the normalized trend of deviations of natural and regulated upstream (NRI_5, RRI_5) and downstream (NDO_5, RDO_5) runoff had similar features over the course of 55 years. This trend may be divided into six periods of different wetness:

Low flow (below the normal):	from 1921-25 until 1933-37	
	from 1943-47 until 1947-51	
	from 1957-61 until 1960-64	
High flow (above the normal):	from 1934-38 until 1942-46	
	from 1948-52 until 1956-60	
	from 1963-67 until 1972-76	

*NOTE: NRI_5, RRI_5, NDO_5 and RDO_5 denote the flow characteristics 5-year running means.

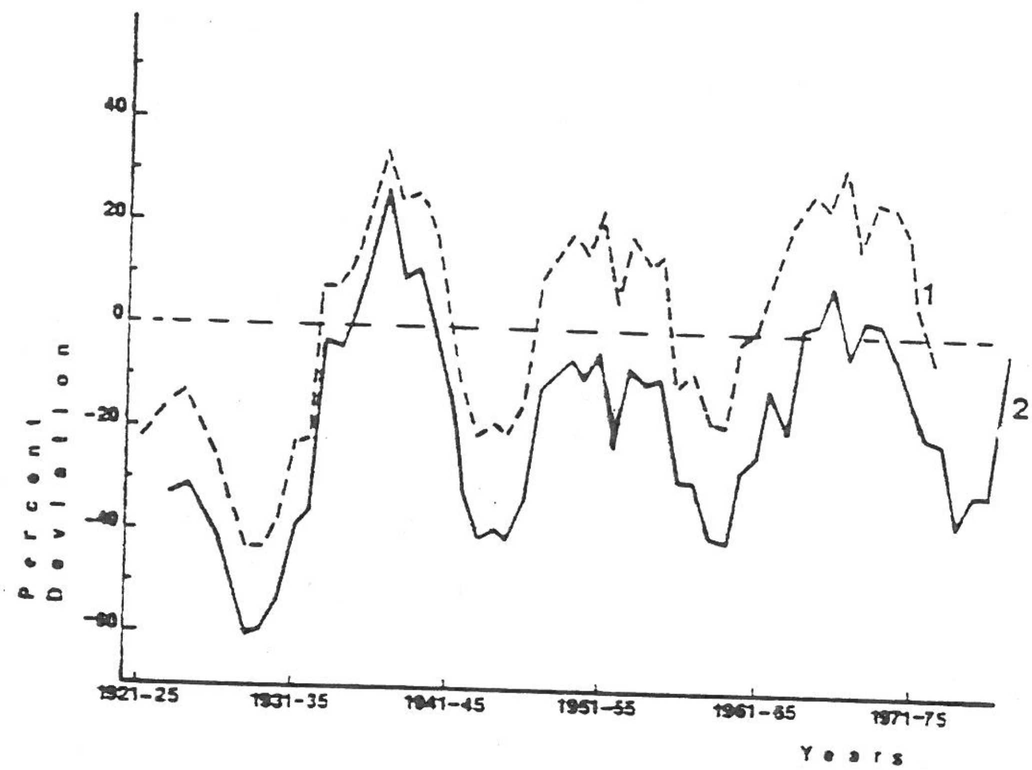


Fig.III.10.Annual Deviations (in percentage) in (1) Natural and (2) Regulated River Inflow from the Annual Mean Natural River Inflow (Q = 28.31 MAF; 1921-78), calculated with 5-year running averages.

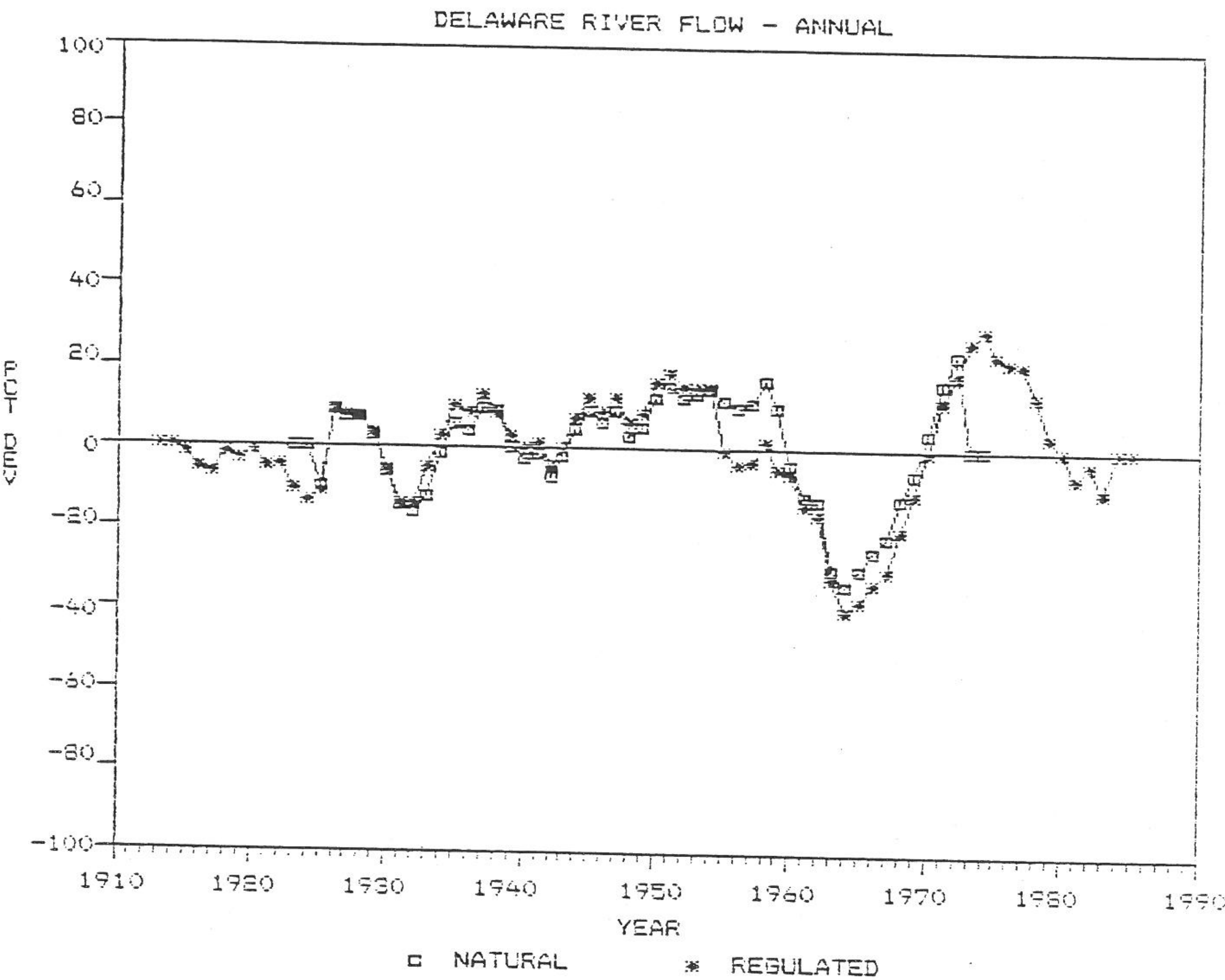


Fig.III.11. Percentage deviation of the Annual natural and regulated flow of the Delaware River at Trenton, N.J. from its normal (Q= 8.96 MAF; 1913-85), calculated with 5-year running means.

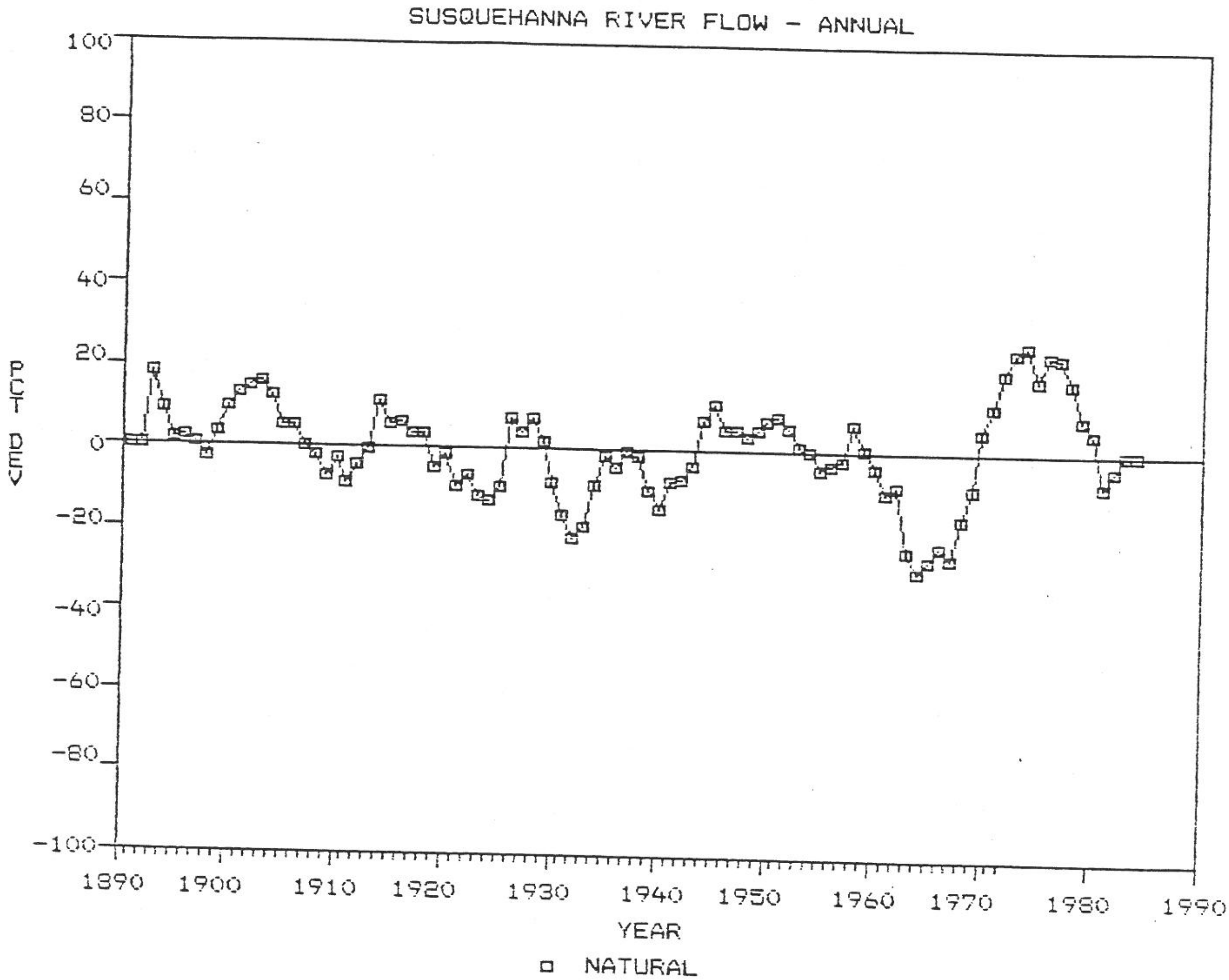


Fig. III.12 Percentage deviation of the Annual natural flow of the Susquehanna River, at Harrisburg, Pa., from its normal (Q= 25.32 MAF; 1891-84), calculated with 5-year running means.

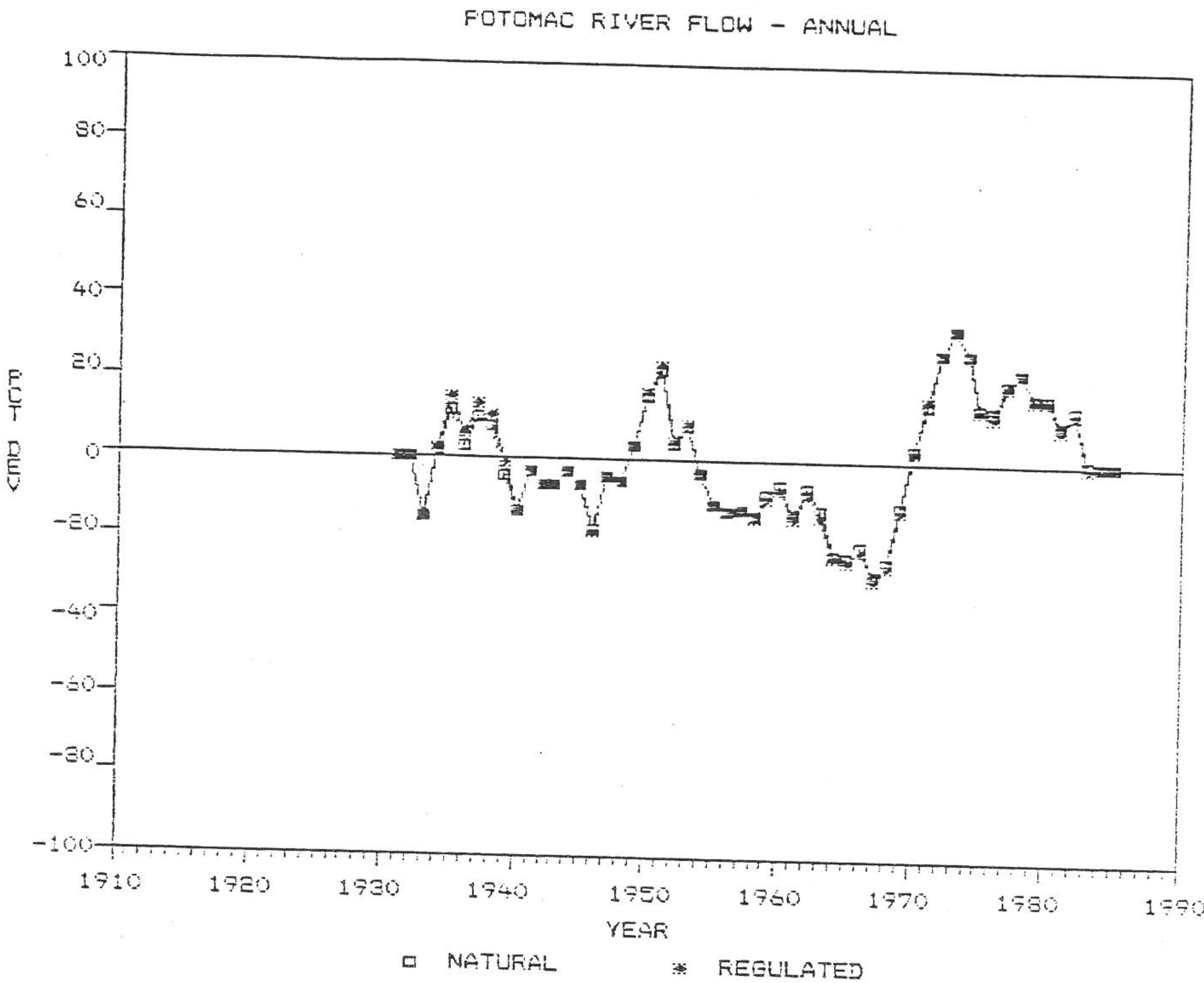


Fig. III.13 . Percentage deviation of the Annual natural and regulated flow of the Potomac River, near Washington, D.C., from its normal (Q= 8.46 MAF; 1931-85), calculated with 5-year running means.

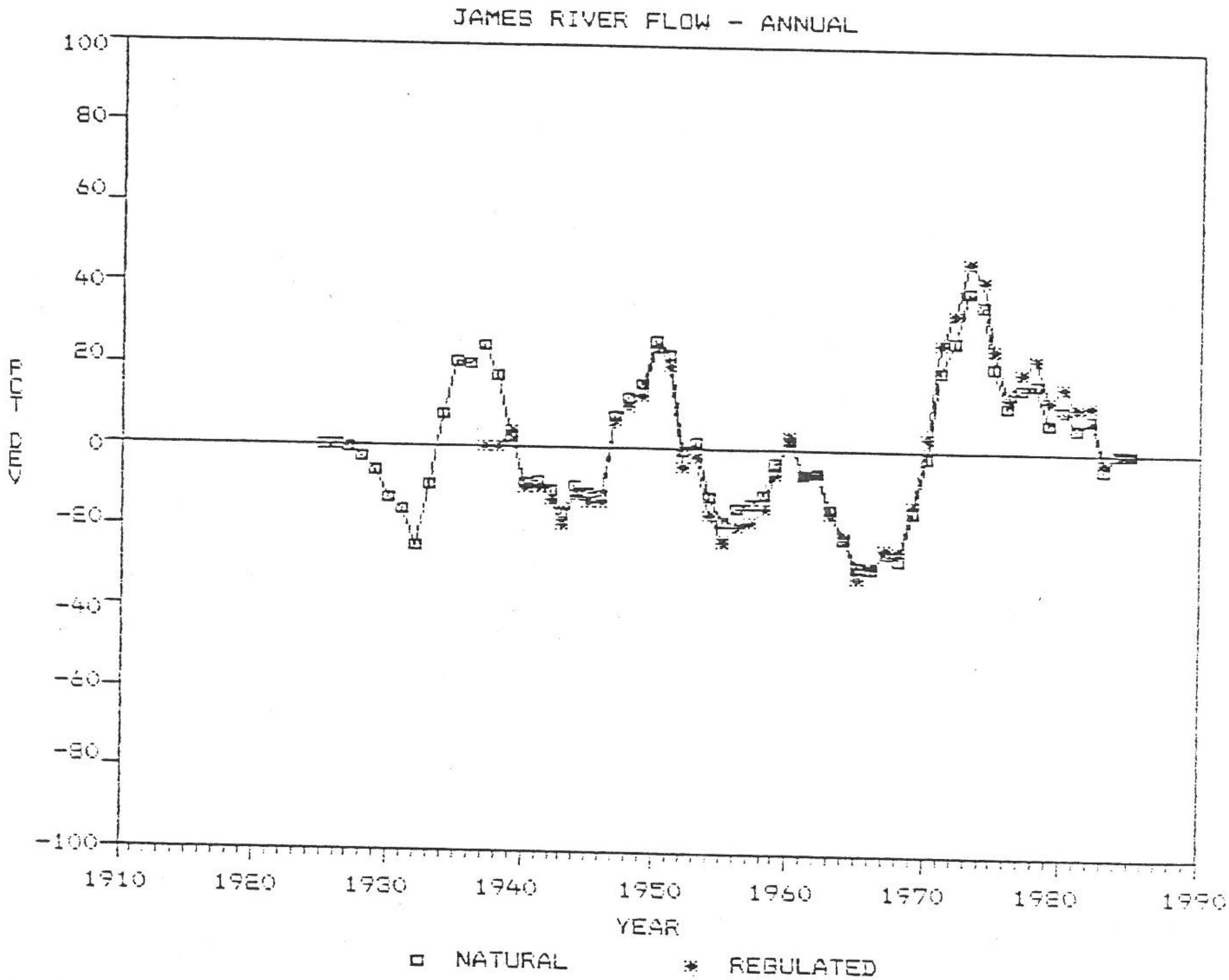


Fig. III.14 . Percentage deviation of the Annual natural and regulated flow of the James River, at Cartersville, Va., from its normal (Q= 5.03 MAF; 1925-85), calculated with 5-year running means.

The trend of deviations for the natural runoff characteristics represents the stochastic components of water balance of the system, i.e., natural runoff to the system without the influence of human regulation, while the trend of regulated characteristics of runoff reflects the combined effect of climatological and anthropogenic factors governing runoff. In this case, the mean regulated water supply to the Bay is comprised of two components: stochastic and deterministic.

3. Because natural factors prevail over human-induced factors, that is, the range of annual water withdrawals is less than the range of natural annual fluctuations, the trend of deviations of these two variables coincides despite the significant differences in the absolute values of 5-year running means and corresponding deviations from normal.

The deviations from the normal runoff, in this context, illustrate the long-term impact of diversions on the natural water supply to the system.

4. On one hand, RRI_5 and RDO_5 are characterized by predominant large negative (percent) deviations from the normal, and on the other, by significant differences in the means of their absolute values (in MAF) for any given 5-year period. The predominant range of deviations of the RRI_5 was -20 to -40% and for RDO_5, -25 to -50%.

Since the inception of the project operations, RRI_5 was higher than the normal (slightly more than 8%) for only one period (1967-71). This was not the case for RDO_5. In practice, RDO did not approach the value of normal water supply to the estuary for any of the 5-year periods since the Shasta Reservoir (1944) and other CVP and SWP facilities were put into operation over the following twenty-nine years. Therefore, a significant amount of water was eliminated from the freshwater balance of the San Francisco Bay.

III.1.1 Dynamics of Wetness of 5-Year Running Periods: Annual

Tables III.1-13 describe the redistribution of number of periods of different wetness due to regulation of runoff in comparison with the unimpaired 5-year running runoff and show that: 1. Under natural conditions, more than 60% of the running means of water supply to the Bay fluctuated within 25% of normal since the beginning of regulation (including the post-project period), while the number of periods of sub-normal and dry years (i.e., 25% or more below normal) increased more than five times for RRI_5 and for RDO_5 and therefore more than 40% of the 5-year periods for regulated water supply fall into the category of lower than sub-normal wetness.

2. There were many fewer periods of highest abnormal wetness for RRI_5 and RDO_5 than there were for natural water supply NRI_5 and NDO_5 (Table III.1).

3. For the category of critical wetness a succession of 5-year running periods of very low flow (1928-34) ended because of regulation and was observed again only in 1975-79. In both sets of years, the impact of diversions was exacerbated by the natural lack of water.

Therefore, upstream and downstream post-project regulation has brought about a significant increase in periods of low wetness which cannot be attributed to natural conditions. Consequently, this development contributes to the overall reduction of 5-year running mean annual water supply to the system on a scale which the riverine-estuarine system has never experienced perhaps since records began in 1878.

III.1.2 Dynamics of Wetness of 5-Year Running Periods: Monthly

III.1.2.1 Winter (December, January, February, March)

For the winter period, the greatest changes in the number of periods of different wetness occurred for December and March.

1. For December the number of wettest and wet periods since project operations began declined for the RRI_5 and RDO_5 as much as 3-6 times (Table III.2). The number of critical dry periods for the RRI_5 and RDO_5 increased 3.4-4.3 times.

For the same period, there were no significant changes in the number of sub-normal and dry periods for RRI_5 and RDO_5 because of project operations, but the periods of critical dry wetness for RRI_5 and RDO_5 increased in response to both pre- and post-project water regulation.

2. January: The ratio of periods of different wetness before and after project operations began for January (Table III.3) did not change significantly except for the number of wettest and wet periods for RRI_5 since operations began. In general, the water supply for January is the most stable and the periods of different wetness for impaired and unimpaired flow did not change significantly.

3. For February (Table III.4) there were significant amounts of water for withdrawals, and therefore the wetness indices, especially for Delta outflow, are different after regulations. Thus, while the number of wet periods was reduced to less than half of pre-project levels, the amount of sub-normal and dry years increased almost two times.

In general, February experienced greater deficit than January, but less than that in March.

4. March shows routine signs of the impact of upstream and downstream regulation on the water supply of the river-Delta-Bay

ecosystem (Table III.5).

In general, the number of wet periods for RRI_5 and RDO_5 was reduced to as little as half, the number of sub-normal and critical dry periods increased several times, and the critical dry years appeared which did not occur under natural conditions of runoff in the system.

Therefore, winter season water regulation is characterized by an overall decrease in the number of periods of high and normal wetness, and by an increase in the number of periods of sub-normal wetness. Both of these trends continue into the spring months where they reach their peaks.

III.1.2.2 <u>Spring</u> (April, May, June)

1. The typical feature in the distribution of periods of different wetness for this season is that the wet periods (i.e., when the runoff is higher by 25% or more than the mean) ceased to exist for both RRI_5 and RDO_5 (Tables III.6-8).

2. However, the number of 5-year periods of sub-normal wetness of the RRI_5 and RDO_5 increased 8-10 times for April, 4-5 times for May, and 1.6-2.3 times for June.

3. Although under conditions of unimpaired runoff there were no 5-year periods with means as much as 50% of normal for spring, a new characteristic of regulated water supply appeared due to diversions, especially for the post-project period. That is, a predominant number of the RRI_5 and RDO_5 were characterized as critical dry.

This trend is of great concern because it describes the beginning of a chronic deficit in water supply in the upstream and downstream sections of the Sacramento-San Joaquin basin. It means that since the late 1950's, this deficit was exacerbated by water withdrawals during the major part of winter that resulted in the development of a precarious water balance in the Delta and San Francisco Bay for all of the other seasons. This tendency persisted for almost three decades for the spring as well as winter, that is, for the seasons from which almost 80% of the water supply was derived under conditions of natural runoff fluctuations.

III.1.2.3 <u>Summer</u> (July, August)

The regulation of water supply for these months has two distinct features (almost the same as for autumn).

1. <u>July</u> water supply for 5-year periods was not improved by regulation. For the RRI_5 and RDO_5 wet periods ceased to exist (see Table III.9). At the same time, there was a drastic increase in the number of dry and critical dry periods of

wetness, which did not occur under natural conditions for the 1921-78 period, even in the case of 1929-34, considered as one of the periods of lowest water supply since records began.

At the same time, the number of periods of sub-normal and dry years (i.e., 25% or more below normal) increased as much as two times for RRI_5, but remained unchanged for RDO_5 in comparison with NDO_5.

While the 5-year periods for July may be characterized as having a deficit in water supply, that was not the case for August.

2. August: Water releases either from storage facilities or from the drainage network for both July and August radically modified the 5-year running mean water supply (Table III.10). Whether this was a positive or negative event for the river and Delta is impossible to determine because there were no appropriate data on the quality of incoming water. However, the number of wet periods occurring after the beginning of project operations increased significantly for RRI_5 (11 times) although at the same time decreased for RDO_5 (1.5 times). At the same time, the number of sub-normal and dry years for RRI_5 changed very little relative to NRI_5 while there were three times more such periods for RDO_5.

It should be noted that during the pre-project period, water regulation was so extensive that there were thirteen 5-year periods of critical dry water supply for RRI_5 and none for NRI_5 during the same period. However, due to increases in water releases during August for the post-project period, there were no cases of critical years of wetness for the RRI_5 and RDO_5 during the past three decades.

For summer, only July does not reflect an improvement in its water regime, while the runoff characteristics for August (i.e., water supply for 5-year periods) increased significantly due to artificial regulation of streamflow.

III.1.2.4 Autumn (September, October, November)

1. The water supply (5-year periods) for the first two months of autumn is different from that of November (Tables III.11-13), but at the same time illustrate an even greater increase in wetness than August. The number of wettest and wet 5-year periods for September and October for RRI_5 and RDO_5 increased greatly (2-11 times).

At the same time, since the start of project operations, there have been no sub-normal, dry or critical 5-year periods for RRI_5 or RDO_5. This suggests that the long-term post-project hydrological regime in the River-Delta system is quite different than what would have been observed under natural fluctuations of runoff, or even under regulated conditions for the pre-project period.

2. In contrast to the two preceding months, November had less pronounced changes attributable to late Autumn releases from storage, especially for the post-project period in the wettest and wet years relative to NRI_5 and RRI_5.

3. The number of wet periods for RDO_5 was reduced to almost one third, but the number of sub-normal and critical periods increased 1.3-1.6 times. Therefore, the water supply in November, as calculated for 5-year periods, has been subjected to changes, and as a result, did not contribute many wettest and wet periods typical of NDO_5.

In conclusion, the upstream and downstream water withdrawals and diversions significantly reduced water supply to the entire River-Delta-Bay ecosystem.

The number of wet and above-normal 5-year periods of water supply were reduced many times, and in some vital months of winter and spring were eliminated.

Table III.1 The number of 5-year running mean periods of runoff of different wetness in relation to the normal - Annual

Runoff Character-istics	Wettest and Wet Periods	Number of Periods	Sub-normal and Dry Periods	Number of Periods	Critical Dry Periods	No. of Pds.
Qnri	3741* 3842, 4044, 6569, 6771, 6973	6	2832, 2933, 3034, 3135	4		0
Qrri	3842	1	2425, 2529, 2630, 2731, 3236, 3337, 4347, 4448, 4549, 4650, 4751, 5761, 5862, 5963, 6064, 6165, 6266, 7579, 7680, 7781,	20	2832, 2933, 3034, 3135	4
Qndo	3741, 3842, 3943, 4044, 5256, 6569, 6670, 6771, 6973, 7074, 7175	11	2832, 2933, 3034, 3135	4		0
Qrdo	3842	1	2226, 2327, 2428, 2529, 2630, 2731, 3236, 3337, 4347, 4448, 4549, 4650, 4751, 5761, 5862, 5963, 6064, 6165, 6266, 6468, 7276, 7377, 7478, 7680, 7781	25	2832, 2933, 3034, 3135, 7579	5

<u>Note</u>:

1. Wettest and wet periods - the Qnri and Qrri and Qndo and Qrdo of any period are 25% or more above "normal" for the month (28.3 and 27.2 MAF, respectively).

2. Sub-normal and dry periods of wetness - when the same runoff parameters are 25% or more below "normal."

3. Critical dry periods of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

*Tabled numbers represent 5-year periods, e.g., 3741 = 1937-1941.

Table III.2 The number of 5-year running mean periods of runoff of different wetness in relation to the normal - December

Runoff Character-istics	Wettest and Wet Periods	Number of Periods	Sub-normal and Dry Periods	Number of Periods	Critical Dry Periods	No. of Pds.
Qnri	3842* 4246, 4953, 5054, 5155, 5256, 5357, 5458, 5559, 5660, 6165, 6266, 6367, 6468, 6569, 6771, 6973, 7074	18	2226, 2327, 2428, 2529, 2630, 2731, 2832, 2933, 3034, 3640, 5862, 5963, 6064	13	3135, 3236, 3337, 5761	4
Qrri	3842, 5155, 5256, 6367, 7074, 7175	6	2425, 2529, 2630, 2731, 2832, 3034, 6064	7	2933, 3135, 3236, 3337, 5761, 5862, 5963, 7579, 7680, 7781	10
Qndo	3842, 4246, 4953, 5054, 5155, 5256, 5357, 5458, 5559, 5660, 6165, 6266, 6377, 6468, 6569, 6771, 6973, 7074	18	2226, 2327, 2428, 2529, 2630, 2731, 2832, 2933, 3034, 3236, 3640, 5862, 5963, 6064	14	3135, 3337, 5761	3
Qrdo	5155, 5256, 6367	3	2226, 2327, 2529, 2630, 2731, 2832, 3438, 3539, 3640, 4448, 4549, 4650, 7377, 7470, 7882	15	2428, 2933, 3034, 3135, 3236, 3337, 5761, 5862, 5963, 6064, 7579, 7680, 7781	13

Note:

1. Wettest and wet periods - the Qnri and Qrri and Qndo and Qrdo of any period are 25% or more above"normal" for the month (2.44 and 2.52 MAF, respectively).

2. Sub-normal and dry periods of wetness - when the same runoff parameters are 25% or more below "normal."

3. Critical dry periods of wetness - when the Qnri, Qrri, Qndo are 50% or more below "normal."

*Tabled numbers represent 5-year periods, e.g., 3842 = 1938-1942.

Table III.3 The number of 5-year running mean periods of runoff of different wetness in relation to the normal - January

Runoff Characteristics	Wettest and Wet Periods	Number of Periods	Sub-normal and Dry Periods	Number of Periods	Critical Dry Periods	No. of Pds.
Qnri	3943* 4044, 5156, 6569, 6670, 6771, 6872, 6973, 7074	9	2125, 3236, 3397, 3438, 3539, 4448, 4650, 4751, 5761, 5862	10	2226, 2327, 2428, 2529, 2630, 2731, 2832, 2933, 3034, 3135, 4549, 5963 6064	13
Qrri	3943, 4044, 4953, 5054, 5155, 5256, 5357, 6569, 6670, 6771, 6872, 6973, 7074, 7175	14	3135, 3236, 3337, 3438, 3539, 3640, 4448, 4549, 4650, 4751, 7579	11	2425, 2529, 2630, 2731, 2832, 2933, 3034, 5761, 5862, 5963, 6064	11
Qndo	3443, 4043, 5054, 5155, 5256, 5357, 6569, 6670, 6771, 6972, 6973, 7074, 7175	13	2125, 3236, 3337, 3438, 3539, 4650 4751, 5761, 5862	9	2226, 2327, 2428, 2529, 2630, 2731, 2832, 2933, 3034, 3135, 4448	14
Qrdo	3943, 4044, 5054, 5155, 5256, 5357, 6569, 6670, 6771, 6872, 6973, 7074	12	3135, 3236, 3337, 3438, 3539, 3640, 4448, 4549, 4650, 4751, 6165	11	2226, 2327, 2428, 2529, 2630, 2731, 2832, 2933, 3034, 5761, 5862, 5963, 6064, 7579	14

<u>Note</u>:

1. Wettest and wet periods - the Qnri and Qrri and Qndo and Qrdo of any period are 25% or more above "normal" for the month (3.35 and 3.54 MAF, respectively).

2. Sub-normal and dry periods of wetness - when the same runoff parameters are 25% or more below "normal."

3. Critical dry periods of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

*Tabled numbers represent 5-year periods, e.g., 3943 = 1939-1943

Table III.4 The number of 5-year running mean periods of runoff of different wetness in relation to the normal - February

Runoff Character-istics	Wettest and Wet Periods	Number of Periods	Sub-normal and Dry Periods	Number of Periods	Critical Dry Periods	Numbe of Perio
Qnri	3640* 3741, 3842, 3943, 4044, 4145, 5458, 5559, 5660, 5761, 5862	11	2832, 4448, 4549, 4751, 6468, 7377, 7478	7	2933, 3034, 3135, 4650	4
Qrri	3438, 3640, 3741, 3842, 3943, 4044, 4145, 6670, 6771, 6973	10	2731, 3236, 4347, 4448, 4751, 5357, 6468, 7377, 7478, 7579	10	2832, 2933, 3034, 3135, 4549, 4650	6
Qndo	2428, 2529, 3438, 3640, 3741, 3842, 3943, 4044, 4145, 5660, 5862	14	2832, 4448, 4549, 4650, 4751, 6468,	7	2933, 3034, 3135	3
Qrdo	3640, 3741, 3842, 6670, 6771, 6973	6	2731, 2832, 4347, 4448, 4549, 4751, 5357, 6468, 7377, 7478	13	2933, 3034, 3135, 4650, 7579	5

Note:

1. Wettest and wet periods - the Qnri and Qrri and Qndo and Qrdo of any period are 25% or more above "normal" for the month (3.84 and 3.92 MAF, respectively).

2. Sub-normal and dry periods of wetness - when the same runoff parameters are 25% or more below "normal."

3. Critical dry periods of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

*Tabled numbers represent 5-year periods, e.g., 3640 = 1936-1940.

Table III.5 The number of 5-year running mean periods of runoff of different wetness in relation to the normal - March

Runoff Character-istics	Wettest and Wet Periods	Number of Periods	Sub-normal and Dry Periods	Number of Periods	Critical Dry Periods	No. of Pds.
Qnri	3438* 3539, 3640, 3741, 3842, 3943, 4044, 7074, 7175, 7276, 7478	11	2226, 2327, 2933, 3034, 3135, 3236, 4448, 6064, 6165, 6266	10		0
Qrri	3438, 3539, 3640, 3741, 3842, 3943, 4044	7	2832, 3034, 3236, 4448, 4549, 4650, 4751, 5357, 5963, 6064, 6367, 6468, 7276, 7377, 7478, 7579	16	2933, 3135, 6165,	4
Qndo	3438, 3539, 3640, 3741, 3842, 3943, 4044, 7074, 7175, 7276, 7478	14	2125, 2226, 2327, 2933, 3034, 3135, 3236, 4448, 6064, 6165, 6266	14		0
Qrdo	3438, 3539, 3640, 3741, 3842, 3943, 4044	7	2832, 2933, 3034, 3236, 4448, 4549, 4650, 4751, 5357, 5963, 6468, 6569, 6872, 7276, 7377, 7478, 7579, 7680	18	2226, 3135, 6064, 6165, 6266, 6367	6

<u>Note</u>:

1. Wettest and wet periods - the Qnri and Qrri and Qndo and Qrdo of any period are 25% or more above "normal" for the month (3.85 and 3.89 MAF, respectively).
2. Sub-normal and dry periods of wetness - when the same runoff parameters are 25% or more below "normal."
3. Critical dry periods of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

*Tabled numbers represent 5-Cyear periods, e.g., 3438 = 1934-1938.

Table III.6 The number of 5-year running mean periods of runoff of different wetness in relation to the normal - April

Runoff Characteristics	Wettest and Wet Periods	Number of Periods	Sub-normal and Dry Periods	Number of Periods	Critical Dry Periods	No. of Pds.
Qnri	3438* 3539, 3741, 3842	4	2832, 2933, 3034	3		0
Qrri	3741, 3842	2	2731, 2832, 3135, 3236, 4246, 4347, 4448, 4549, 4650, 4751, 4953, 5155, 5256, 5559, 5660, 5761, 5862, 5963, 6064, 6165, 6266, 6468, 6569, 6670, 6771, 7074, 7175, 7276, 7377, 7478	30	2933, 3034, 5357,	8
Qndo	3438, 3539, 3741, 3842	4	2832, 2933, 3034	3		0
Qrdo	3741	1	2731, 3135, 3236, 4246, 4347, 4448, 4549, 4650, 4751, 4953, 5155, 5256, 5559, 5660, 5761, 5862, 6165, 6266, 6569, 6670, 6771, 7074, 7175, 7276, 7478, 7882	26	2832, 2933, 3034, 5357, 5963, 6064, 6468, 6872, 6973, 7377, 7579, 7680, 7781	13

Note:

1. Wettest and wet periods - the Qnri and Qrri and Qndo and Qrdo of any period are 25% or more above "normal" for the month (4.14 and 4.10 MAF, respectively).

2. Sub-normal and dry periods of wetness - when the same runoff parameters are 25% or more below "normal."

3. Critical dry periods of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

*Tabled numbers represent 5-year periods, e.g., 3438 = 1934-1938.

Table III.7 The number of 5-year running mean periods of runoff of different wetness in relation to the normal - May

Runoff Character-istics	Wettest and Wet Periods	Number of Periods	Sub-normal and Dry Periods	Number of Periods	Critical Dry Periods	No. of Pds.
Qnri	3539* 3741, 3842, 5256, 5458, 6569, 6771	7	2731, 2832, 2933, 3034, 3135	5		0
Qrri		0	2425, 2529, 3236, 3337, 4246, 4347, 4448, 4549, 4650, 4751, 4953, 5054, 5155, 5256, 5357, 5458, 5559, 5660, 6367, 6569, 6670, 6771	22	2630, 2731, 2832, 2933, 3034, 3135, 5761, 5862, 5963, 6064, 6165, 6266, 6468, 6872, 6973, 7074, 7175, 7276, 7377, 7478, 7579, 7680, 7781	23
Qndo	3741, 3842, 6771	3	2731, 2832, 2933, 3034, 3135	5		0
Qrdo		0	2226, 2327, 2529, 3236, 3337, 4246, 4448, 4549, 4650, 4751, 4953, 5054, 5155, 5256, 5357, 5458, 5559, 5660, 6367, 6569, 6771	21	2428, 2630, 2731, 2832, 2933, 3034, 3135, 4347, 5761, 4861, 5963, 6064, 6165, 6266, 6468, 6670, 6872, 6973, 7074, 7175, 7276, 7377, 7478, 7579, 7680, 7781, 7882	27

Note:

1. Wettest and wet periods - the Qnri and Qrri and Qndo and Qrdo of any period are 25% or more above "normal" for the month (4.26 and 4.15 MAF, respectively).

2. Sub-normal and dry periods of wetness - when the same runoff parameters are 25% or more below "normal."

3. Critical dry periods of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

*Tabled numbers represent 5-year periods, e.g., 3539 = 1935-1939.

Table III.8 The number of 5-year running mean periods of runoff of different wetness in relation to the normal - June

Runoff Character-istics	Wettest and Wet Periods	Number of Periods	Sub-normal and Dry Periods	Number of Periods	Critical Dry Periods	No. of Pds.
Qnri	3842* 5256, 6569, 6771	4	2327, 2428, 2529, 2630, 2731, 2832, 2933, 3034, 5963, 6064	10		0
Qrri		0	3236, 3337, 3943, 4246, 4448, 4549, 4650, 4852, 4953, 5054, 5155, 5256, 5357, 5458, 5559, 5660, 6367, 6468, 6569, 6670, 6872, 6973, 7175	23	2428, 2529, 2630, 2731, 2832, 2933, 3034, 3135, 4347, 4751, 5761, 5862, 5963, 6064, 6165, 6266, 7074, 7276, 7377, 7478, 7579, 7680, 7781,	23
Qndo	3842, 5256, 6569, 6771	4	2327, 2428, 2529, 2630, 2731, 2832, 2933, 3034, 5963	9		0
Qrdo		0	2226, 3236, 3337, 3943, 4246, 4953, 5054, 5155, 5256, 5458, 5559, 5660, 6367, 6569, 6670, 6771	16	2327, 2428, 2529, 2630, 2731, 2832, 2933, 3034, 3135, 4347, 4448, 4549, 4650, 4751, 5357, 5761, 5862, 5963, 6064, 6165, 6266, 6468, 6872, 6973, 7074, 7175, 7276, 7377, 7478, 7579, 7680, 7781, 7882	33

Note:

1. Wettest and wet periods - the Qnri and Qrri and Qndo and Qrdo of any period are 25% or more above"normal" for the month 2.65 and 2.51 MAF, respectively).

2. Sub-normal and dry periods of wetness - when the same runoff parameters are 25% or more below "normal."

3. Critical dry periods of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

*Tabled numbers represent 5-year periods, e.g., 3842 = 1938-1942.

Table III.9 The number of 5-year running mean periods of runoff of different wetness in relation to the normal - July

Runoff Character-istics	Wettest and Wet Periods	Number of Periods	Sub-normal and Dry Periods	Number of Periods	Critical Dry Periods	No. of Pds.
Qnri	3842* 4145, 5256, 6367, 6569, 6670, 6771	7	2428, 2630, 2731, 2832, 2933, 3034, 3135, 3337, 4650, 4751	10		0
Qrri		0	3438, 3539, 3640, 3741, 3943, 4044, 4145, 4246, 4852, 4953, 5054, 5155, 5761, 5862, 5963, 6064, 6165	20	2425, 2529, 2630, 2731, 2832, 2933, 3034, 3135, 3236, 3337, 4347, 4448, 5357	16
Qndo	3842, 4044, 4145, 5256, 6367, 6569, 6670, 6771	8	2428, 2529, 2630, 2731, 2832, 2933, 3034, 3135, 3236, 3337, 4549, 4650, 4751, 5963, 6064	15		0
Qrdo		0	3741, 4145, 4852, 4953, 5256, 6367, 6468, 6569, 6670, 6872, 6973, 7074, 7175, 7276, 7882	15	2226, 2327, 2428, 2529, 2630, 2731, 2832, 2933, 3034, 3135, 3236, 3337, 3438, 3539, 3640, 3943, 4044, 4246, 4347, 4448, 4549, 4650, 4751, 5054, 5155, 5357, 5458, 5559, 5660, 5761, 5862, 5963, 6064, 6165, 6266, 7377, 7478, 7579, 7680, 7781	40

Note:

1. Wettest and wet periods - the Qnri and Qrri and Qndo and Qrdo of any period are 25% or more above "normal" for the month (1.04 and 0.83 MAF, respectively).

2. Sub-normal and dry periods of wetness - when the same runoff parameters are 25% or more below "normal."

3. Critical dry periods of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

*Tabled numbers represent 5-year periods, e.g., 3842 = 1938-1942.

Table III.10 The number of 5-year running mean periods of runoff of different wetness in relation to the normal - August

Runoff Character-istics	Wettest and Wet Periods	Number of Periods	Sub-normal and Dry Periods	Number of Periods	Critical Dry Periods	No. of Pds.
Qnri	6569* 6771	2	2731, 2832, 2933, 3034, 3135	5		0
Qrri	5660, 5761, 5862, 5963, 6064, 6165, 6266, 6367, 6468, 6569, 6670, 6771, 6872, 6973, 7074, 7175, 7276, 7377, 7579, 7680, 7781,	22	3741, 3842, 3943, 4044, 4145, 4246, 4347	7	2425, 2529, 2630, 2731, 2832, 2933, 3034, 3135, 3236, 3337, 3438, 3539, 3650	13
Qndo	3842, 4145, 5256, 5458, 6367, 6468, 6569, 6670, 6771, 6872, 7175, 7478	12	2327, 2428, 2529, 2630, 2731, 2731, 3337, 4650, 4751	9	2832, 2933, 3034, 3135	4
Qrdo	6569, 6670, 6771, 6872, 6973, 7074, 7175, 7276	8	2226, 2327, 2428, 2529, 2630, 2731, 2832, 2933, 3034, 3135, 3236, 3337, 3438, 3539, 3640, 3741, 3841, 3943, 4044, 4145, 4246, 4347, 4448, 4650, 5357, 7781	26		0

Note:

1. Wettest and wet periods - the Qnri and Qrri and Qndo and Qrdo of any period are 25% or more above the mean "normal" for the month (0.54 and 0.32 MAF, respectively).

2. Sub-normal and dry periods of wetness - when the same runoff parameters are 25% or more below "normal."

3. Critical dry periods of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

*Tabled numbers represent 5-year periods, e.g., 6569 = 1965-1969.

Table III.11 The number of 5-year running mean periods of runoff of different wetness in relation to the normal - September

Runoff Character-istics	Wettest and Wet Periods	Number of Periods	Sub-normal and Dry Periods	Number of Periods	Critical Dry Periods	No. of Pds.
Qnri	5559, 7175, 7478	3	2832, 2933, 3034, 3135, 3236, 3337	6		0
Qrri	4549, 4650, 4751, 4852, 4953, 5054, 5155, 5256, 5357, 5458, 5559, 5660, 5771, 5862, 5963, 6064, 6165, 6266, 6367, 6468, 6569, 6670, 6771, 6872, 6973, 7074, 7175, 7276, 7377, 7478, 7579, 7680, 7781	33	2425, 2731, 2832, 2933, 3034, 3135, 3236, 3337	8		0
Qndo	5458, 5559, 5660, 5761, 5559, 6973, 7175, 7478	8	2428, 2529, 2630, 2731, 2832, 2933, 3034, 3135, 3236, 3337	10		0
Qrdo	4448, 4549, 4650, 4751, 4852, 4953, 5054, 5155, 5256, 5357, 5458, 5559, 5660, 5761, 5862, 5963, 6064, 6165, 6266, 6367, 6468, 6569, 6670, 6771, 6872, 6973, 7074, 7175, 7276, 7377, 7478, 7882	35	2226, 2327, 2428, 2529, 2630, 2731, 2832, 3337, 3438	9	2933, 3034, 3135, 3236	4

Note:

1. Wettest and wet periods - the Qnri and Qrri and Qndo and Qrdo of any period are higher by as much as 25% and over the mean "normal" for the month (0.45 and 0.30 MAF, respectively).
2. Sub-normal and dry periods of wetness - when the same runoff parameters are as low as 25% and over their "normal."
3. Critical dry periods of wetness - when the Qnri, Qrri, Qndo and Qrdo are as low as 50% and over their "normal."

Table III.12 The number of 5-year running mean periods of runoff of different wetness in relation to the normal - October

Runoff Character-istics	Wettest and Wet Periods	Number of Periods	Sub-normal and Dry Periods	Number of Periods	Critical Dry Periods	No. of Pds.
Qnri	5458* 6064, 6165, 6266, 6367, 7276	6	2529, 2630, 2731, 2832, 2933, 3034, 3135, 3236, 3337, 3438	10		0
Qrri	5458, 5559, 5660, 5671, 5862, 5963, 6064, 6165, 6266, 6367, 6468, 6569, 6670, 6771, 6872, 6973, 7074, 7275, 7276, 7377, 7478, 7579, 7680, 7781	24	2933, 3034, 3135, 3236, 3337,	5		0
Qndo	4751, 4852, 5963, 6064, 6165, 6266, 6367, 6973, 7074, 7175, 7276, 7377, 7478	13	2630, 2731, 2832, 2933, 3034, 3135, 3236, 3337, 3438	9		0
Qrdo	5155, 5458, 5559, 5660, 5761, 5963, 6064, 6165, 6266, 6367, 6468, 6569, 6670, 6771, 6872, 6973, 7074, 7275, 7276, 7377, 7478, 7579	22	2933, 3034, 3135, 3236, 3337	5		0

Note:

1. Wettest and wet periods - the Qnri and Qrri and Qndo and Qrdo of any period are 25% or more above "normal" for the month (0.58 and 0.46 MAF, respectively).

2. Sub-normal and dry periods of wetness - when the same runoff parameters are 25% or more below "normal."

3. Critical dry periods of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

*Tabled numbers represent 5-year periods, e.g., 5458 = 1954-1958.

Table III.13 The number of 5-year running mean periods of runoff of different wetness in relation to the normal - November

Runoff Characteristics	Wettest and Wet Periods	Number of Periods	Sub-normal and Dry Periods	Number of Periods	Critical Dry Periods	No. of Pds.
Qnri	4751* 4852, 4953, 5054, 5155, 6367, 6468, 7074, 7175, 7276, 7377, 7478	12	2226, 2832, 3438, 3640, 3943, 4044, 5357, 5458, 5559, 5660, 5761, 5862, 5963	13	2933, 3034, 3135 3236, 3337	5
Qrri	4751, 4852, 4953, 5054, 5155, 7074, 7175, 7276, 7377, 7478	10	2832, 3943, 4044, 4145, 5256, 5862, 5963, 7781	8	2933, 3034, 3135, 3236, 3337	5
Qndo	4751, 4852, 4953, 5054, 5155, 6367, 7074, 7175, 7276, 7377, 7478	11	2226, 2832, 3438, 3539, 3640, 3741, 3842, 3943, 4044, 4650, 5256, 5357, 5458, 5559, 5660, 5761, 5862, 5963	18	2933, 3034, 3135, 3236, 3337	5
Qrdo	5155, 7074, 7175 7276	4	2832, 3438, 3539, 3640, 3741, 3842, 3943, 4044, 4145, 4246, 4448, 4549, 4650, 5256, 5357, 5458, 5559, 5660, 5671, 5862, 5963, 6064, 7579, 7882	24	2226, 2933, 3034, 3135, 3236, 3337, 7680, 7781	8

Note:

1. Wettest and wet periods - the Qnri and Qrri and Qndo and Qrdo of any period are 25% or more above "normal" for the month 1.14 and 1.25 MAF, respectively).

2. Sub-normal and dry periods of wetness - when the same runoff parameters are 25% or more below "normal."

3. Critical dry periods of wetness - when the Qnri, Qrri, Qndo and Qrdo are 50% or more below "normal."

*Tabled numbers represent 5-year periods, e.g., 4751 = 1947-1951.

III.2 Variables of the Natural and Regulated 5-Year Running Mean River Inflow to the Delta

III.2.1 Annual Deviations of 5-Year Running Mean Water supply and their Statistics

The histogram (Fig. III.15) of annual natural and regulated river inflow (NRI_5 and RRI_5) shows the following:

1. Upstream water diversion made the distribution of 5-year running mean water supply more uniform.

2. The number of events of highest inflow (30-39 MAF)of would-be NRI_5 was nearly replaced by the range of RRI_5 events of 21-29 MAF.

3. The number of events in the lowest range of would-be NRI_5 of 16-20 MAF (years of sub-normal wetness) increased as much as five times in comparison with the natural frequency of occurrence of these volumes of runoff. The lowest range of RRI_5 of 10-15 MAF (not observed under natural conditions) became a new feature of the river inflow to the Delta. The majority of RRI_5 events corresponded to the probability of exceedance of the 5-year running annual would-be natural mean river inflow of 75%, or a recurrence interval of not less than one time in four years (Fig. III.17, Appendix 8,9)

4. The entire perennial range of extreme values (minimum and maximum) of RRI_5 was reduced as much as 1.1-1.3 times (Table III.4), and the normal RRI_5 of 22.75 MAF is equal to 80% of the would-be natural. This volume corresponds to the probability of exceedance of 80-85%, that is, years of sub-normal wetness which may be observed under natural conditions not less than once in only 6-8 years.

The deviations of the 5-year running mean regulated river inflow from normal (and comparison with the deviations of the 5-year running mean natural river inflow Fig. III.10) illustrate:

1) The presence of a periodicity of different wetness which may be classified as sub-normal (with a probability of exceedance of more than 50%) and wet periods (with a probability of exceedance of less than 50%); and

2) The impact of upstream diversions from the Sacramento-San Joaquin Rivers on the water supply to the Delta.

The normalized curve of deviations for unimpaired runoff for the majority of months, but especially for spring, when runoff is characterized as high and relatively stable, may depict different periods of wetness. Using May as an example (the month of most stable and highest runoff) we can create the following periods of wetness:

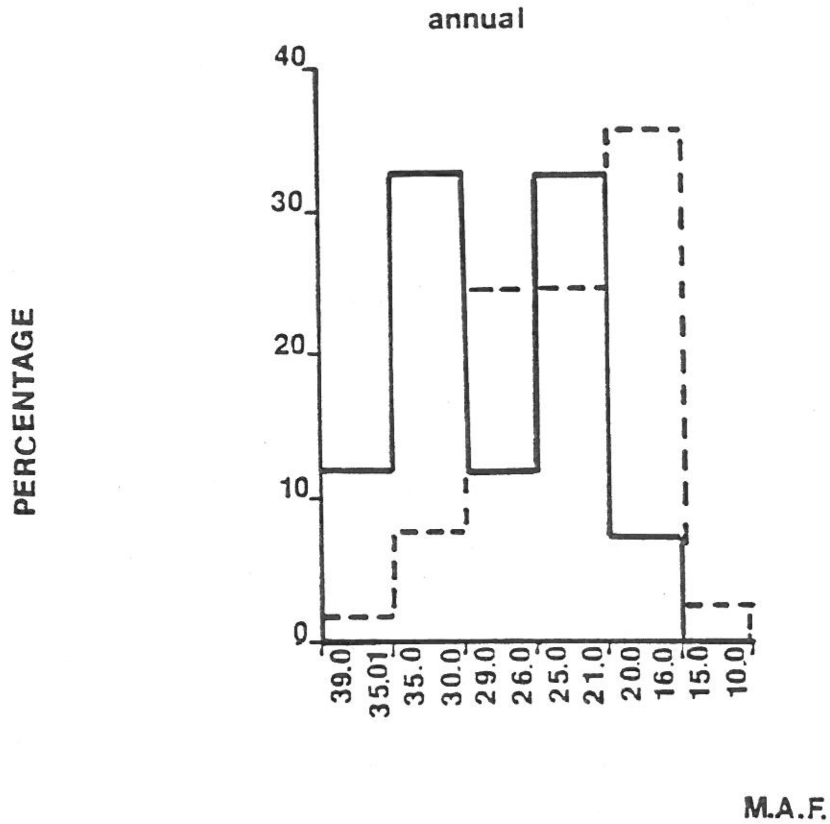


Fig.III.15. Histogram of Occurrence of (1) Natural (1921-78) and (2) Regulated (1921-82) Annual River Inflow to the Delta, calculated with 5-year running means.

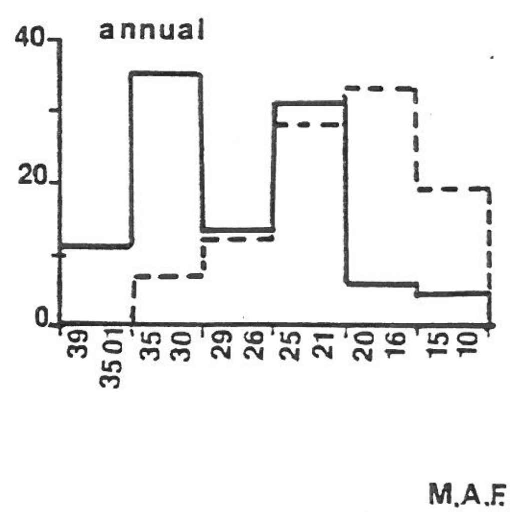


Fig.III.16. Histogram of Occurrence of (1) Natural (1921-78) and (2) Regulated (1921-82) Annual Delta Outflow to the Bay, calculated with 5-year running means.

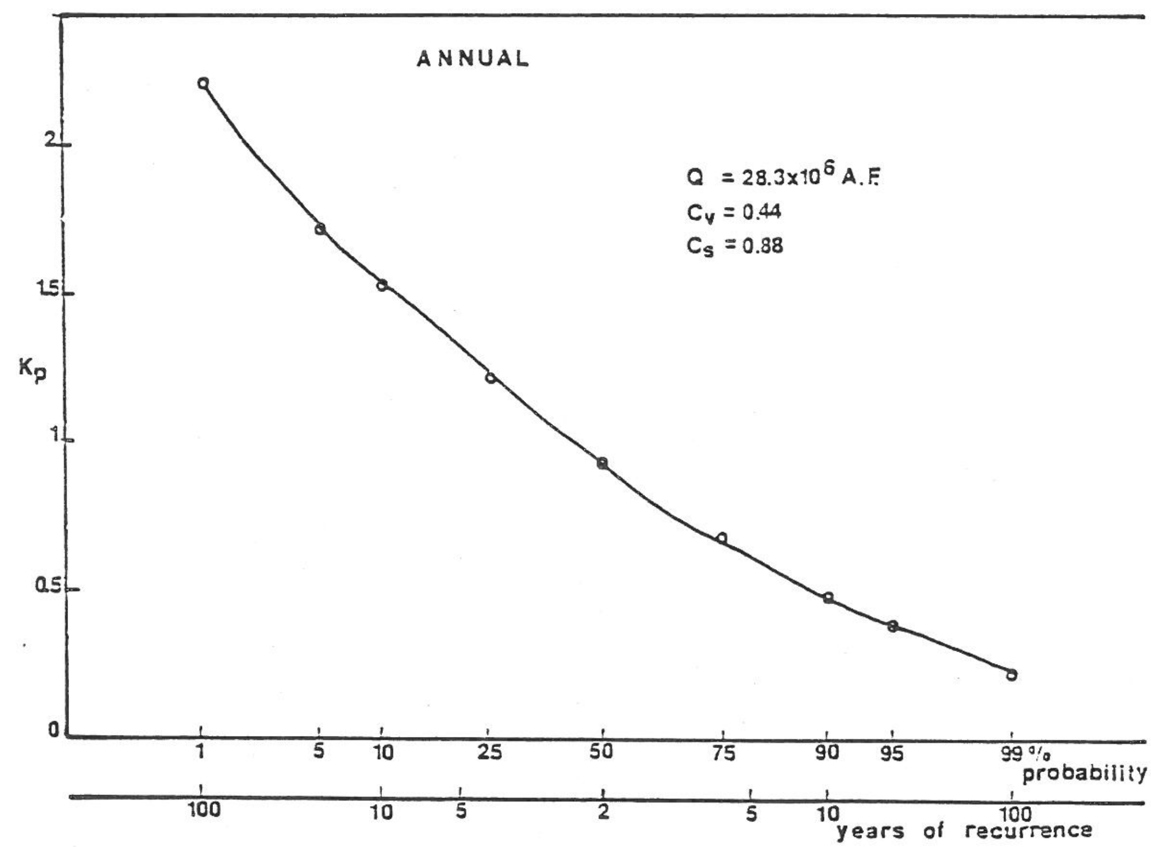


Fig. III.17 . Probability Curve of the Annual Natural River Inflow, calculated with 5-year running means.

Sub-normal: 1) from 1921-25 until 1931-35
2) from 1943-47 until 1945-49
3) from 1953-57 until 1960-64

Above normal: 1) from 1933-37 until 1942-46
2) from 1948-52 until 1956-60
3) from 1962-66 until 1970-75

In general, each of these periods has a predominant duration of 5-6 years and can be divided into two phases: a phase of rise and a phase of fall of water supply to the Delta. This type of regularity, as mentioned above, has been found for a variety of different rivers.

According to the Department of Water Resources, the period 1929-34 is characterized as critically dry. The mean annual runoff corresponds to a probability of occurrence of 97-99%, or recurrence of not less than once per 85-100 years. The average river inflow of 1929-33 and 1930-34 of 2.3 million acre feet has probabilities of occurrence of 99, 95 and 90% for the months of April, May and June, or recurrence of not less than once per 100, 20 and 10 years, respectively.

The same periodicity can be seen, although less clearly, for other seasons of the year. It should be noted that 5-year running means of regulated river inflow reiterate the same features of cyclicity except for the months of August, September and October (these exceptions are due to the water discharges and emergency storage releases to mitigate the impact of the polluted agricultural water on the water quality of the river-Delta ecosystem).

III.2.2 Seasonal Deviations of 5-Year Running Mean Water Supply and their Statistics

III.2.2.1 WINTER

Winter, as discussed earlier, is characterized by the highest amplitude of natural runoff fluctuations due to variations of precipitation over the watershed. The cumulative impact of these fluctuations can be seen from Figs. III. 18-21 and Tables III.15,16.

Normal NRI_5 for January, February and March (Tables III.15,16, Figs.19-21) is nearly the same, although the latter two months have less pronounced fluctuations and therefore more stable runoff. Among the four winter months, January has the greatest range of deviations from normal NRI_5 (+120 to -70%), far greater than for any other month of the year.

The predominant range of fluctuations of river inflow for the winter months was:

	NRI_5 Range	RRI_5 Range
December	40%	+30 to -40%
January	+120 to -70%	50%
February	30%	35%
March	30%	+30 to -40%

The trend of deviations for the winter months and especially for January and February, reflects a periodicity in wetness alternation which may be divided into three periods of sub-normal river inflow to the Delta:

1. 1921-25 to 1935-39, 1942-46 1949-53, and 1956-60 to 1963-67;

2. 3 wet periods (5-year average water supply above the monthly normal): 1941-45 to 1942-46, 1951-55 to 1956-60, and 1963-67 to 1972-76.

Of these periods, the maximum negative deviation of the NRI_5 and RRI_5 was observed for <u>December, January, February</u> and <u>March</u> (pre-project period) from 1921-25 to 1935-39. The maximum positive deviations of NRI_5 and RRI_5 were observed for December, February and March from 1941-45 until 1942-46 and for January during 1963-67 to 1972-76.

The water supply to the Delta-Bay system, i.e., average of the NRI_5 of <u>December, February</u> and <u>March</u>, reflects the strong impact of storage accumulation since the projects were put into operation. During a period of more than forty years, river inflow (5-year running means) for <u>January</u>, of all the winter months, was the least influenced by water accumulation in storage and other facilities. However, since 1965-69, the seasonal diversions affected <u>January</u> river inflow and the calculations show that on the average approximately 1.0 MAF has not reached the Delta system for that month.

The histograms for NRI_5 and RRI_5 for the winter months (Fig. III.22) illustrate how water withdrawals have truncated the highest probability of occurrence of inflow to close to normal and produced a more even distribution of all other ranges of inflow, except for the last month of the winter, March.

<u>March</u> illustrates the effect of diversions which result in elimination of the probability of occurrences of highest river inflow within the range of 3.6-7.6 MAF (the occurrence of this range was reduced 2.5 times), but the occurrence of RRI_5 between 2.0-3.5 MAF was increased more than two times and has the same probability of occurrence as the typical for NRI_5 for December under pre-project conditions.

Due to this shift, the value of RRI_5, corresponds to years of sub-normal wetness, i.e., recurrence once in 2-6 years of the would-be natural conditions.

The water supply to the system in general was reduced 10-20% during the winter for the months of December, January and February, and 20-40% for March since the beginning of full project operations for any probability of occurrence for the regulated 5-year mean water monthly supply.

Although in some periods which include successive wet years, RRI_5 may be higher than the natural, this may reflect the impact of emergency releases from dams made to prevent dangerous overflow conditions. Examples of this type of development are the periods 1971-75, 1973-77 (December), 1945-49 (January) and 1965-69, 1970-75 (February).

As a result of seasonal regulation, March (1967-78) was characterized by the most significant reduction of 5-year mean river inflow. During this period, the succession of lower values of March RRI_5 corresponded to 75-90% probability of exceedance of the would-be natural river inflow, sub-normal wetness, (or a recurrence interval of not less than once in 4-10 years (Figs. III.23,24, Tables III. 15,16), while at the same time natural runoff had a probability of 10-25%, i.e., wetness above normal. Due to water withdrawals, the value of the residual runoff corresponded to the sub-normal wetness. This is a typical example of how runoff regulation truncates peaks of the NRI_5 and transfers it from wet to sub-normal categories.

At the same time, the residual inflow for February is the least regulated runoff observed since the beginning of operation of the CVP and SWP.

While withdrawals in March ranged from 1.6 up to 2.6 MAF, in January, they equalled 1.3-1.7 MAF (39-50% of January mean perennial NRI_5, or 17-23% of the NRI_5 for the 1966-70 and 1969-73 periods). The highest water withdrawals took place after several successive 5-year periods of sub-normal river inflow, as occurred from 1957-61 until 1961-65.

It should be noted that the absolute quantity of water and not the percentage of diversion, must be known in order to assess impacts on riverine-estuarine systems, especially for periods of sub-normal natural river inflow.

For example, the 1930-34 period for December and February, in which the mean water withdrawals were 0.33 MAF (or 13-15% of the natural for the given period) the RRI was equal to 1.2-1.5 MAF (sub-normal wetness). However, almost the same percentage of diversion in December 1966-70 produced a RRI_5 of 2.3 MAF. But the latter corresponds to nearly normal river inflow to the system for that month.

Table III.14 The Differences Between the Mean Annual Natural and Regulated Sacramento-San Joaquin River Inflow to the Delta , Calculated with 5-Year Running Means (1923-1978)

Years	Qn $\times 10^3$ AF	Qr $\times 10^3$ AF	Qn-Qr $\times 10^3$ AF	$\frac{Qn-Qr}{Qn} \times 100$
1924-28	23619.6	18976.80	4642.8	19.6
25-29	24558.2	19647.40	4908.8	20
26-30	23275.4	18525.80	4750.1	20
27-31	21327.6	16591.20	4583.1	25
28-32	18443.4	13860.80	4566.6	28
29-33	16023.6	11457.00	4558.0	28
30-34	16015.0	11578.40	4481.6	25
31-35	17622.4	13140.80	4595.2	21
32-36	21936.2	17341.00	3968.0	18
33-37	22155.6	18187.60	3187.8	10
34-38	30633.0	27445.20	3253.8	11
35-39	30613.4	27359.60	3162.6	10
36-40	32343.1	29180.40	2934.2	8
37-41	35596.2	32662.00	3160.4	8
38-42	38974.4	35814.00	4181.6	12
39-43	34956.0	30774.40	4560.2	13
40-44	35826.0	31265.80	5162.4	15
41-45	33734.8	28572.40	5841.2	19
42-46	30149.2	24307.80	5832.4	23
43-47	24989.2	19156.60	5629.6	25
44-48	22443.4	16813.80	5489.6	24
45-49	22839.8	17350.20	5324.6	24
46-50	22165.4	16840.80	5330.2	22
47-51	24155.2	18825.00	5279.4	19
48-52	30668.4	24939.00	6231.2	19
49-53	31947.6	25716.40	6758.4	20
50-54	33440.2	26681.80	6793.0	21
51-55	32241.0	25448.00	7835.6	22
52-56	34728.0	26892.40	7834.2	26
53-57	29510.2	21676.60	7439.2	22
54-58	33502.2	26063.00	6661.2	21
55-59	31781.2	25120.20	6725.0	21
56-60	32174.4	25449.40	5483.8	22
57-61	25290.4	19806.60	5822.6	22
58-62	25778.2	19855.00	6274.4	27
59-63	23075.4	16801.00	6259.6	27
60-64	22816.8	16557.20	7175.6	26
61-65	27615.6	20440.00	7210.4	25
62-66	28431.2	21220.80	7204.4	22
63-67	32113.6	24909.20	6509.4	22
64-68	28865.8	22356.40	6509.4	22
65-69	35962.8	28178.20	6431.8	18
66-70	34929.0	28497.20	6966.4	18
67-71	37605.8	30639.40	6073.0	18
68-72	32816.6	26473.50	6720.4	19
69-73	35686.8	28966.40	7253.0	20
70-74	35307.0	28554.0	6753.0	19
71-75	34062.0	26882.8	7179.2	21
72-76	29565.0	24068.6	5496.4	18
73-77	26998.0	22452.8	4545.2	17
74-78	28635.0	22093.6	6541.4	23

Table III.15 Statistics of the 5-Year Running Mean Monthly and Annual Natural River Inflow to the Delta - 1922-1978

Month	Range Q MAF	Mean Q MAF	Cv	Cs	Standard Deviation MAF
October	0.35- 1.07	0.58	.31	1.3	0.18
November	0.41- 2.27	1.13	0.40	0.73	0.46
December	0.78- 4.53	2.47	0.38	0.18	0.95
January	1.27- 7.50	3.37	0.51	0.80	1.72
February	1.64- 6.46	3.84	0.30	0.06	1.16
March	2.18- 6.58	3.85	0.27	0.61	1.05
April	2.35- 5.61	4.19	0.17	-0.31	0.70
May	2.50- 5.49	4.26	0.18	-0.27	0.76
June	1.71- 3.70	2.63	0.19	-0.12	0.50
July	0.63- 1.58	1.03	0.23	0.20	0.24
August	0.36- 0.74	0.54	0.18	-0.26	0.10
September	0.31- 0.58	0.45	0.16	-0.21	0.07
ANNUAL	16.01-38.97	28.35	0.20	-0.26	5.82

Table III.16 Variables of a theoretical curve of probability of exceedance of monthly 5-years running mean Natural River Inflow.

Probability of exceeding	1	5	10	25	50	75	90	95	99
Years of recurrence	100	20	10	4	2	4	10	20	100
October	1.15	0.93	0.82	0.67	0.54	0.45	0.39	0.37	0.34
November	2.42	1.95	1.74	1.39	1.07	0.80	0.60	0.50	0.33
December	4.77	4.05	3.68	3.09	2.45	1.83	1.28	0.99	0.42
January	8.32	6.54	5.66	4.38	3.13	2.12	1.35	1.01	0.37
February	6.57	5.76	5.30	4.61	3.80	3.07	2.38	1.96	1.23
March	6.74	5.74	5.24	4.47	3.73	3.12	2.62	2.35	1.93
April	5.70	5.28	5.07	4.69	4.23	3.73	3.27	2.93	2.35
May	5.888	5.45	5.24	4.81	4.30	3.75	3.24	2.94	2.30
June	3.73	3.42	3.26	2.97	2.66	2.31	1.97	1.79,	1.39
July	1.62	1.43	1.34	1.18	1.02	0.87	0.73	0.66	0.52
August	0.75	0.69	0.66	0.61	0.55	0.48	0.41	0.37	0.30
September	0.61	0.56	0.54	0.50	0.45	0.41	0.36	0.33	0.27
Annual	40.54	37.14	35.44	32.32	28.63	24.66	20.98	18.71	14.18

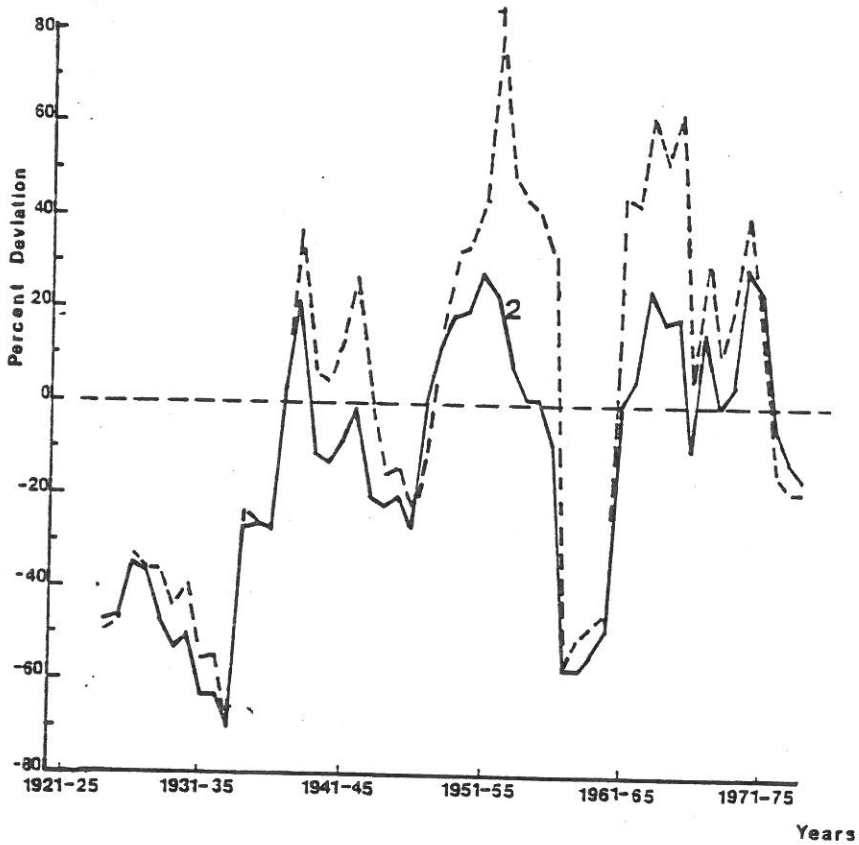


Fig.III.18 .Deviations (in percentage) for the month of December in (1) Natural and (2) Regulated River Inflow from the December Mean Natural River Inflow (Q = 2.44 MAF; 1921-78), calculated with 5-year running averages.

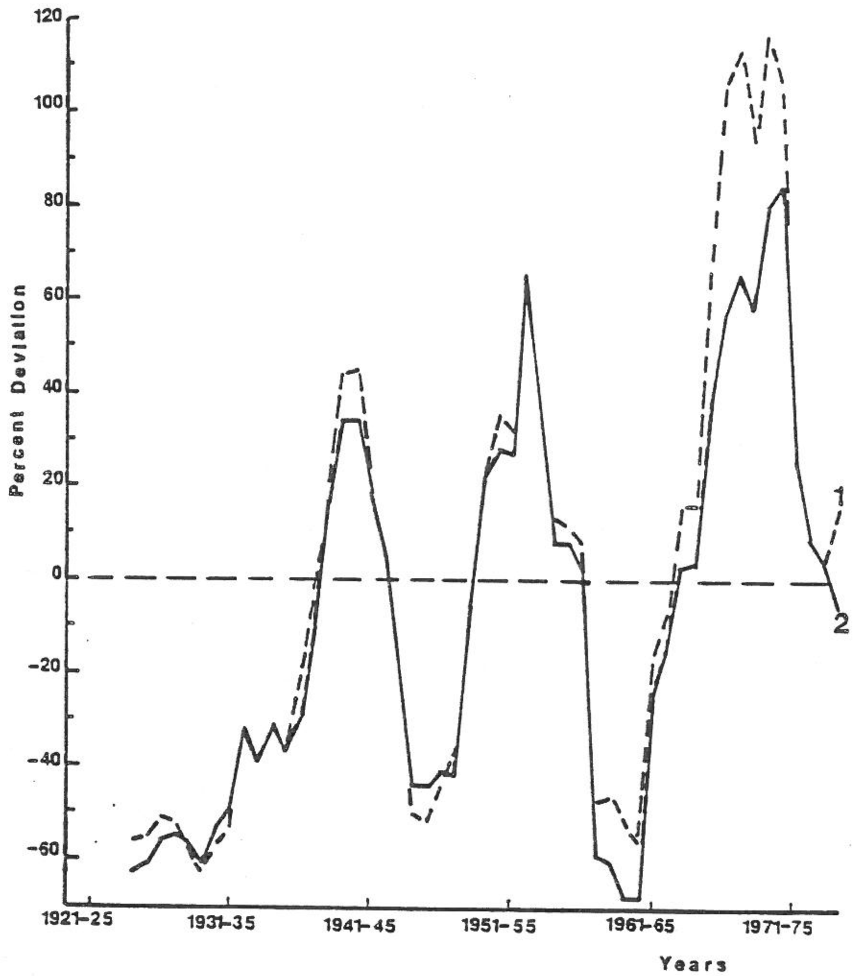


Fig.III.19.Deviations (in percentage) for the month of January in (1) Natural and (2) Regulated River Inflow from January Mean Natural River Inflow (Q = 3.39 MAF; 1921-78), calculated with 5-year running means.

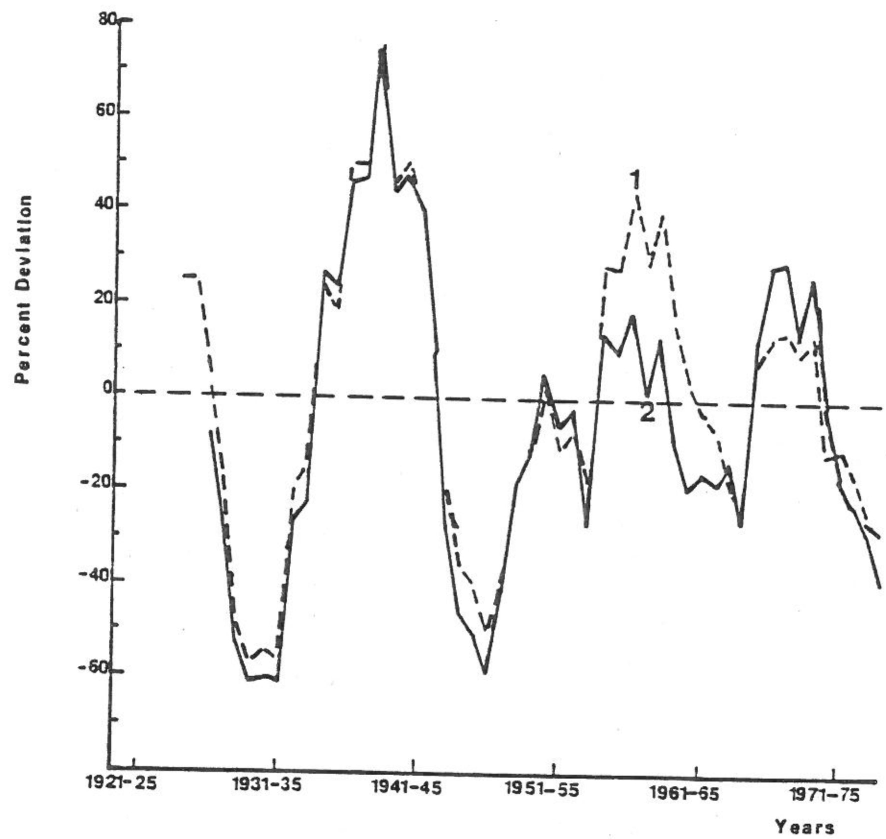


Fig.III.20.Deviations (in percentage) for the month of February in (1) Natural and (2) Regulated River Inflow from February Mean Natural River Inflow (Q = 3.80 MAF; 1921-78), calculated with 5-year running averages.

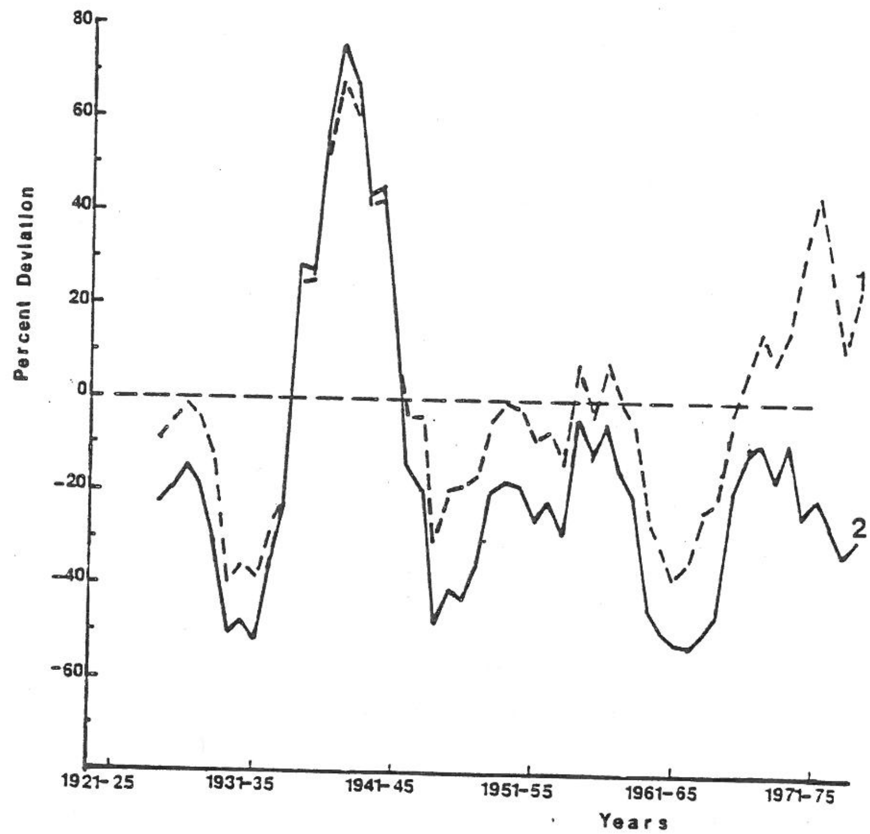


Fig.III.21.Deviations (in percentage) for the month of March in (1) Natural and (2) Regulated River Inflow from March Mean Natural River Inflow (Q = 3.85 MAF; 1921-78), calculated with 5-year running averages.

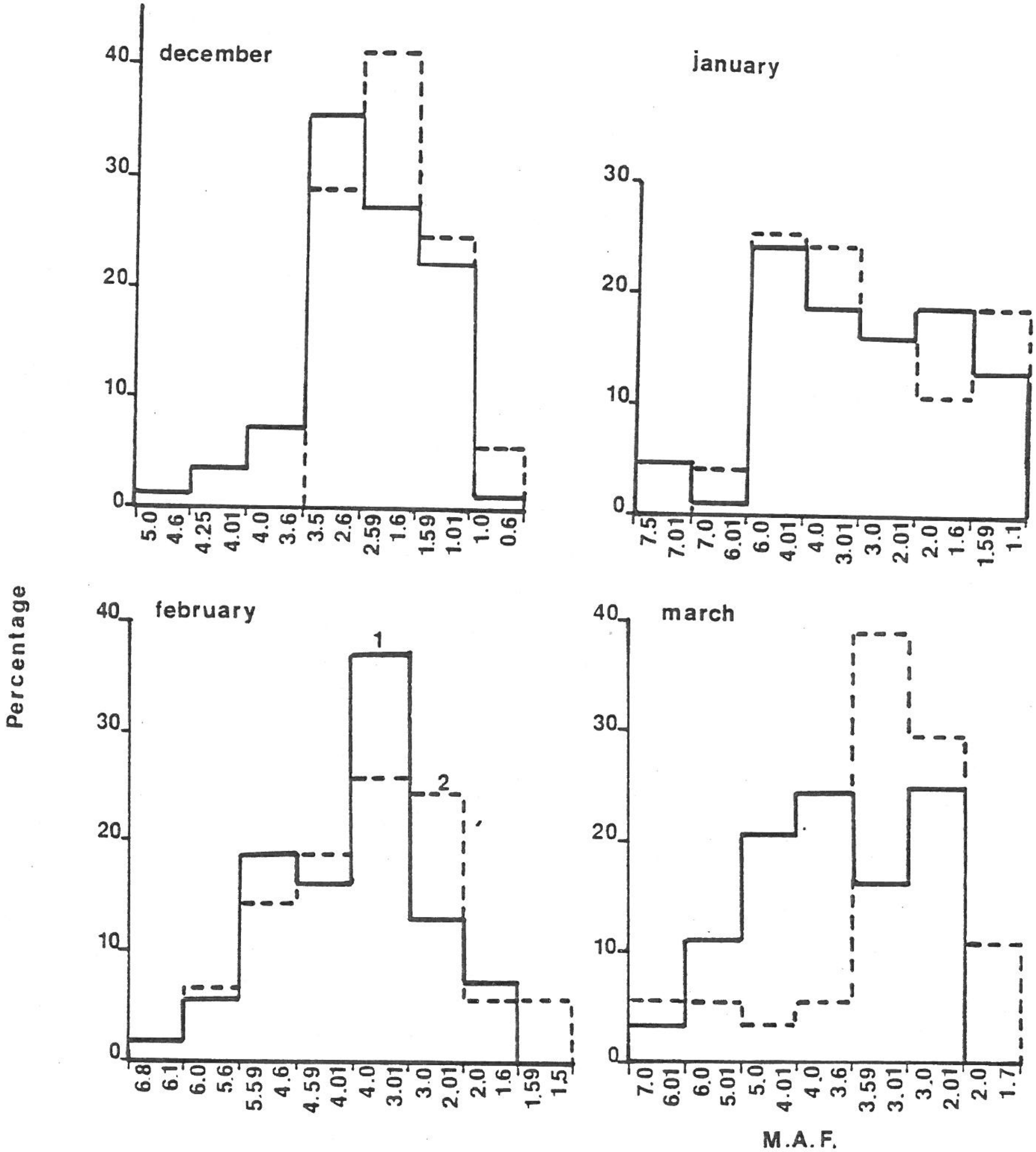


Fig.III.22 Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1921-82) River Inflow for the Winter Months, calculated with 5-year running means.

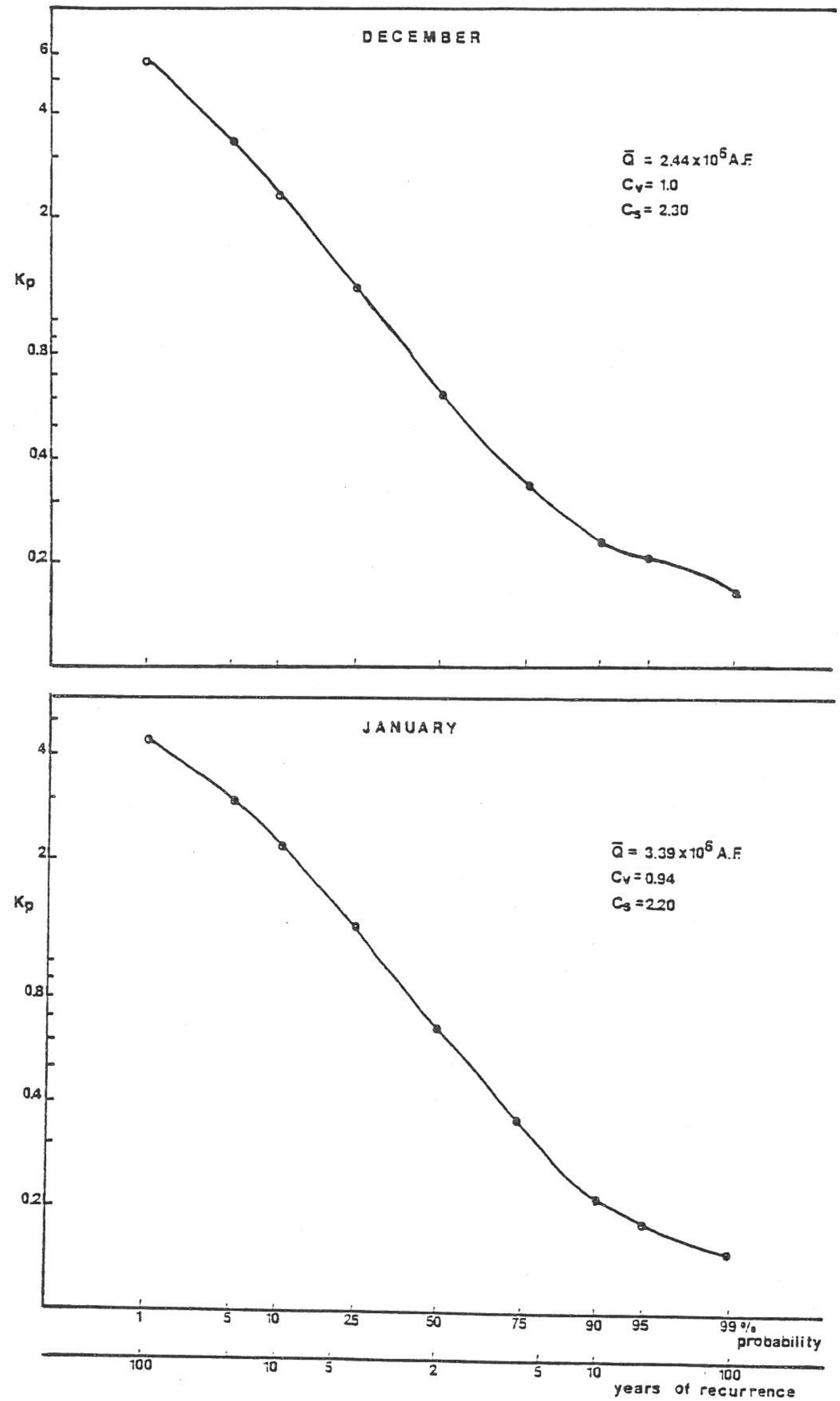


Fig.III.23. Probability Curve of the Natural River Inflow for the Winter Months, calculated with 5-year running means.

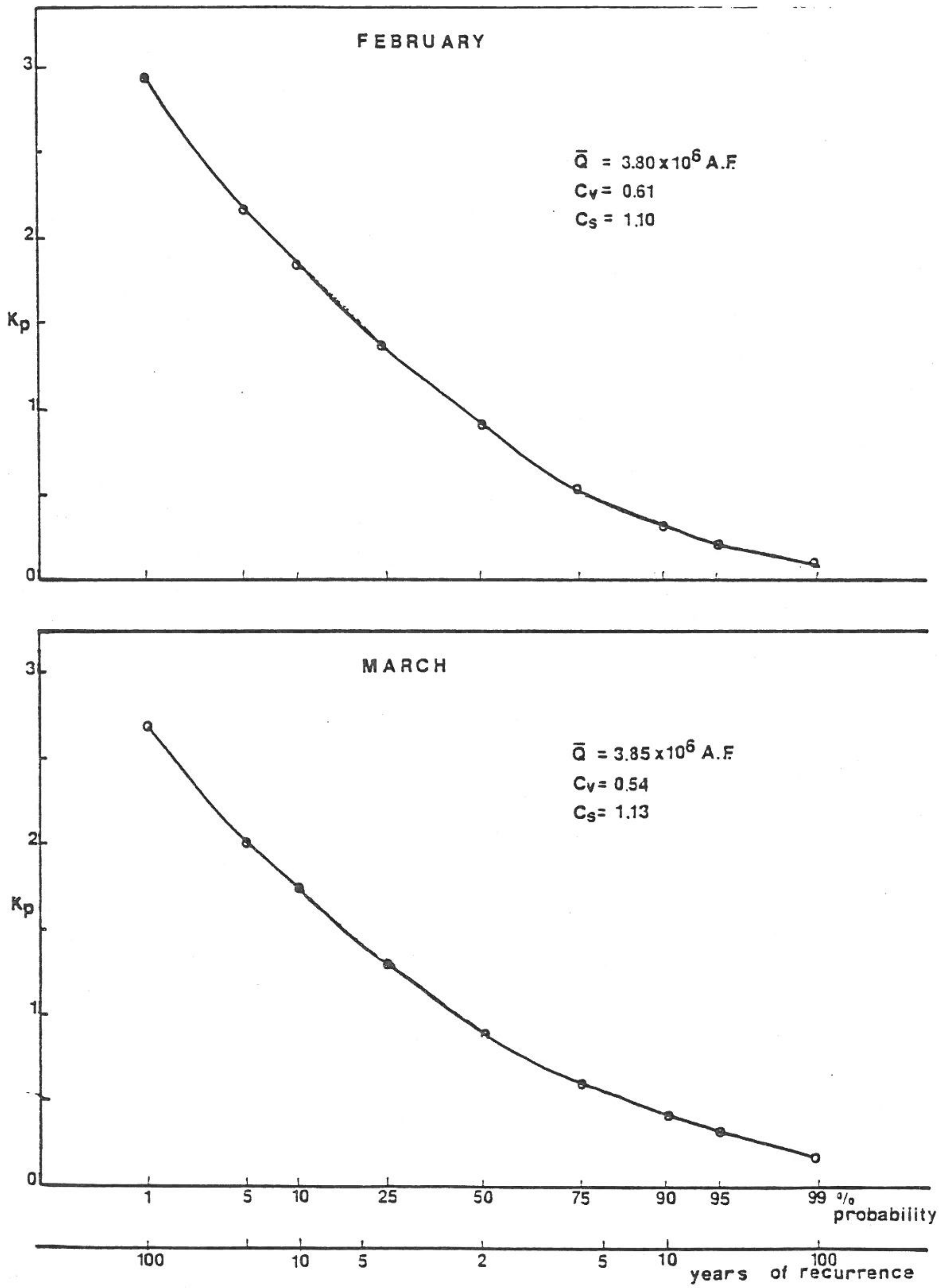


Fig.III.24. Probability Curve of the Natural River Inflow for the Winter Months, calculated with 5-year running means.

In another example, February of 1955-59, the diversion of 0.7 MAF (14% for the given period) left a residual flow equal to 4.2 MAF which is a typical flow of high wetness (25% probability of exceedance, or recurrence interval of not less than once in four years, Fig. III.22).

Therefore, when one describes the role of diversions, it is important to operate not only with percentages but also to define the absolute amount of water diverted and the period of wetness observed to determine whether or not the system has a water surplus for any of the seasons.

It is important to note that for the period of 1974-78, December was characterized by a small excess in water supply (0.05 MAF) although natural and residual inflow corresponded to the sub-normal wetness (75% probability of exceedance, Fig. II. 23).

For the same period, mean water withdrawals for January, February and March were 0.8, 0.4 and 2.1 MAF respectively, despite the fact that January's residual river inflow was close to normal, while February and March correspond to sub-normal (75-80% probability of exceedance (Fig. III.23). The Delta-Bay system did not receive almost 3.9 MAF or 34.3% of the mean flow for the winter. Therefore, when discussing a winter surplus and considering that volume as available for diversion, water planners should note:

1. Not only the percentage of water diverted but, most importantly, the volume withdrawn as well as the wetness of the period and its probability of occurrence under natural conditions.

2. The algebraic sum of the natural and regulated water supply for the given period in order to obtain the actual value of residual mean inflow and corresponding percentage of diversion for the season for a given period of time (i.e., successive months).

3. In light of the above, all winters for the period from 1968-72 until 1974-78, as well as many other periods for the post-project conditions, have not had surplus residual river inflow to the Delta-estuary system. It is likely that this exacerbated the precarious spring water balance of the estuary when water withdrawals reach their maximum.

III.2.2.2 SPRING

General Remarks

Since 1944, the combined effects of upstream and downstream water withdrawals and diversions have become permanent features of the system, especially for April-May-June. Regulated Delta outflow patterns have shifted away from the patterns of natural flow fluctuations and created a "new" river system (Figs. III. 25-28) which has little resemblance (in relative and absolute values) to the deviations of regulated and would-be natural Delta outflow.

It is difficult to analyze and compare the periodicity of natural and regulated water supply variables since deviations from normal unimpaired 5-years running monthly mean have a range of ± 30%, deviations of regulated flow have a predominant negative range from -35 to -85%. Such an extreme range of negative deviations has never been observed in this system in the one hundred years since records were begun (data of the Department of Public Works, 1872-1929) even for the very low flow period between 1924-34 when the deviations of natural Delta outflow for the spring months reached its maximum of 45%.

In years such as 1923-24 and 1930-31, spring regulated river inflow to the Delta was one quarter to one tenth the average. This inflow corresponded to the natural flow probability of between 90-95%, i.e., occurrence of one time per 10-20 years, or in the case of 1930-31, 99% probability (or not less than one time per 100 years), which implies that the occurrence of such flows under natural conditions would be very rare.

During these years, salt intrusion into the Delta was pronounced and surface salinity was 1-2 g/l (Department of Public Works, 1927-31). Unfortunately, there is no information on salinity along the deep layers of the channels, but from similar developments in other countries, it is assumed that the salt concentration would have been in the range of 2-6 g/l in this area.

For the period 1921-78, the extreme 5-year running mean values of natural river inflow to the Delta during April and May did not change greatly (Tables II. 15-17). However, regulated river inflow extremes changed significantly and were 1.7-2.5 times lower than the natural extremes.

Spring Runoff Variables of the Post-Project Periods

Among these changes, the most pronounced reduction was observed in the maximum values during May (post-project conditions, 1944-1978; Fig. III.27).

The amplitude of flow for April and May for the post-project conditions was reduced as much as 1.5-3 times from the pre-project amplitudes.

For June the extreme values and amplitude for the two periods of regulated river inflow were almost unchanged.

In general, for the spring, the extreme value of regulated river inflow under post-project conditions was reduced as much as

1.4-2 times. Therefore, the regulation of water supply to the Delta resulted in an overall reduction of the highest extremes and at the same time the lowest extremes were almost unchanged.

For the post-projects period, the water supply to the Delta was what, under natural conditions, would be characteristic of dry months.

The predominant range of natural river inflow fluctuations for each of the three spring months (Fig. III.25) was within ± 20% of mean spring flow, and at the same time, regulated river inflow fluctuations from the mean had a predominant negative range between -35 and -70%. Since the late 1940's, i.e., post-project, each of the three spring months and the total spring flow were characterized by a steady increase of flow deviations toward more negative values.

It should be noted that from 1963-67 until 1973-77, the persistent highest values of negative deviations of regulated river inflow for May were nearly equal to those observed in the much shorter period between 1923-27 and 1929-33, (pre-project) under regulated conditions. Due to the fact that May is characterized as having the highest values of runoff fluctuations and water supply to the Delta, the impact of May's highest upstream diversions, exacerbated by the preceding April and following June diversions, can be seen from the steady decline of water supply for the entire spring and the overall increase of negative deviations of runoff fluctuations.

This modification of seasonal 5-year running NRI_5 due to diversion can be traced from the histogram of frequency of occurrence of river inflow for 5-year periods (Fig. III. 28).

The April, May and June histograms show two distinctive features:

1) The water supply of high ranges for May (4.2-5.5 MAF) and June (3.0-3.8 MAF) ceased to exist, as for April their occurrence was reduced as much as two times.

2) The frequency of occurrence of residual water supply shifted from relatively near the mean to lower ranges of the RRI_5.

It is interesting to note that the distribution of the April regulated river inflow has ranges similar to those of May under regulated conditions, but the May regulated river inflow distributions resemble those of June under natural conditions. This implies that the mean unimpaired water supply for spring, which had a prevailing range between 3-4 MAF and a probability of exceedance between 25 and 75% (or recurrence of at least once per 2-4 years) is replaced by a mean regulated spring water supply range of 1.5-2.9 MAF. But the latter corresponds to the probability of exceedance of 75-90% (or recurrence of not less than one time per 4-10 years) of the would-be natural sub-normal

Table. III.17 The Perennial Extremes of 5-Year Running Mean Natural and Regulated River Inflow to the Delta (1921-78, in Million Acre Feet - For April, May, June and Spring)

		APRIL		MAY		JUNE		SPRING	
		NRI	RRI	NRI	RRI	NRI	RRI	NRI	RRI
Pre-Project	Maximum	5.6 (1938-42)	5.5 (1938-42)	5.5 (1937-41)	4.1 (1938-42)	3.5 (1938-42)	2.6 (1938-42)	4.9 (1938-42)	4.1 (1938-42)
	Minimum	2.3 (1929-33) (1930-34)	1.4 (1929-33) (1930-34)	2.5 (1930-34)	1.3 (1930-34)	1.7 (1928-32)	0.8 (1928-32)	2.2 (1930-34)	1.2 (1930-34)
Post Project	Maximum	5.0 (1963-67)	3.3 (1954-58)	5.3 (1967-71)	3.3 (1941-45) (1948-52)	3.7 (1967-71)	2.1 (1967-71)	4.5 (1965-69)	2.9 (1948-52)
	Minimum	3.3 (1973-77)	1.9 (1953-57) (1968-72)	3.3 (1959-63)	1.4 (1973-76)	1.9 (1959-63)	0.9 (1959-63)	3.1 (1959-63)	1.5 (1959-63)

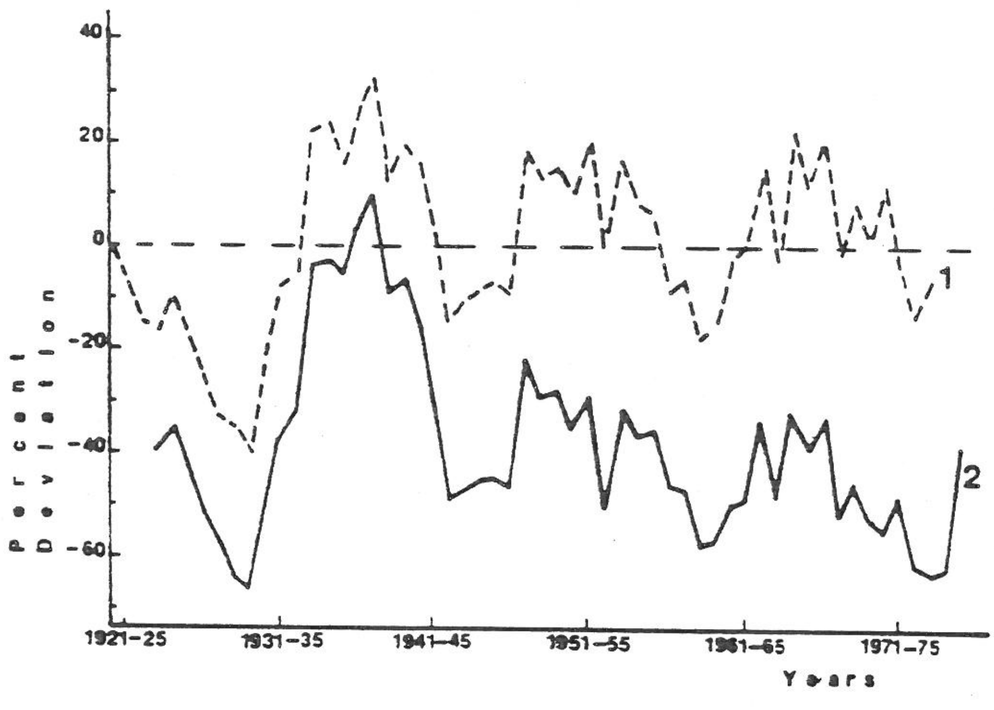


Fig. III.25. Deviations (in percentage) for the Spring in (1) Natural and (2) Regulated River Inflow from the Spring Mean Natural River Inflow (Q = 3.72 MAF; 1921-78), calculated with 5-year running averages.

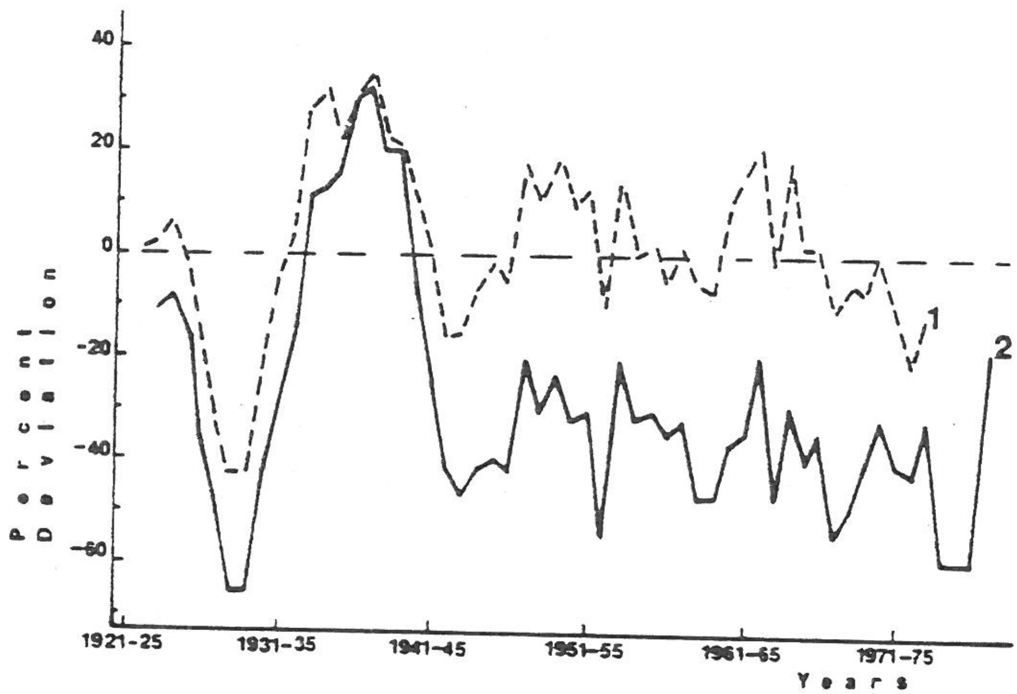


Fig.III.26.Deviations (in percentage) for the month of April in (1) Natural and (2) Regulated River Inflow from April Mean Natural River Inflow (Q = 4.15 MAF; 1921-78), calculated with 5-year running averages.

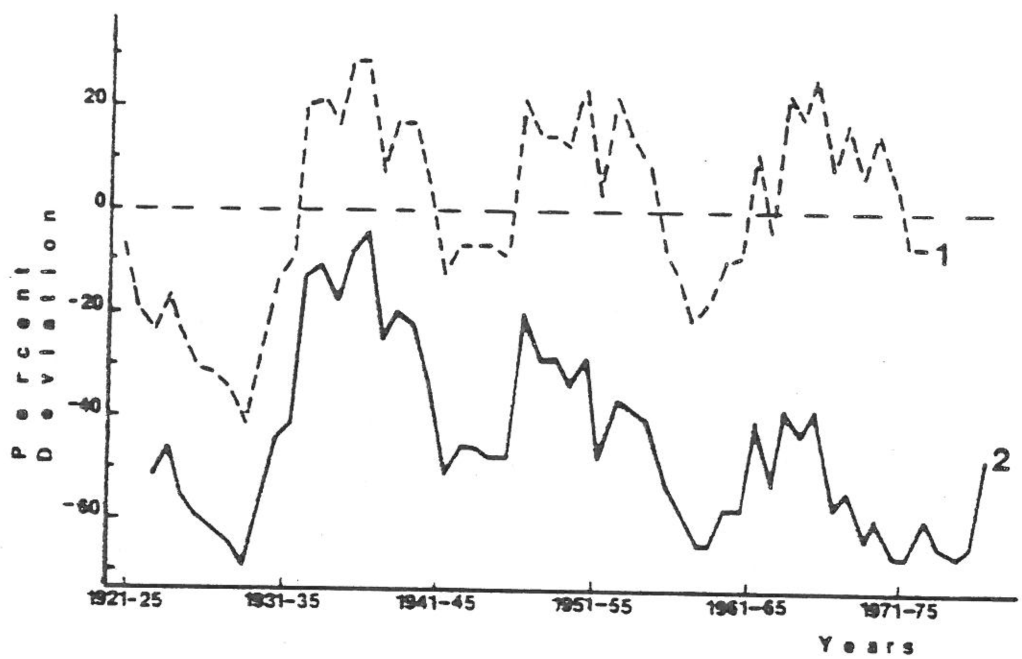


Fig.III.27.Deviations (in percentage) for the month of May in (1) Natural and (2) Regulated River Inflow from May Mean Natural River Inflow (Q = 4.26 MAF; 1921-78), calculated with 5-year running averages.

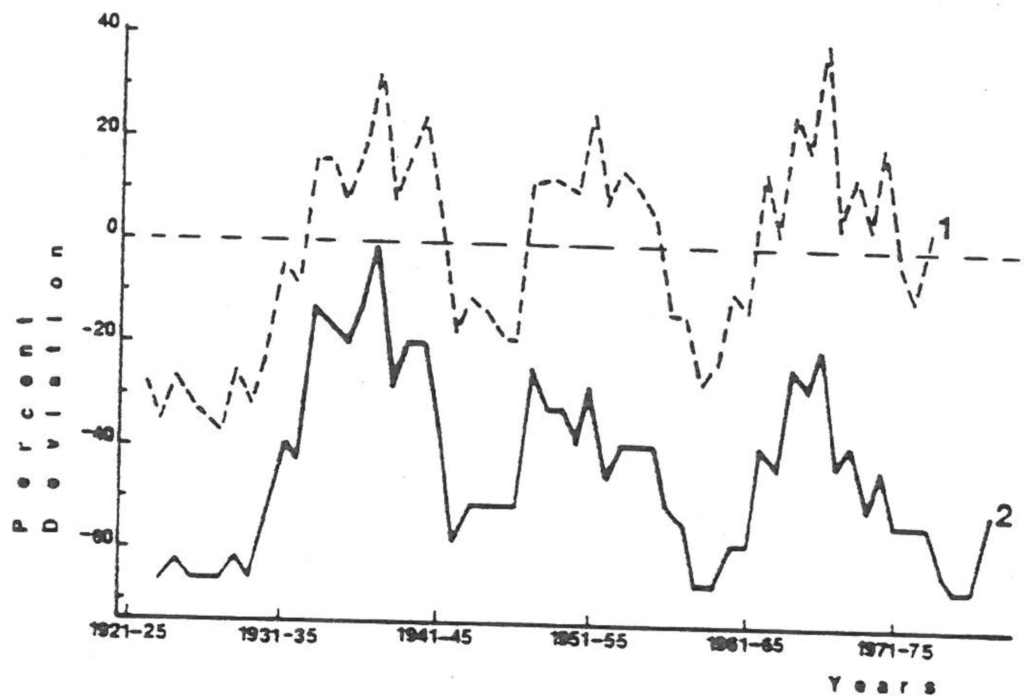


Fig.III.28.Deviations (in percentage) for the month of June in (1) Natural and (2) Regulated River Inflow from June Mean Natural River Inflow (Q = 2.65 MAF; 1921-78), calculated with 5-year running averages.

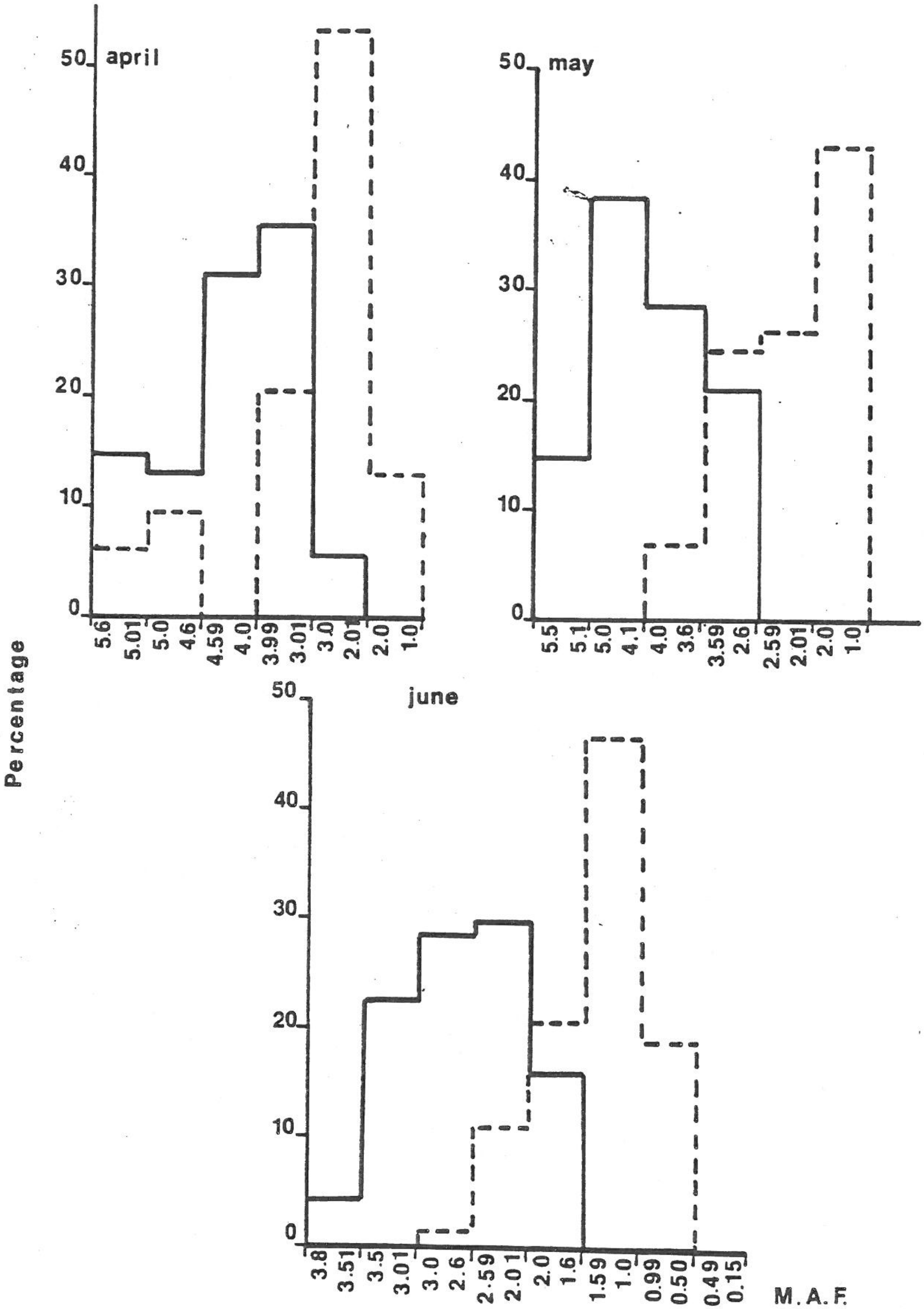


Fig.III.29. Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1921-82) River Inflow for the Spring Months, calculated with 5-year running means.

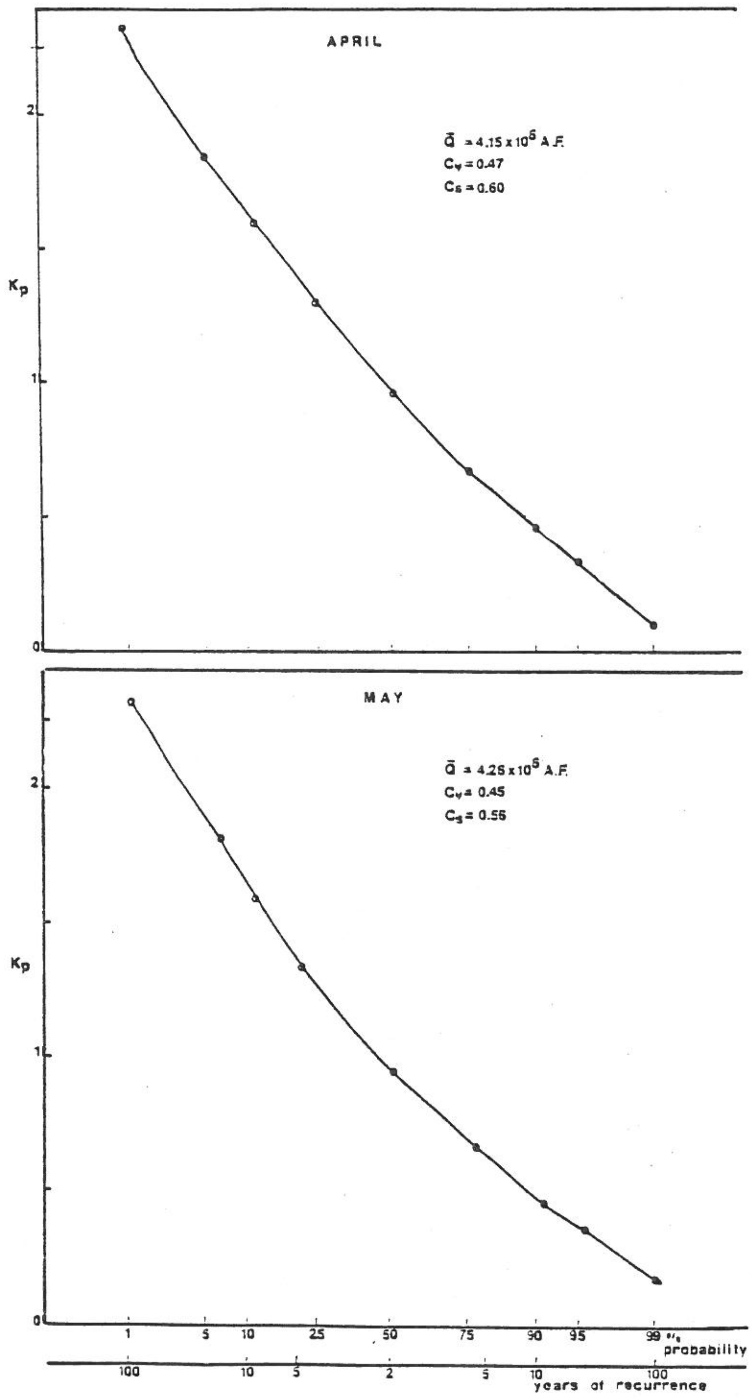


Fig.III.30. Probability Curve of the Natural River Inflow for the Spring Months, calculated with 5-year running means.

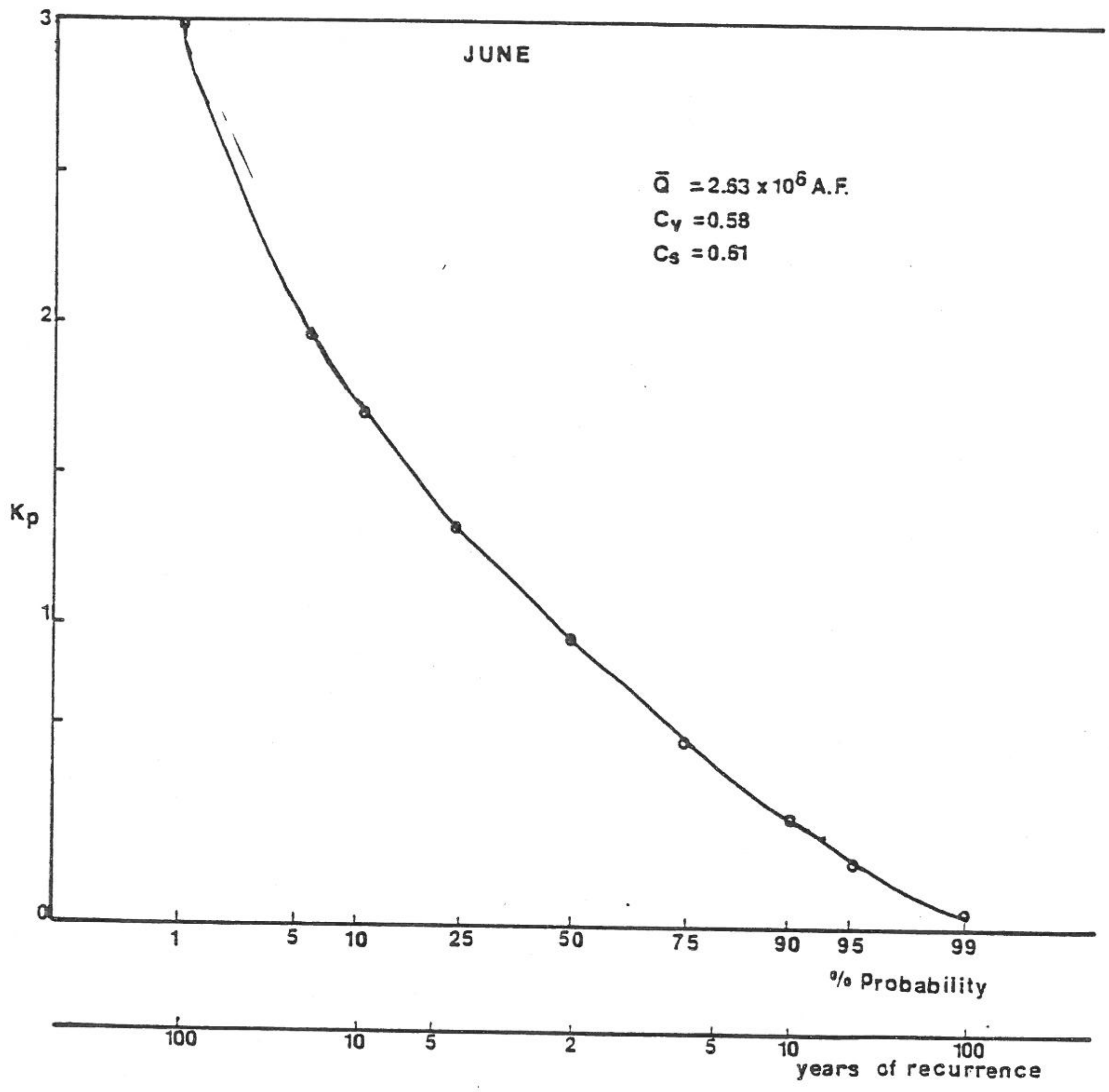


Fig.III.31. Probability Curve of the Natural River Inflow for the Spring Months, calculated with 5-year running means.

spring river inflow to the Delta (Figs. III. 30, 31) for the 5-year periods between 1921-78. If the same type of comparison is made for each month separately, even more dramatic changes are apparent.

The predominant range for regulated water supply from the river basins to the Delta for the 5-year running periods for April (2.4-2.6 MAF), May (0.6-2.0 MAF) and June (1.2-1.5 MAF) during 1965-69 to 1974-78 period corresponds to probabilities of exceedance of 99, 99 and 97-99%, respectively of the would-be natural water supply for the same months and period (Figs. III.30, 31, Table III.16).

At the same time, the natural water supply for April (3.6-4.0 MAF), May (4.0-5.0 MAF) and June (2.6-3.0 MAF) corresponds to a probability of exceedance of 50-75%, 25-50% and 25-50%, respectively.

This reveals that if there were no diversions, the Delta would have received one of the highest periods of water supply with an average recurrence of not less than once per 2-4 years. Instead, the Delta received a water supply which corresponded to the critical or historical critically dry periods which would be observed not less than one time per 90-100 or even more years.

This difference illustrates the level of changes in river inflow to the Delta which became the constant feature of the new regime of the river-Delta relationship.

For example, during the post-project period, the mean maximum value of diversion in April equalled 2.1 MAF (1962-66), or -43% of the mean natural river inflow, in May - 3.2 MAF (1971-75), or -65% of the mean natural river inflow, and in June - 1.7 MAF (1971-75), or -54% of the mean natural river for conditions of wet years (above normal) for these spring months.

From these examples, as well as many similar ones in other parts of the report, it is important to remember one important finding, namely, the relative value of diversions, expressed in percentage, for any given period of time corresponds to different volumes of diverted water. This implies that the same percentage of diversions for the spring months related to sub-normal dry or critical dry periods of natural river inflow may not only correspond to different volumes of diverted water, but their effects on the system will also be quite different, particularly when the same amount of water is withdrawn for years of different wetness classified as wet or sub-normal spring.

III. 2.2.3 SUMMER (July, August)

The temporal distribution of deviations of RRI_5 during the summer (July, August) has three distinctive features over the NRI_5 the basis of which can only be explained by the significant modification of runoff due, on one hand, to water released to maintain the water quality in the Delta, and on the other, to the increased amount of returning water discharged to the Sacramento and San Joaquin Rivers system. These features (Figs. III. 32, 33) are:

1. The trend of deviations for July has to some extent, the same trend of fluctuations as those of NRI_5 up to the late 1960's. After that time, deviations of water supply to the Delta during July (Fig. II. 32) under regulated conditions were positive and their absolute value was higher than that observed for natural river inflow. This implies that for the period from 1965-69 until 1972-76, regulated water supply from the rivers to the Delta was higher than the natural flow for the first time since records began.

2. For August (Fig. III. 33), this difference was even more pronounced than for July from the late 1950's until 1978. The steady increase of positive deviations (net gains) of the regulated river inflow in comparison with natural flow resulted not only in changes in the traditional interrelation between these two types of deviations of inflow (natural and regulated), but was also characterized by a dramatic increase of returning water supply to the Delta which has not been observed since 1872, when records began.

3. Therefore, the summer period, traditionally considered as a time of minimum water supply to the Delta network, was altered by a significant amount of water coming from storage releases or the agricultural drainage system, or both. This additional water which accounted for almost 600,000 acre feet on the average added to the water balance of the Delta, might change the chemical structure of the Delta water masses which would no longer be comparable to that existing before this water surplus became a constant feature in the Delta water balance.

Thus, before the regulation of Delta water supply, the predominant deviations of the residual inflow for the summer months were negative and in the range of -35 to -80%.

Since the water conveyance facilities were put into full operation in the late 1960's, the predominant (i.e., water supply above normal) deviations for July were in the range of +5-15%, but for August +80-100% (and reached 135%).

It is interesting to note that the period between 1922 and 1938 for July and August was the last time the upstream diversions, superimposed on sub-normal and dry periods of wetness, resulted in the development of the driest water regime in the river and consequently in the Delta, the recurrence of which has not been observed in the following fifty years of regulation of the Sacramento-San Joaquin Rivers' water resources.

In sum, for the last two decades, the summer Delta water balance may be characterized as highly positive. There is no doubt that storage releases during the summer months, with some

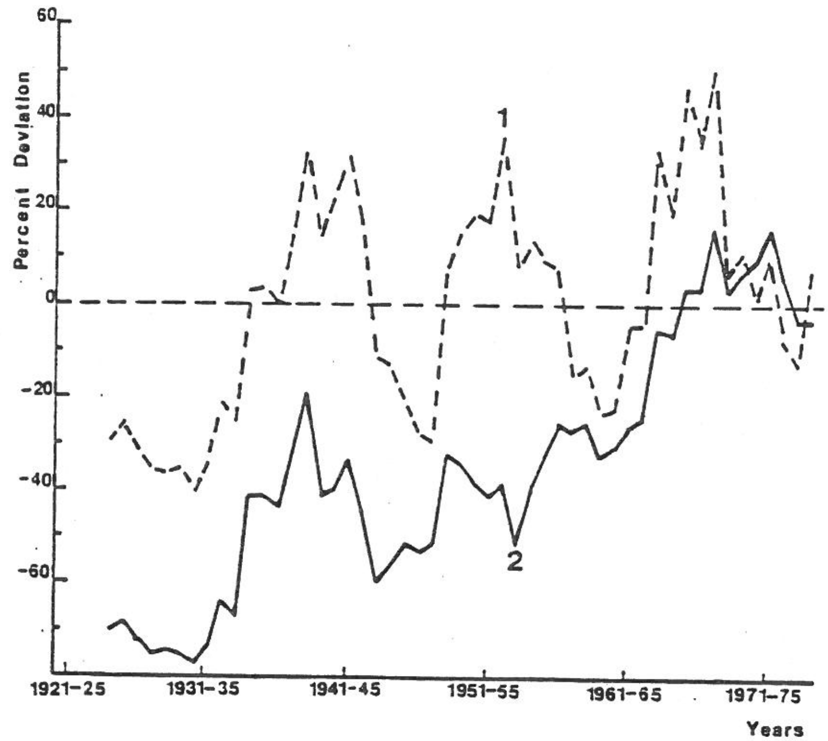


Fig.III.32.**Deviations (in percentage) for the month of July** in (1) Natural and (2) Regulated River Inflow from the July Mean Natural River Inflow (Q = 1.04 MAF; 1921-78), calculated with 5-year running averages.

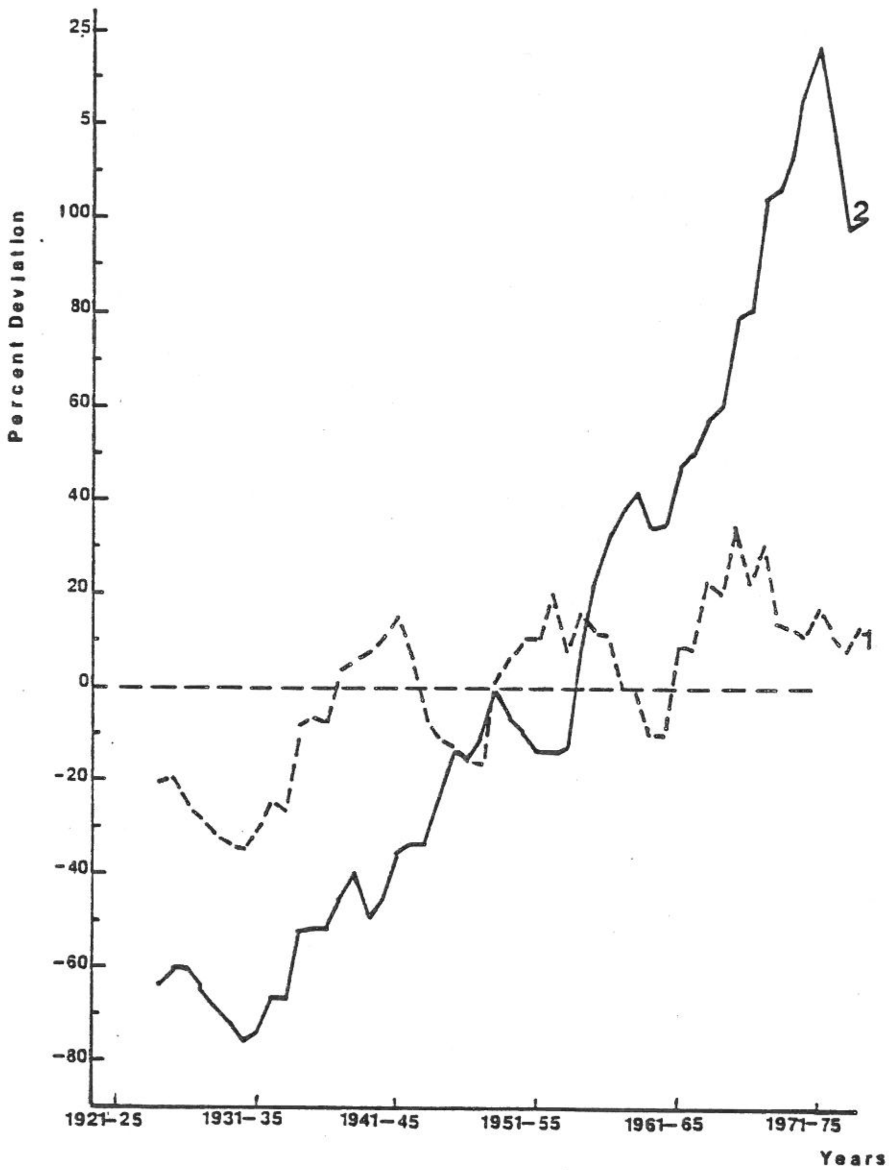


Fig.III.33.Deviations (in percentage) for the month of August in (1) Natural and (2) Regulated River Inflow from the August Mean Natural River Inflow (Q = 0.54 MAF; 1921-78), calculated with 5-year running averages.

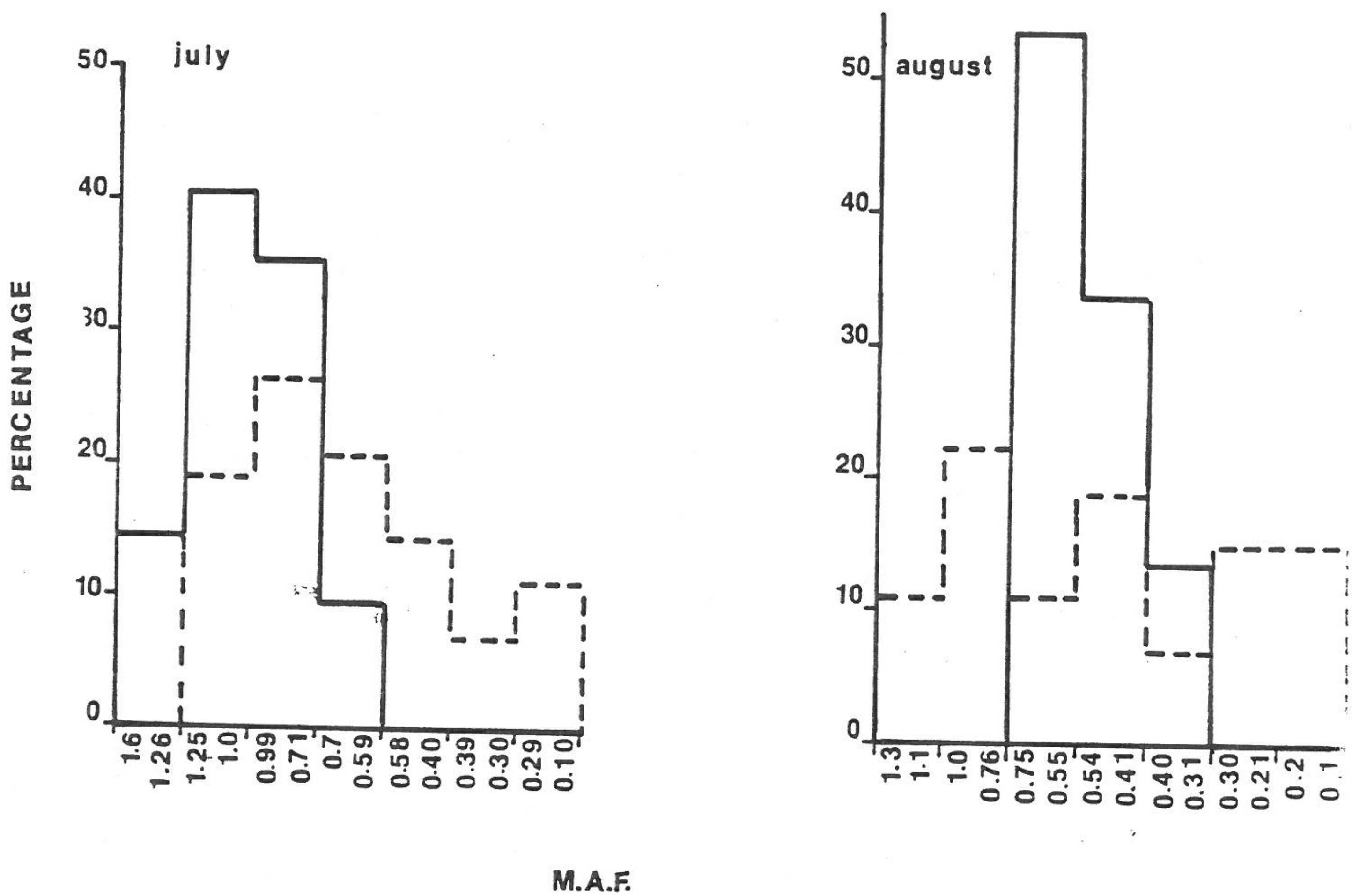


Fig.III.34 Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1921-82) River Inflow for the Summer Months, calculated with 5-year running means.

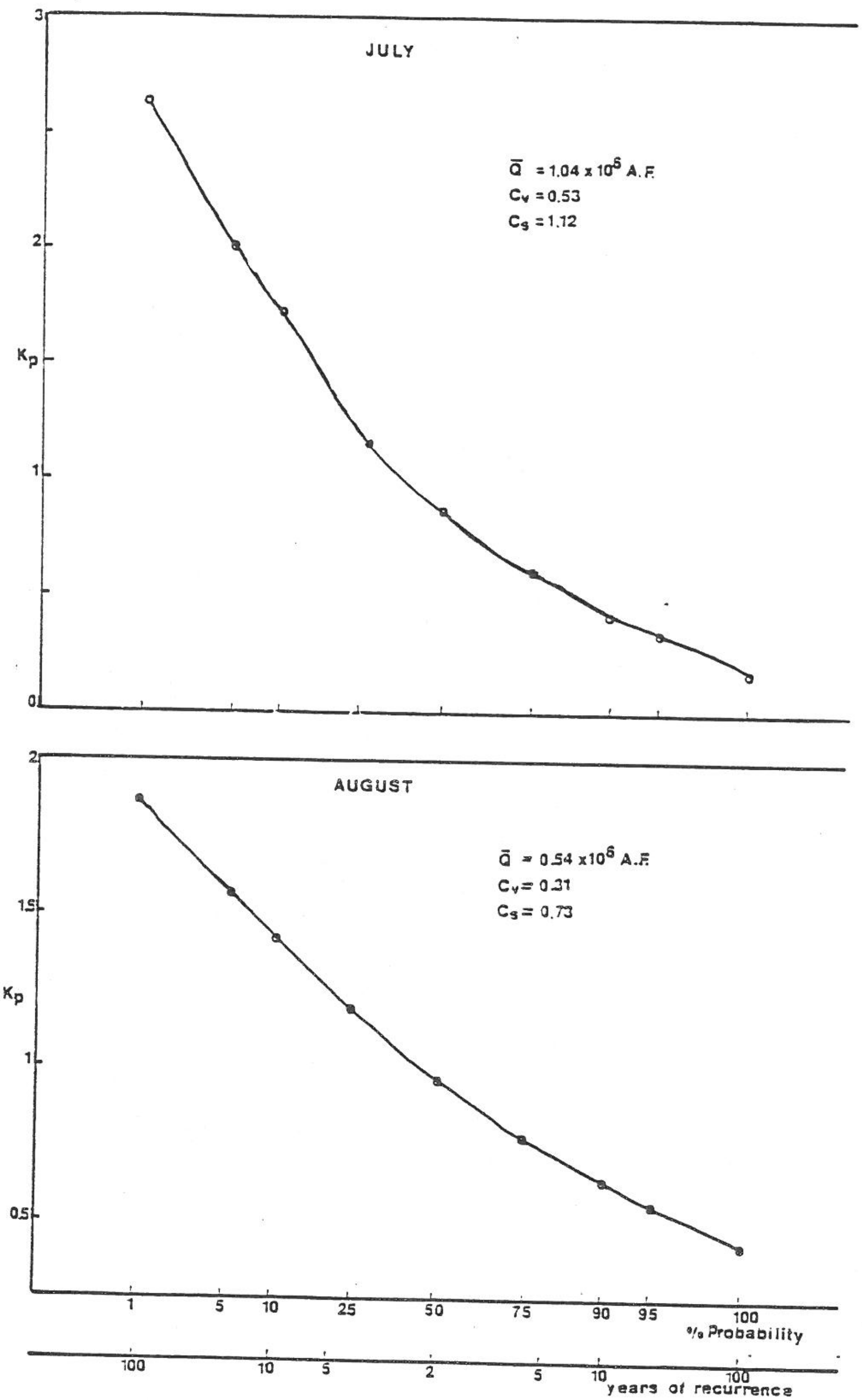


Fig.III.35. Probability Curve of the Natural River Inflow for the Summer Months, calculated with 5-year running means.

amount of returning water added, are responsible for this increase in Delta water supply. However, information on whether these releases improve the water quality of the Delta tributaries is insufficient, which precludes the analysis of the dynamics of chemical constituents for pre- and post-project periods.

The scale of alteration of river inflow due to regulation can be seen from the histograms (Fig. III. 34). In both cases, July and August, the number of near normal regulated inflow events increased several times.

It is important to note that the highest values of RRI_5 observed for August do not correspond adequately to the observed probability of recurrence for the highest values of the NRI_5 (i.e., probability of exceedance 1-25%; Fig. III. 35, Table III. 16). As a rule, the highest values of the regulated inflow for the wet and above normal monthly events are several times higher than those for the natural inflow. At the same time, the values of RRI_5 for sub-normal and dry years are almost equal to those observed under natural conditions.

For example, 1-10% probability of exceedance for RRI_5 is as much as two times higher than that for NRI_5 (Table III. 16,) however, the RRI_5 for sub-normal and dry months with a 75-95% probability of exceedance (that is a recurrence interval of not less than once in 4-20 years) does not differ very much from that of the NRI_5.

There is a very specific shift in water supply distribution during the summer, namely: the highest range of runoff for July, observed under natural conditions, was replaced by the regulated values of runoff which were typical for August under would-be natural conditions, while the August regulated inflow acquired the highest ranges which were typical for July natural inflow (Fig. III. 34).

Due to the lack of field observations, it is difficult to assess, how such redistribution of river inflow, affects the summer dynamics of chemical and biological constituents of the river-Delta-estuary system. Hypotheses regarding the impacts of such flows range from suggestions that they represent some kind of positive changes in water quality of the Delta to statements that they have not prevented salt intrusion into the western part of the Delta or the deterioration of water quality in areas of agricultural, industrial and municipal intakes.

III.2.2.4 AUTUMN

General Remarks:

As was mentioned above, more than 60% of the total seasonal rainfall occurred during the five months of November through March. In this regard, the first two months of autumn

(<u>September</u> <u>and</u> <u>October</u>) experienced a lack of water supply. This water supply depends, under natural conditions, on precipitation, ground water discharges to the river bed, the overall water supply if any, from the preceding summer months, and in addition, under regulated conditions, on water releases from storage facilities and drainage systems.

Presumably, the groundwater impact on the freshwater balance can be seen from the relatively stable and periodic fluctuations of NRI_5 within the predominant range for <u>September</u> of 20% for NRI_5 and NDO_5, with the exception of the dry period in the late 1920's (Fig. III.36).

For <u>October</u> and <u>November</u> this stable periodicity is slightly distorted perhaps due to sporadic rainfall, but again, the predominant ranges were 20% for October and 25% for November (Figs. III.37, 38).

It should be noted that the maximum positive deviations for these months are typical of Delta outflow. Although, in general, the trends of NRI_5 and NDO_5 have more similarities than differences. However, due to the fact that during autumn the upstream and downstream regulated runoff reflects the pressure of different anthropogenic factors, i.e., storage water releases affecting first RRI_5, and drainage releases affecting RDO_5, there are some significant differences in the deviations of these regulated 5-year upstream and downstream regulated mean water supply characteristics in their absolute values. Therefore, their analysis will be described separately.

<u>SEPTEMBER</u>

The comparison between the deviations of NRI and RRI shows very strong influence of man's activities on the river watershed. Since the early 1940's, or the very beginning of the CVP operations, and later, when SWP's small and large facilities were put into operation (that has followed an increase of discharges of returning waters from agricultural fields and some specified water releases to improve water quality in the Delta) the trend of RRI_5 deviations has been quite different from that observed for NRI_5. In this regard, it can be seen that the RRI_5 deviations are characterized by (as will be shown later for RDO_5) two distinctive periods:

1. <u>The pre-project period</u>, from the 1920's up to 1943, when differences in the deviations of the two river inflow characteristics are very small and their variables have the same temporal trend (Fig. III.36, Table III.18).

2. <u>The post-project period</u>, since 1944, in which the RRI_5 deviations have only positive values and are several times higher than the same for NRI_5.

Table III.18 The Differences Between the Mean Natural and Regulated Sacramento-San Joaquin River Inflow to the Delta for the Month of September, Calculated with 5-Year Running Means (1923-1978)

Years	Qn $\times 10^3$ AF	Qr $\times 10^3$ AF	Qr-Qn $\times 10^3$ AF	$\frac{Qr-Qn}{Qn} \times 100$
1924-28	369.8	314.80	55.0	-14.9
25-29	376.2	341.40	34.8	- 9.3
26-30	364.4	354.20	10.2	- 2.8
27-31	351.6	330.00	21.6	- 6.1
28-32	333.2	303.60	29.6	- 8.9
29-33	322.6	283.40	39.2	-12.2
30-34	313.4	263.00	50.4	-16.1
31-35	313.0	252.40	60.6	-19.4
32-36	331.2	288.00	43.2	-13.0
33-37	331.0	299.80	31.2	- 9.4
34-38	382.2	351.00	31.2	- 8.2
35-39	399.6	371.00	28.6	- 7.2
36-40	413.0	388.40	24.6	- 6.0
37-41	454.0	398.20	55.8	-12.3
38-42	495.2	428.40	66.8	-13.5
39-43	477.2	402.80	74.4	-15.6
40-44	479.4	416.20	63.2	-13.2
41-45	476.0	447.40	28.6	- 6.0
42-46	446.8	480.80	34.0	7.6
43-47	409.4	482.40	73.0	17.8
44-48	402.4	540.60	138.2	34.3
45-49	399.2	574.80	175.6	44.0
46-50	398.2	573.60	175.4	44.0
47-51	397.6	585.60	188.0	47.3
48-52	449.2	636.40	187.2	41.7
49-53	470.2	652.60	182.4	38.8
50-54	495.2	654.80	159.6	32.2
51-55	495.8	636.60	140.8	28.4
52-56	529.2	679.20	150.0	28.3
53-57	514.2	695.60	181.4	35.3
54-58	534.4	767.80	233.4	43.7
55-59	560.8	795.20	234.4	41.8
56-60	558.0	817.00	259.0	46.4
57-61	520.8	766.00	245.2	47.1
58-62	491.6	762.00	270.4	55.0
59-63	469.0	752.00	283.0	60.3
60-64	418.8	782.00	363.2	86.7
61-65	447.0	872.00	425.0	95.1
62-66	449.2	892.00	442.8	98.6
63-67	483.4	992.00	508.6	105.2
64-68	465.0	948.00	483.0	103.9
65-69	509.0	1076.00	567.0	111.4
66-70	498.0	1108.00	610.0	122.5
67-71	532.6	1280.00	747.4	140.3
68-72	524.6	1242.00	717.4	136.8
69-73	536.2	1302.00	765.8	142.8
70-74	534.6	1346.00	811.4	151.8
71-75	561.8	1388.00	826.2	147.1
72-76	538.0	1242.00	704.0	130.9
73-77	515.8	1106.00	590.2	114.4
74-78	581.2	1134.00	552.8	95.1

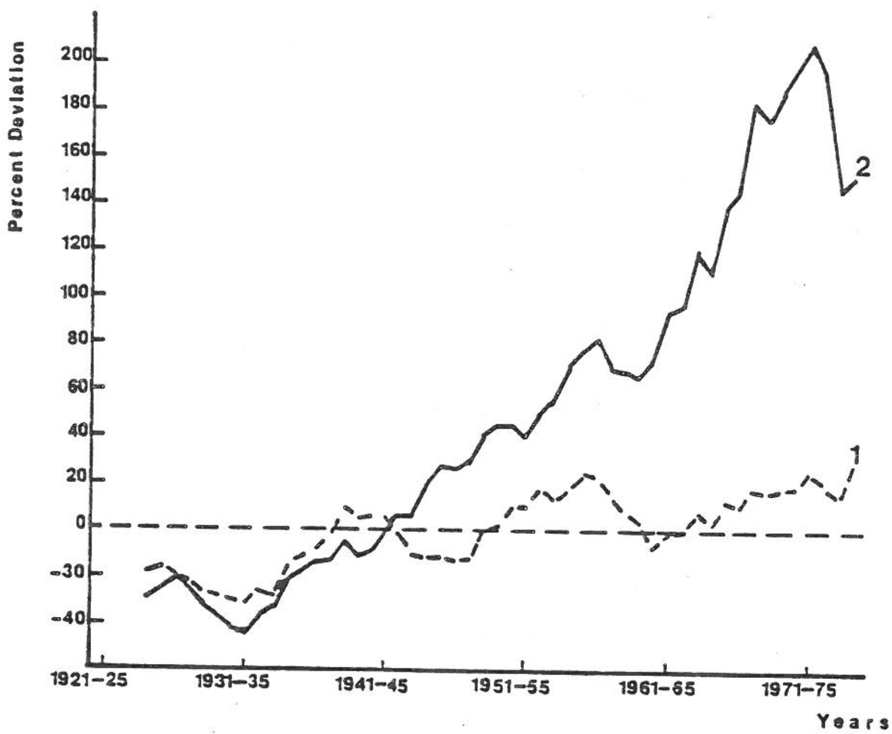


Fig. III.36. Deviations (in percentage) for the month of September in (1) Natural and (2) Regulated River Inflow from the September Mean Natural River Inflow (Q = 0.45 MAF; 1921-78), calculated with 5-year running averages.

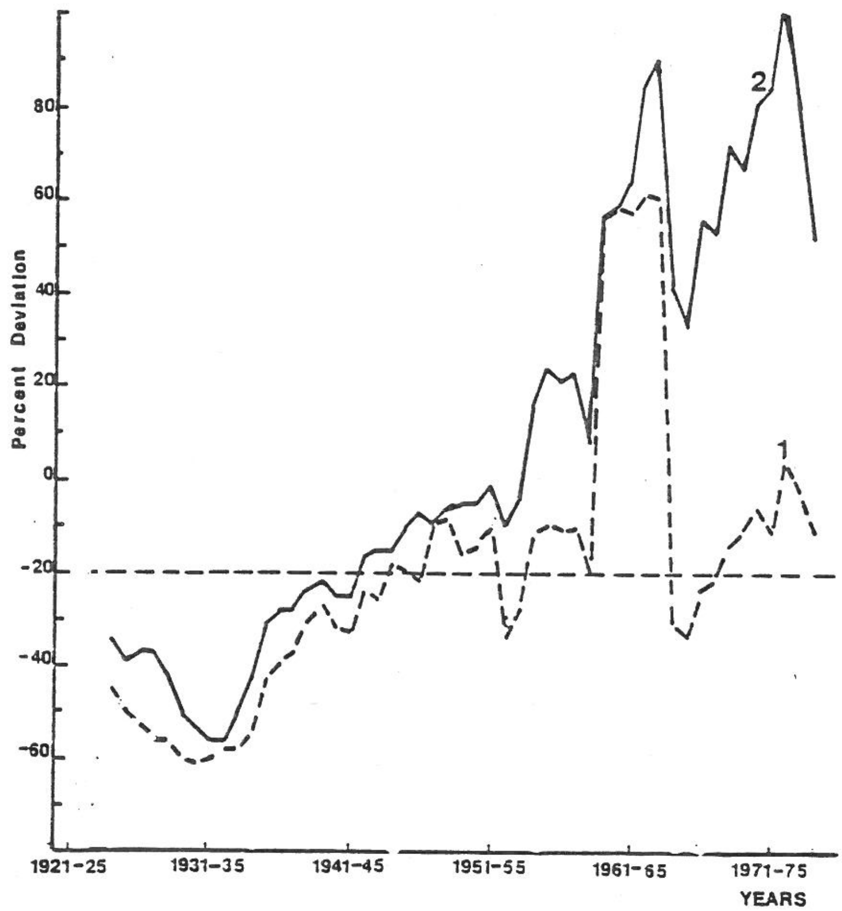


Fig. III.37 .**Deviations** (in percentage) for the month of October in (1) Natural and (2) Regulated River Inflow from the October Mean Natural River Inflow (Q = 0.58 MAF; 1921-78), calculated with 5-year running averages.

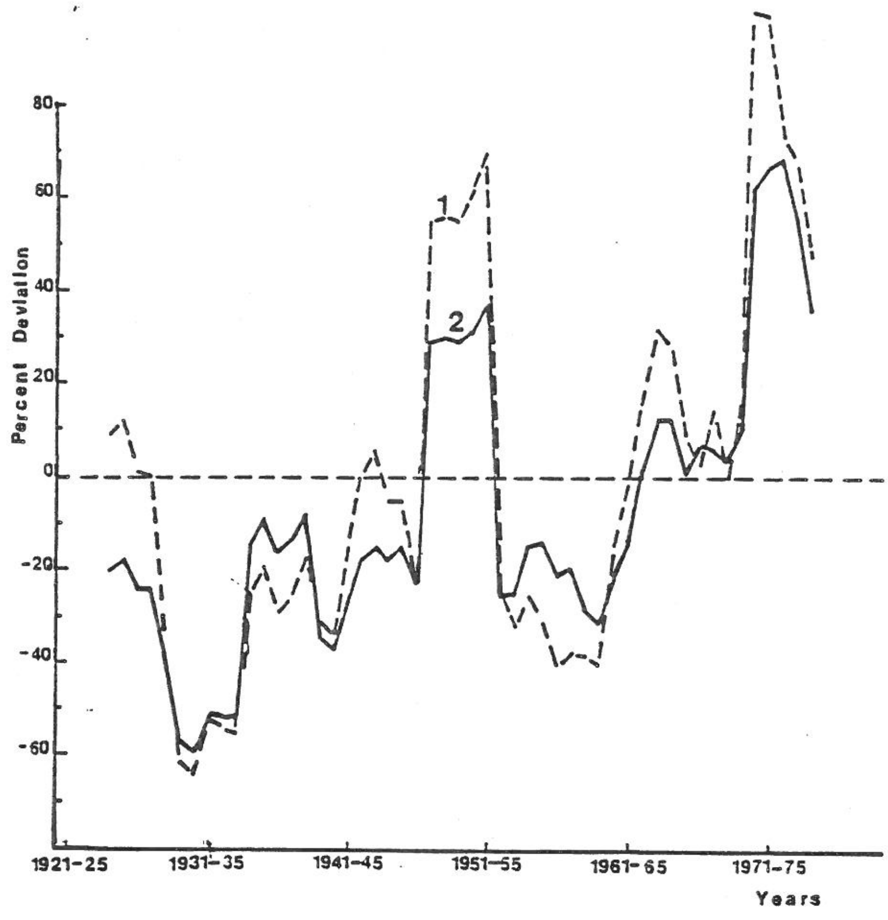


Fig.III.38.Deviations (in percentage) for the month of November in (1) Natural and (2) Regulated River Inflow from the November Mean Natural River Inflow (Q = 1.13 MAF; 1921-78), calculated with 5-year running averages.

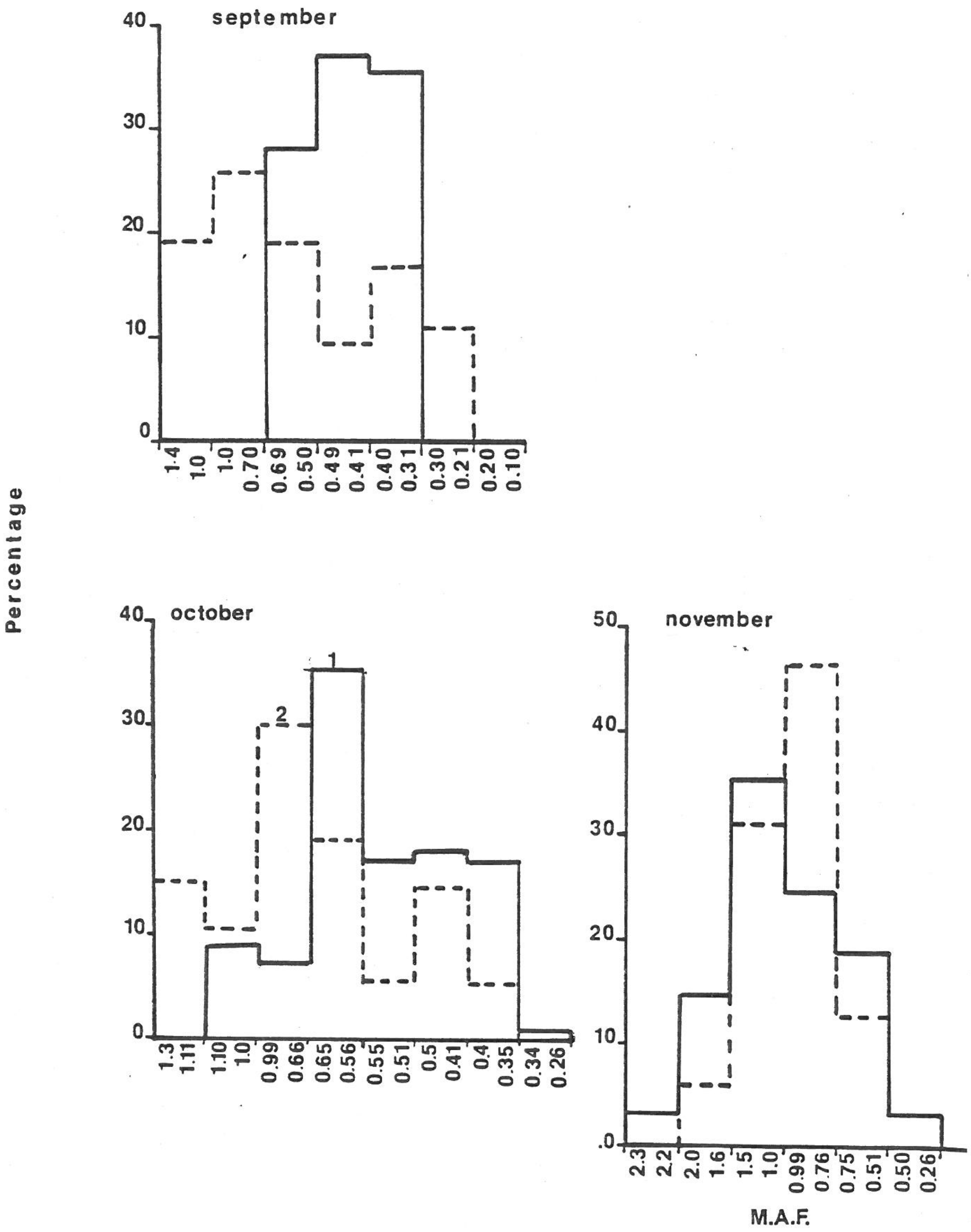


Fig.III.39. Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1921-82) River Inflow for the Autumn Months, calculated with 5-year running means.

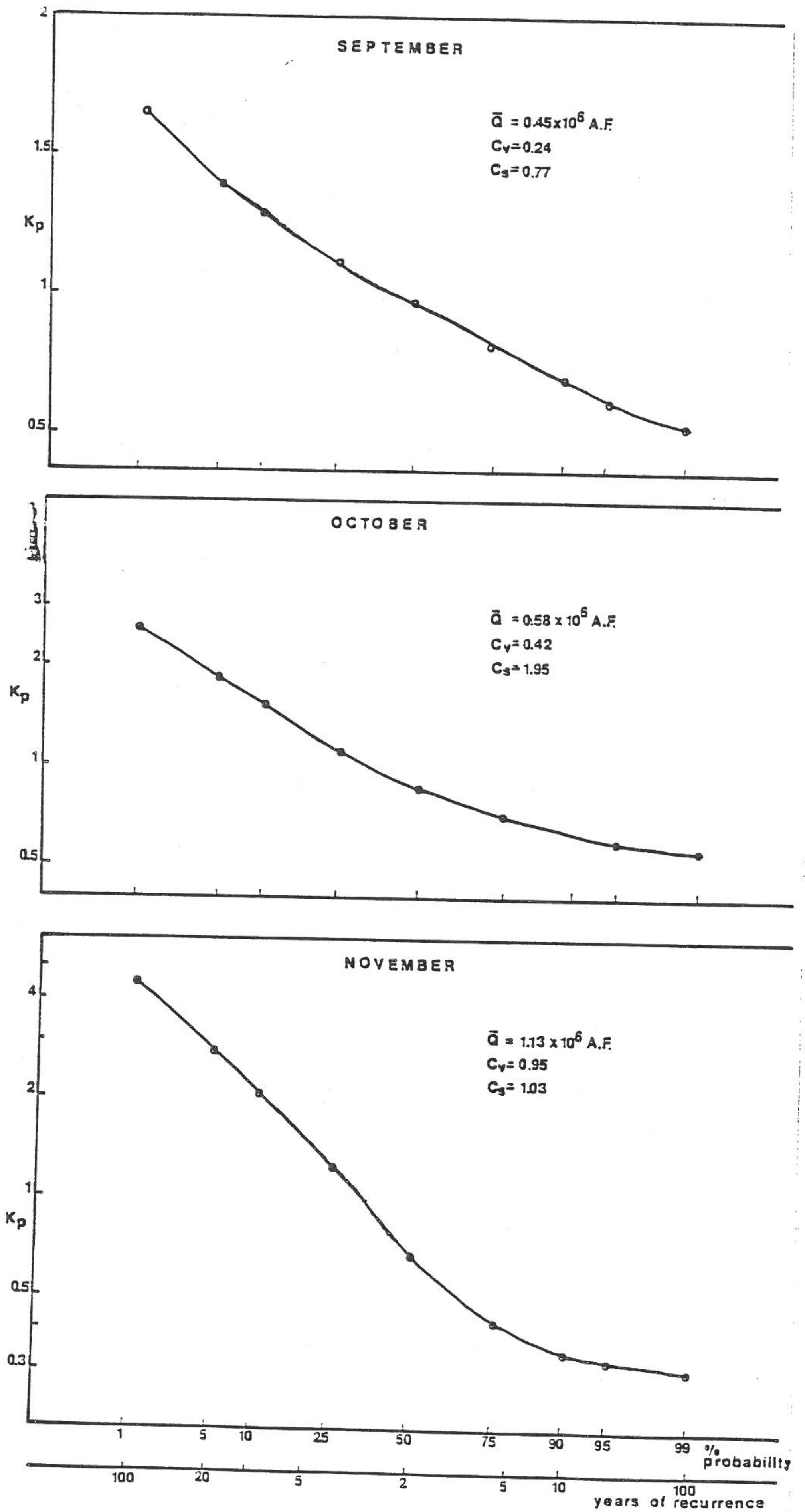


Fig.III.40. Probability Curve of the Natural River Inflow for the Autumn Months, calculated with 5-year running means.

More to the point, even if the natural deviations had the same observed periodicity for wet and dry periods as those for annual and seasonal deviations (late winter, spring and summer), this was not the case for regulated water supply to the Delta for September. It is possible that the water balance of the rivers was not only improved but enhanced due to the fact that for the last 40 years RRI_5 of any 5-year period has gradually increased to the point when the amount of available water from the river discharges is as much as 2-3 times higher (Table III.18) than the volume of natural inflow.

For example, since 1942-46 the additional amount of water entering the river from different sources increased from 0.3 MAF to a maximum of 0.83 MAF in 1971-75, and later was reduced almost 1.5 times due to the very low flows of 1976-77. Table III. 18 illustrates the increase of mean RRI_5 to the Delta due to human factors. All other periods (other than 1950-54) show a gradual increase of 1.3-1.5 times in comparison with the preceding period. However, three questions should be raised:

1. Does this increase of hundreds of thousands of acre feet in discharges during these months compensate for the millions of acre feet of losses sustained during the preceding seasons, especially late winter-spring?

2. Is the quality of returning water adequate for improving Delta water quality?

3. Has this increase of RRI_5 relative to natural flow provided better conditions for the living resources in the Delta-estuary ecosystem?

4. Are these water releases capable of reducing the salt concentration in the estuarine system, especially the Delta-Suisun Bay if during the preceding months the system had deficits from diversions of more than 5 MAF of freshwater during December-June?

Unfortunately, there is no statistically validated information which can be used to answer these extremely important questions.

The changes in the regime of NRI_5 during <u>September</u> can be seen from the histogram (Fig. III. 39). It shows that the number of events in the predominant range of NRI_5 of 0.31-0.69 MAF was reduced for RRI_5 as much as two times and a new predominant range, a higher flow of 0.8-1.4 MAF for RRI_5 appeared which had no precedent under natural conditions, as well as a low inflow range 0.2-0.3 MAF for RRI_5

As a result of these substitutions, the values of highest RRI_5 for the probability of exceedance of 1-25% increased 1.8-2.5 times. The range of 0.5-0.6 MAF was replaced by the range of 0.9-1.6 MAF.

Overall, the new RRI_5 of 50% of probability of exceedance (Table III. 16,) is 1.5 times higher than flow of the same probability under natural conditions, which was 0.45 MAF.

It should be noted that the values of RRI_5 of the so-called above normal or wet conditions are almost 2 times higher than what would be for the natural discharges. The values of sub-normal RRI_5 of different probabilities do not differ much from the same values for the NRI_5. The explanation may be very simple, namely, during sub-normal wetness for given months, there is not much water to be released from storage facilities or discharged from the drainage network of the agricultural fields, and therefore, there are no water supplies.

OCTOBER

The most noticeable changes in water supply to the Delta/Bay system for this month took place after the completion of the SWP facilities. RRI_5 for the pre-project period was characterized by almost the same amplitude of deviations as the natural water supply (Fig. III. 37). From 1959-63 to the end of the period of consideration, 1974-78, the positive deviation of RRI_5 from the normal ranged between 53 and 120%. As in the case of September, this water supply may be attributed to releases from the drainage network of agricultural fields and discharges from storage facilities. During this period of time, this positive water balance (i.e., $Qrri>Qnri$) accounted for approximately 400-600 thousand acre feet which was almost equal to the values of NRI_5 (or 1/2 the volume of the Delta itself).

The shift of frequency of events of different ranges of water supply (Fig. III. 39) and the appearance of events with runoff not observed in the historical past, provide us with information on the impact of increased water releases on the predominant values of natural runoff. This is similar to that observed in September, namely, an overall leveling of the runoff patterns, characterized by the increase of the highest artificial runoff values and consecutive reduction of the frequency of values of low and close-to-the-mean volumes of water supply to the system.

As a result of these substitutions in October, as in September, the values of highest runoff (artificial wettest, wet and normal water supply-- probability of exceedance of 1-50%) increased 1.2-1.4 times, although the values of runoff of probabilities of exceedance of 75-99% (that characterize sub-normal water supply) did not increase significantly (Fig. III.40, Table III. 16,). This suggests that under conditions of sub-normal wetness there will not be discharges of returning waters of such values that may influence the would-be natural runoff (with years of recurrence of at least one time in 4-20 or more years).

NOVEMBER

The regulated water supply for this month (Fig. III. 38) is close to the average NRI_5 (except in the periods from 1934-38 to 1938-42 and 1952-56 to 1959-63). In general, this month has lower water withdrawals (especially for agricultural needs), and the trend of deviations for RRI_5 is similar to that of the NRI_5. Because of the beginning of the rainy season, with the subsequent increase in volume of surface flow from the watershed to the rivers, November has an overall increase of as much as 2-3 times mean natural water supply to the system.

It is interesting to note that the 1.1-1.4 MAF range for RRI_5 for October was almost equal to the predominant range of the would-be NRI for November (it can be assumed that the water quality of RRI_5 for October was less favorable for living resources and other water users than that of the natural water supply).

The histogram for November (Fig. III. 39) demonstrates that under the new water regime characteristics there was a shift from the highest number of events corresponding to the highest runoff to runoff values that would be observed under natural conditions not less than once in 4 years (wet months).

The above normal values of RRI_5 were slightly less than those for would-be natural runoff, but for the sub-normal water supply (Table III. 16,) they are not much different from each other. This suggests that in general, in comparison with the preceding two months of autumn, September and October, the 5-year running mean water supply for November did not experience much impact of runoff regulations.

III.3 Variables of the Natural and Regulated 5-Year Running Mean Delta Outflow to San Francisco Bay

III.3.1 Annual Deviations

The histogram of occurrence of natural and regulated Delta outflow for the 5-year running annual mean (NDO_5, RDO_5) (Fig. III. 16) shows that a number of cases which would be typical for the highest natural outflow decreased more than two times, but at the same time the occurrence of values of low flow increased three times (Table III. 1). This shift to more frequent cases of low regulated Delta outflow illustrates the fact that a new regime of annual water supply to the Bay has been created in comparison to what would have taken place under conditions of unimpaired Delta outflow (Fig. III. 41).

For more than 20 years (1955-78) the five-year running mean RDO_5 to the Bay corresponded to the probability of exceeding of the natural Delta outflow (in the range between 80 and 95%) (Tables III. 19, 20, Fig. III. 42, Appendix 10,11). This means that these volumes of the Delta outflow observed almost every year under regulated conditions would be observed under natural conditions not less than once per 5 to 8 years.

The maximum and minimum losses sustained by upstream and downstream water withdrawals and diversions for the 5-year running means were 11.3 MAF (1971-75) and 3.4 MAF (1937-41) respectively, or 34% and 10% of the mean for those years.

From 1955-59, the minimum water deficit was not less than 7 MAF, and as usual, the highest water withdrawals took place in the years with 5-year running mean runoff close to the normal perennial Delta outflow (27.3 MAF - for the period 1921-78).

The last highest water withdrawals for these periods occurred in 1974-78 when 40% of 11 MAF on the average were diverted per year from the river basin.

In this case, as in many others, the highest diversions coincided with the low natural water supply to the system. That may exacerbate the environmental conditions of the estuary for the following several years as we shall see later.

III.3.2 Monthly Deviations of 5-Year Running Mean Water Supply and their Statistics

The monthly dynamics of natural and regulated Delta outflow fluctuations have some distinctive features the origin of which may be explained by the combined effects of runoff formation, upper river and the inner Delta withdrawals and water releases from reservoirs and agricultural drainage systems.

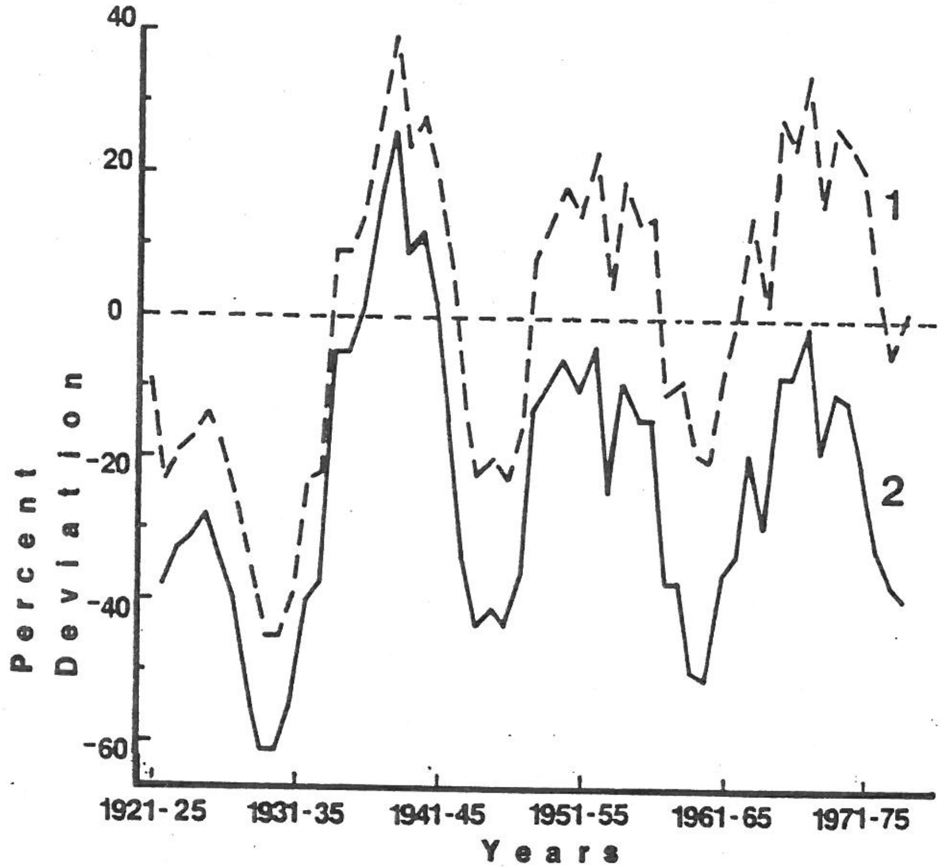


Fig.III.41. Annual Deviations (in percentage) in (1) Natural and (2) Regulated Delta Outflow from the Annual Mean Natural Delta Outflow (Q = 27.72 MAF; 1921-78), calculated with 5-year running averages.

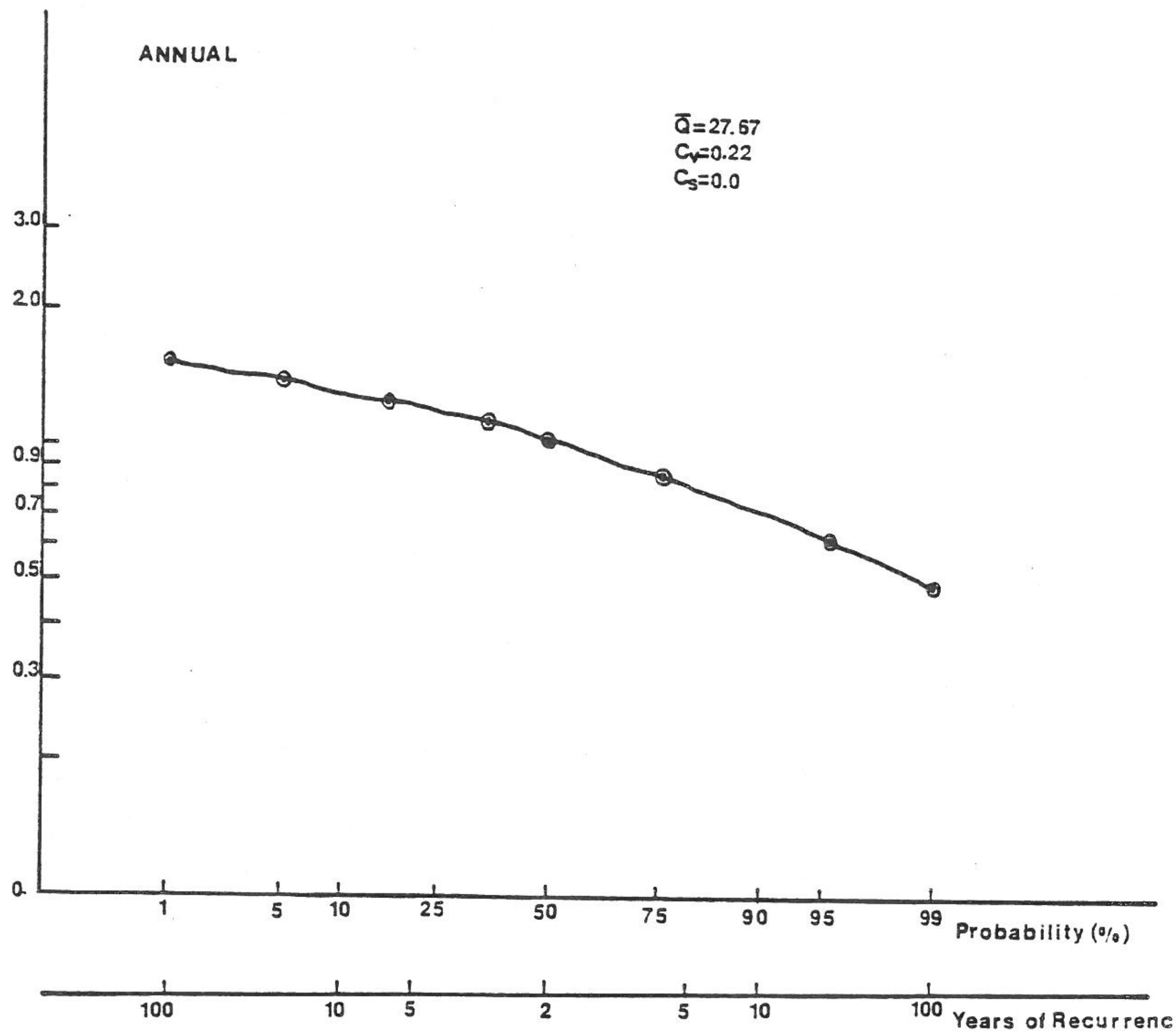


Fig.III.42. Probability Curve of the Annual Natural Delta Outflow, calculated with 5-year running means.

Table III.19 Statistics of the 5-Year Running Mean Monthly and Annual Natural Delta Outflow - 1921-1978

Months	Range Q1 MAF	Mean Q MAF	Cv	Cs	Standard Deviation MAF
October	0.26- 1.03	0.52	0.37	1.32	0.19
November	0.39- 2.36	1.15	0.42	0.69	0.48
December	0.86- 4.70	2.54	0.39	0.80	0.98
January	1.36- 7.69	3.48	0.42	0.84	1.46
February	1.69- 6.40	3.93	0.30	0.04	1.19
March	2.17- 6.71	3.89	0.28	0.64	1.07
April	2.26- 5.58	4.14	0.17	-0.33	0.71
May	2.40- 5.38	4.14	0.18	-0.27	0.75
June	1.56- 3.56	2.48	0.20	-0.12	0.50
July	0.42- 1.36	0.83	0.28	0.18	0.24
August	0.13- 0.52	0.32	0.30	-0.23	0.10
September	0.15- 0.43	0.30	0.26	-0.26	0.08
ANNUAL	15.25-39.56	27.67	0.22	0.0	6.09

Table III.20 Variables of a theoretical curve of probability of exceedance and recurrence of monthly 5-years running mean natural Delta outflow, 1921-1978.

Probability of exceeding, %	1	5	10	25	50	75	90	95	99
Years of recurrence	100	20	10	4	2	4	10	20	100
October	1.14	0.89	0.78	0.62	0.48	0.38	0.32	0.29	0.26
November	2.51	2.02	1.79	1.44	1.09	0.81	0.58	0.46	0.28
December	5.48	4.42	3.91	3.12	2.41	1.80	1.35	1.14	0.77
January	7.86	6.23	5.46	4.32	3.27	2.40	1.78	1.43	0.97
February	6.72	5.90	5.42	4.71	3.91	3.14	2.44	1.96	1.22
March	6.92	5.85	5.34	4.54	3.77	3.11	2.61	2.33	1.87
April	5.59	5.22	5.01	4.64	4.17	3.68	3.23	2.94	2.32
May	5.70	5.30	5.07	4.65	4.18	3.64	3.15	2.86	2.24
June	3.59	3.27	3.11	2.82	2.48	2.16	1.84	1.66	1.29
July	1.40	1.22	1.13	0.98	0.82	0.67	0.53	0.46	0.32
August	0.53	0.47	0.44	0.39	0.32	0.26	0.20	0.16	0.08
September	0.47	0.42	0.40	0.35	0.30	0.25	0.20	0.16	0.10
ANNUAL	41.78	37.63	35.42	31.82	27.67	23.52	19.92	17.71	13.56

Figures III. 43-64 illustrate the presence or dominant role of some of these features for different months of the year.

III.3.2.1 <u>WINTER</u> (December, January, February, March)

<u>General Remarks</u>

The winter months are characterized by significant fluctuations of water supply and the highest amplitude of deviations of 5-year running mean of natural and regulated Delta outflow (Figs. III. 43-46). This may be explained by the influence of climatological factors: air temperature, temperature of soil before snowfall, intensity of rain on snowpack, etc., in the case of NDO_5, and both climatological and total water diversions from the river system in the case of RDO_5.

During the winter months, the highest deviation of RDO_5 from mean and the differences between the NDO_5 and RDO_5 reached their maximum during 1957-61 and later between 1973 and 1981, which coincides with the intensified water withdrawals to provide for the recharging of storage facilities of the CVP and SWP.

The predominant range of negative deviations of RDO_5 from the normal was for this first period, 51-60%, and for the second period 67-74%, while the predominant range of negative deviations of the NDO_5 from normal had a range for the same periods between -20 and -45%.

At the same time, the predominant positive deviations for RDO_5 were in the range of 20-40%, while for NDO_5 they were in the range of 20-60% for the months of December, January and February (Figs. III. 43-45).

It should be noted that for the first three months of winter, the RDO_5 deviations follow the same pattern of the NDO_5 deviations and reached positive values (above normal). That was not typical for March (Fig. III. 46) for which during almost two decades the RDO_5 fluctuated below normal. This trend, as we will see below, became more pronounced during the spring months.

<u>December</u>:

The outflow to the Bay for December has been significantly deprived of natural water supply, and it can be assumed that for December there is little excess water to be accumulated in new water storage facilities if constructed, as has been discussed since the late 1970's.

It should be noted that for the <u>pre-project</u> conditions, maximum negative deviations were observed only for 1929 and 1937nd for the rest of the years, the dominant range was between 0-30%.

From the histograms (Fig. III. 47) it is obvious that the range of the RDO_5 was shifted to values as much as two times smaller than would exist under natural conditions. The flow of 3.0-3.5 MAF, the recurrence of which under natural conditions was at least once every 2-10 years (Fig. III. 48, Table III. 20), was not observed for the period 1944-78 when early winter recharges of storage facilities began taking place.

In practice, the RDO_5 for December, for years of several different wetnesses, corresponds to the predominant probability of occurrence of would-be natural Delta outflow within the range of 85-97% of exceedance, that is, not less than once per 6-30 years, and its low values, e.g., in 1975-79 - 0.8 MAF); 1976-80 - 0.7 MAF; and 1977-81 - 0.6 MAF would have been observed under natural conditions, presumably, only once per 90-110 years. At the same time, the value of the NDO_5 (3.0, 2.2, 2.0 MAF) would have a probability of exceedance of 75-90%, i.e., recurrence of not less than once per 4 or 10 years.

These differences of probability of occurrence between the NDO_5 and the RDO_5 may reflect the role of runoff regulation on the stochastic nature of the flow as was seen before.

In practice, the characteristics of various values of regulated Delta outflow for different probabilities of exceedance (Table III. 20,) were reduced as much as 1.5 times especially for wet and critical wet years relative to NDO_5.

<u>January, February</u>

Over the course of all years of observation, <u>February</u> (Fig. III. 45) is characterized by the highest deviation of the RDO_5 for normal, and in particular during the post-project years of 1952-56 up to 1971-75, during which the deviations were 2-5 times higher than those observed if natural Delta discharges to the Bay were taking place.

The <u>January</u> and <u>February</u> regulated Delta outflow histograms (Fig. III. 47) show, as was the case for December, that the range of the highest Delta outflow ceased to exist and the current conditions of RDO_5 are characterized by the overall increase in ranges of runoff which would be typical for the probability of exceedance of the natural Delta outflow of 75 to 99%, i.e., sub-normal or critical flow conditions.

<u>March</u>

In this month, as for the previous three months of winter, RDO_5 deviations from normal for the pre-project period (1921-43) were relatively close to NDO_5 deviations from the same normal (Fig. III. 46).

However, with the gradual implementation of storage

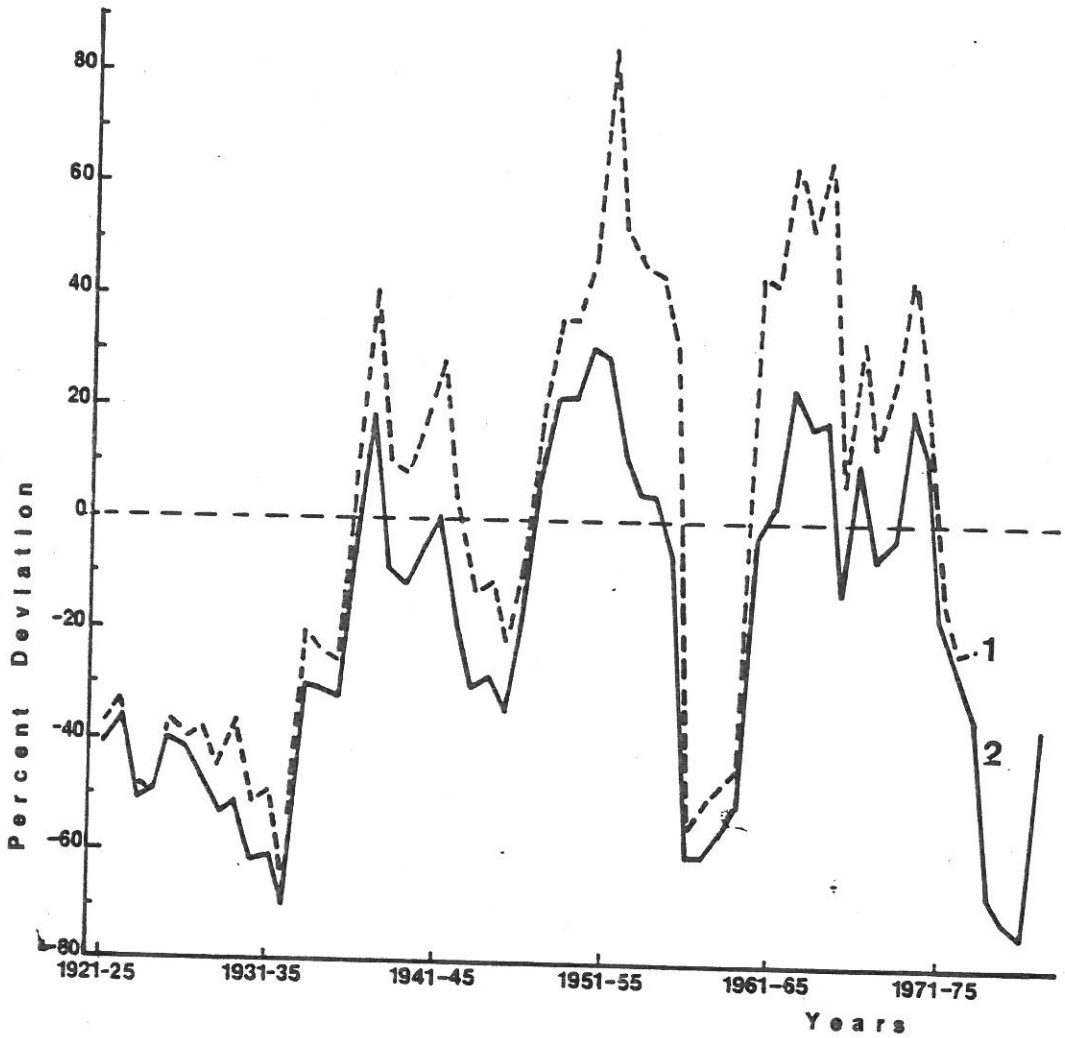


Fig.III.43. Deviations (in percentage) for the month of December in (1) Natural and (2) Regulated Delta Outflow from December Mean Natural Delta Outflow (Q = 2.54 MAF; 1921-78), calculated with 5-year running averages.

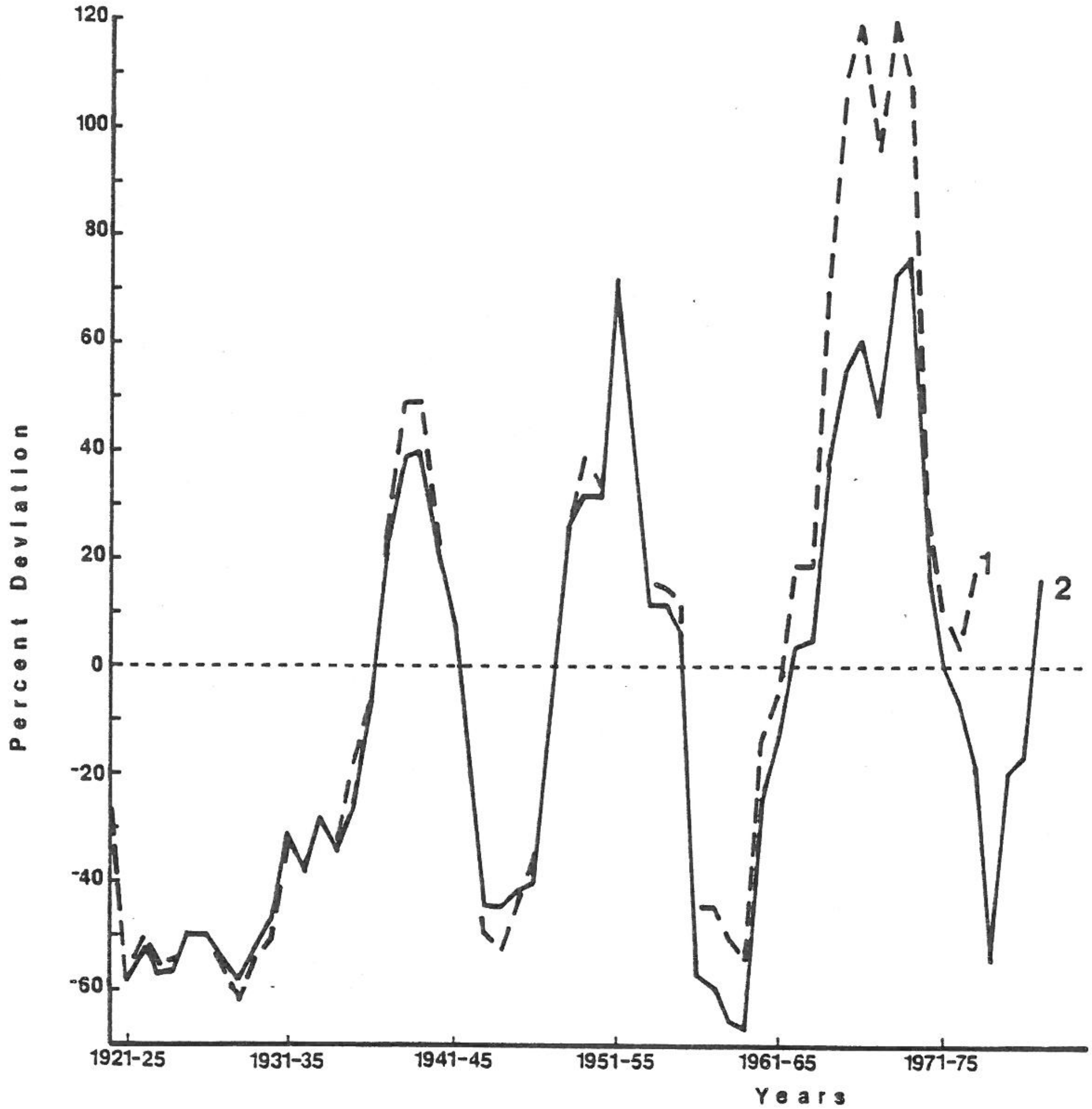


Fig.III.44. Deviations (in percentage) for the month of January in (1) Natural and (2) Regulated Delta Outflow from January Mean Natural Delta Outflow (Q = 3.48 MAF;1921-78), calculated with 5-year running averages.

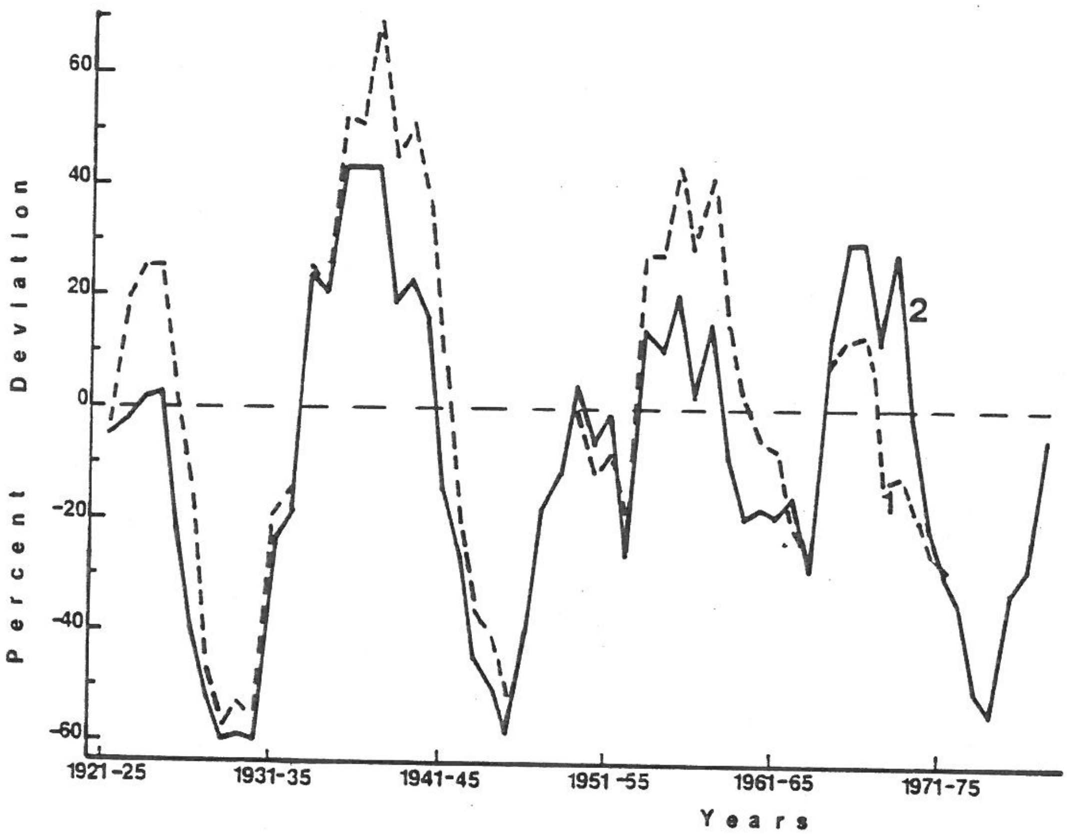


Fig.III.45. Deviations (in percentage) for the month of February in (1) Natural and (2) Regulated Delta Outflow from February Mean Natural Delta Outflow (Q = 3.93 MAF; 1921-78), calculated with 5-year running averages.

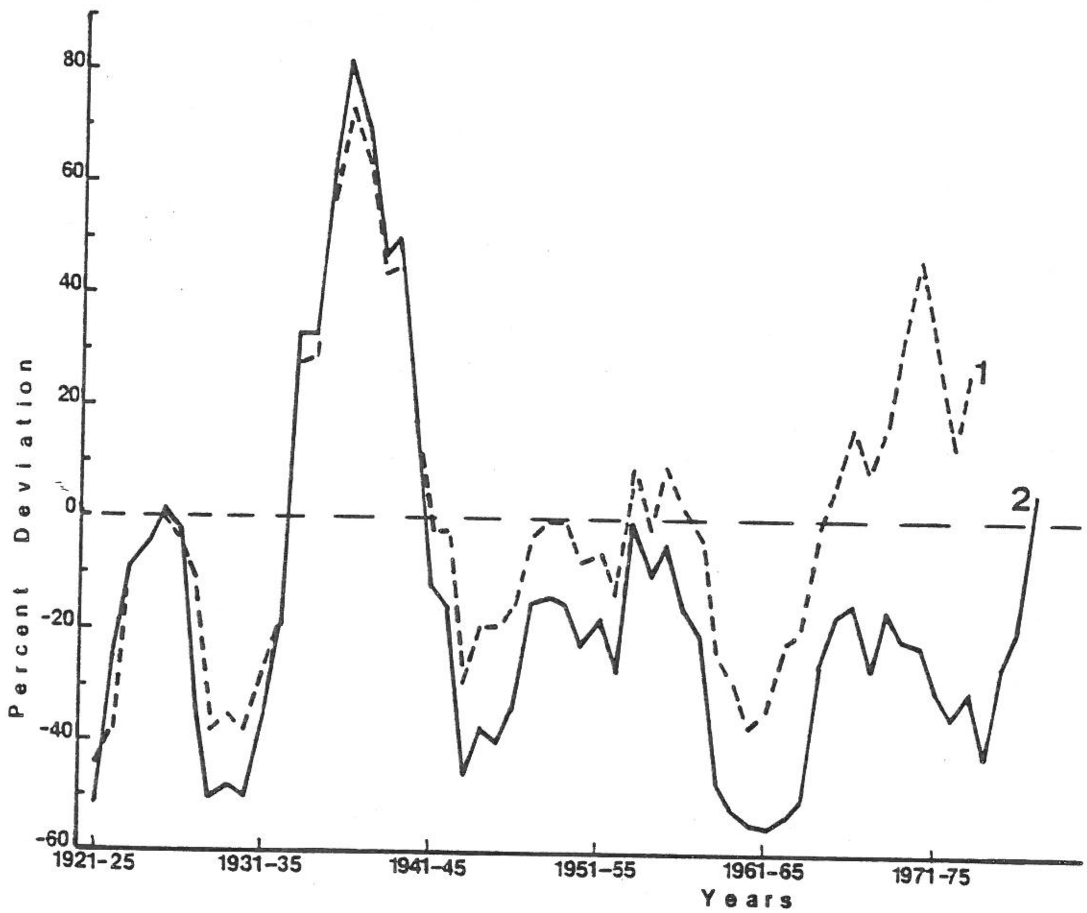


Fig.III.46. Deviations (in percentage) for the month of March in (1) Natural and (2) Regulated Delta Outflow from March Mean Natural Delta Outflow (Q = 3.89 MAF; 1921-78), calculated with 5-year running averages.

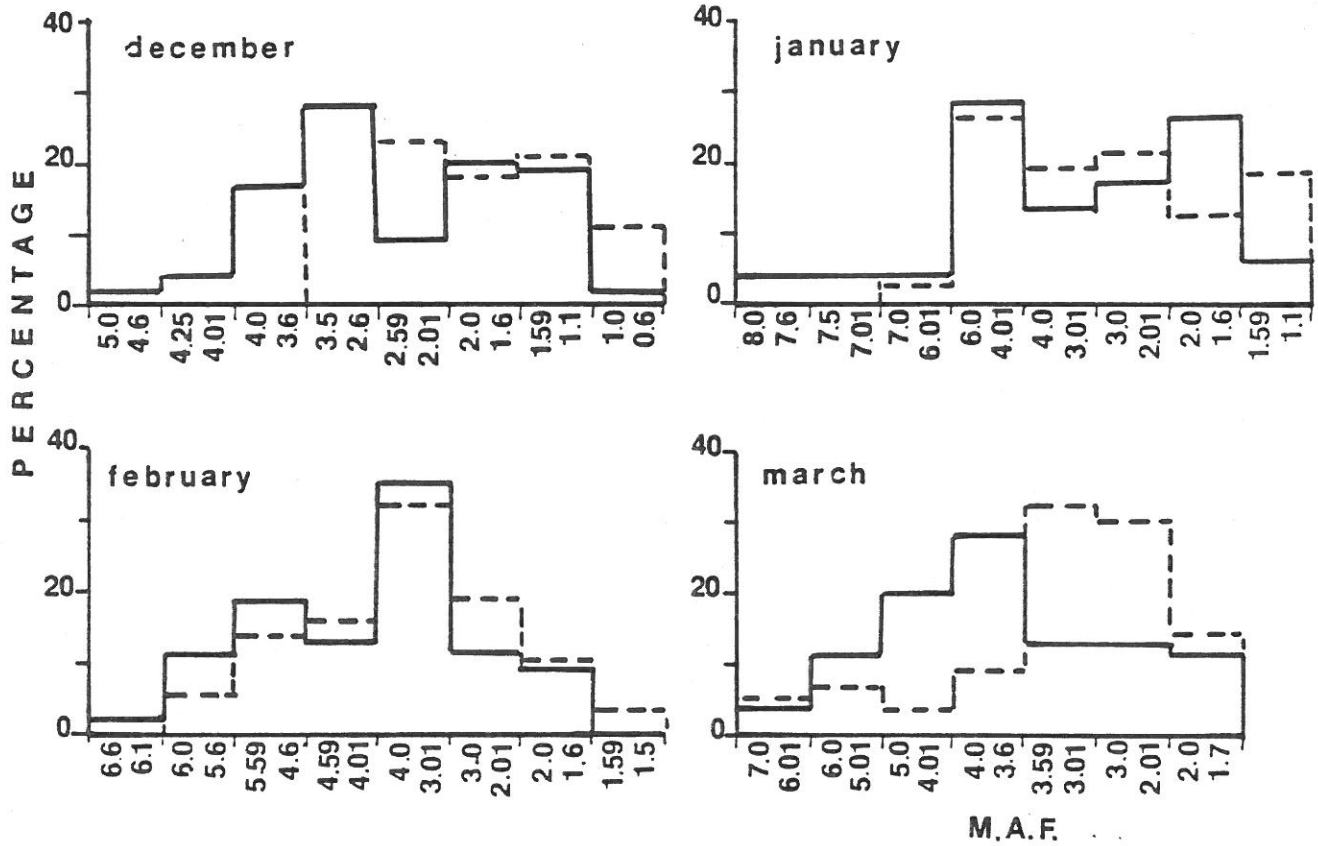


Fig.III.47. Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1921-78) Delta Outflow to the Bay for the Winter Months, calculated with 5-year running means.

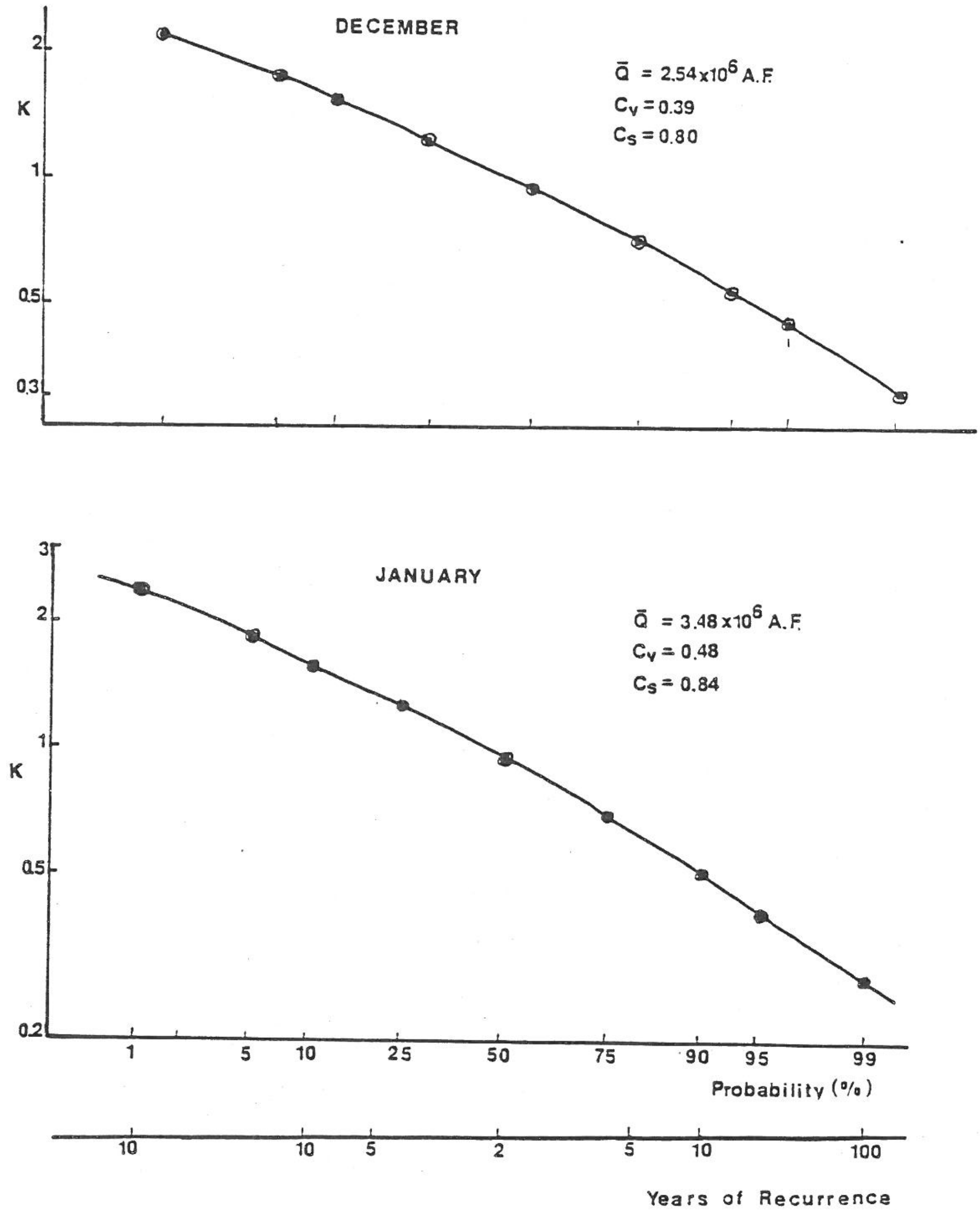


Fig. III.48, Probability Curve of the Natural Delta Outflow for the Winter Months, calculated with 5-year running means.

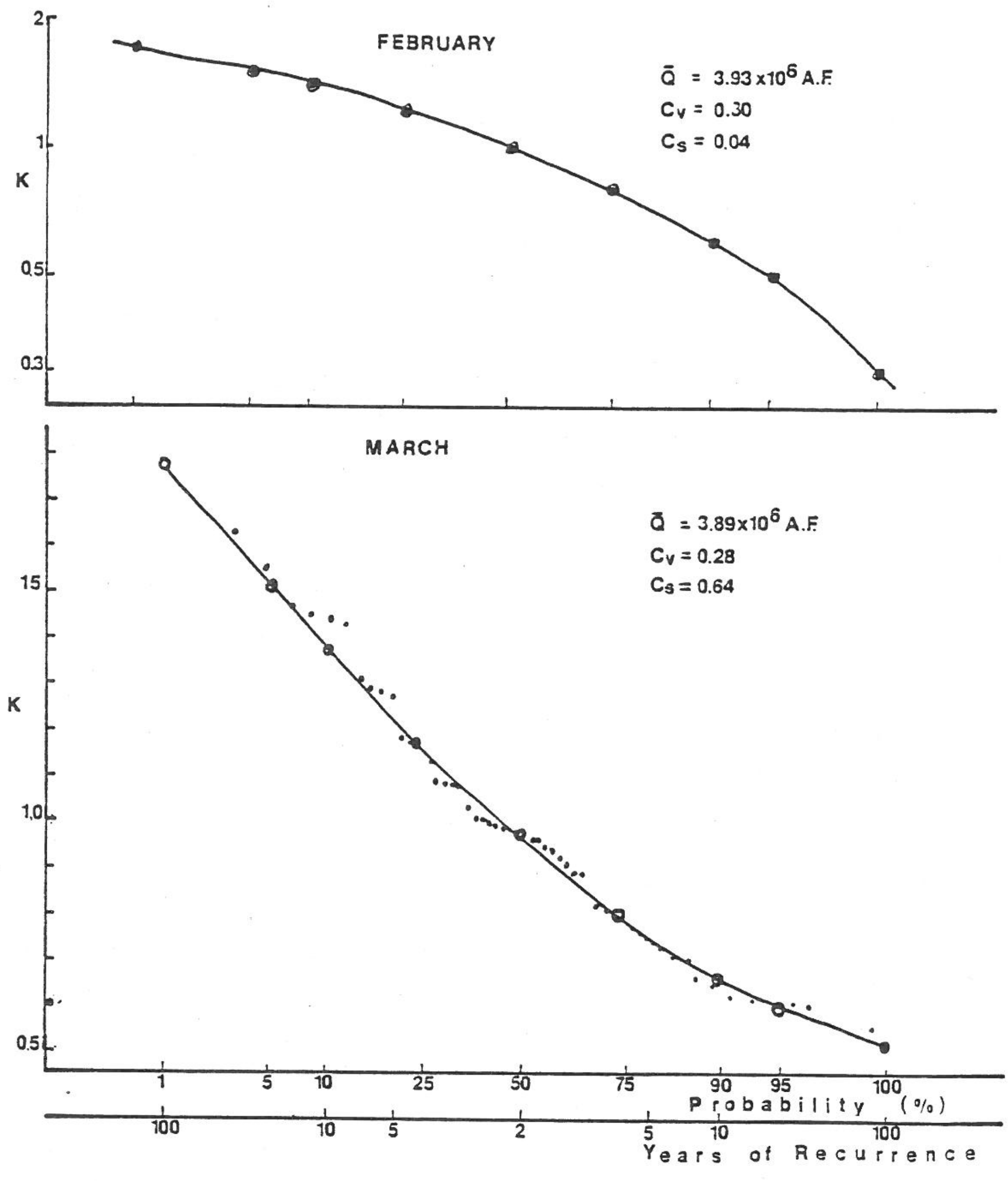


Fig.III.49. Probability Curve of the Natural Delta Outflow for the Winter Months, calculated with 5-year running means.

facilities of the CVP, and later SWP, the differences between NDO_5 and RDO_5 deviations from normal increased gradually beginning with the 1957-61 period and reached a maximum between 1961-65 and 1974-78. It should be noted that since 1966-70, the NDO_5 for nine consecutive 5-year periods had deviations ranging between 9 and 47%, while RDO_5 had negative deviations between -15 and -42%. Therefore, the amplitude between the percentage deviations of RDO_5 was 24-89%. This implies that since March, significant amounts of water begin to be withdrawn from the entire river-Delta system which becomes a permanent feature of the following spring season.

Moreover, it shall be emphasized that deviations of this magnitude are not typical for the combined Sacramento-San Joaquin natural Delta outflow nor for many other rivers which were the subject of our investigation (see Chapter II.1.2). As a rule, this magnitude of negative monthly deviations can be seen only rarely for natural Delta outflow under conditions which may be characterized as critical dry with a probability of exceedance of 90 - 95% (e.g., 1965), or recurrence interval of at least once in 10 to 20 years under natural conditions (Fig. III. 49).

The majority of regulated Delta outflow discharges for consecutive 5-year periods averaged since the early 1960's up to the late 1970's, corresponded to the category of years of sub-normal wetness for this month, while the NDO_5 for the same period could be considered abnormal or wet. The histogram of March (Fig. III. 47) illustrates the scale of changes discussed above. The most typical for this last month of winter is the strong decline in the frequency of occurrence of highest and median values of Delta outflow under regulated conditions with an overall increase in the frequency of occurrence of flow in the range 2.0-3.6 MAF which, under natural conditions, had a very low frequency. This trend of redistribution and shift of water supply from the highest to the median and lowest ranges makes <u>March</u> appear more like the beginning of the spring period of intensive water diversions than like a winter month. Of the four winter months, the NDO_5 for January and February and especially for March should be considered the most affected by water regulation.

Therefore, any discussion that this has a water surplus that can be used for additional water development should be very cautious. It would be prudent to consider the winter as the beginning of the water deficit in the entire system.

III.3.2.2 SPRING

General Remarks

The mean natural spring Delta outflow for each of the 5-year periods reflects such a level of quantitative changes that its residual values (RDO_5) correspond to the flows of periods of dry and sub-normal conditions which are not typical for the NDO_5

(Fig. III. 50).

1) The 1944-78 period (during which the projects began operations), shows negative RDO_5 deviations from normal as much as 1.3-2 times greater than those observed for the would-be natural conditions during the driest years of pre-project period (1929-34).

2) It is important to emphasize that over the course of all years of observation, the extreme values of the NDO_5 have not changed, and their amplitude remains between 1.4-1.7 MAF (Table III.17). At the same time the extremes of the RDO_5 (i.e., maximum and minimum) were 1.2 times less than those for the natural Delta outflow.

The minimum average of 5-year periods of regulated Delta outflow observed between 1968-78 was 1.2 MAF, and this value is 1.7 times less than that observed for the mean spring natural Delta outflow for the driest periods of 1929-34. This period is considered in many reports as an example of the worst water supply conditions in the history of the river-Delta system (DWR).

However, in light of the latest development, it may be concluded that RDO_5 for 1968-78 yielded less water to the Bay than the period of 1929-34. The average spring Delta outflow of 2.1 MAF of 1929-34 corresponds to 80% probability of exceedance (not less than once per 5-6 years) while 1.2 MAF of 1968-78 corresponds to a recurrence interval at least 14.3 years (Table II.38). However, this lowest Delta outflow was artificially repeated (because of diversions) more times than the fearsome spring mean Delta outflow of 1929-34.

3) During the same period (1968-78), the differences between the NDO_5 and the RDO_5 ranged from 1.9 to 2.5 MAF which represented an average of withdrawals from the system of at least 63% of natural flow.

This level of residual discharges to the Bay during the spring for more than a decade may well exacerbate the ecological conditions of the Bay, including the salt regime, residence time and recycling impact of runoff on the water body, input of organic and inorganic matter, sediment load, dissolved oxygen, phyto-, zoo- and ichthyoplankton, fish migration and spawning as well as benthic organisms. It should be noted that during the last four decades, Delta outflow discharges to the Bay have been subjected to such changes that for the last decade we have been dealing with a new type of modified estuary the future restoration and conservation of which, even without additional diversions, is questionable.

APRIL

Water supply to the system in this month (Fig. III. 51) is of paramount importance for providing the appropriate conditions for spawning. At the same time, the stable, high runoff used to play an important role in refreshing and flushing the estuarine system.

Under natural conditions, Delta outflow for the pre-project period was 3.3 MAF and for the post-project was 1.8 MAF (Table III.17). The amplitude of the pre-project period was almost two times higher than the amplitude for the post-project period which may be attributed to the fact that during the late 30's a period of critically dry years was observed, (not documented during the post-project period). The maximum flow for the two periods shows little difference.

Regulated Delta outflow for the pre-project period (3.8 MAF) was as much as 2.1 times higher than for the post-project period, and the maximum of the first period (5.2 MAF) was almost 1.5 times higher than the observed for RDO_5 under post-project conditions; minimums for the two periods were almost the same. The reduction of the maximums of the post-project period may be explained in general by the leveling effect of water withdrawals on extremely high runoff.

Due to the fact that for the pre-project period, the average diversion for 5 years was 11-39% of the mean (with the exceptional minimum of 2.7-4.3% for the years of above-normal wetness, 1936-41), there was little difference between the extreme values of water supply for natural Delta outflow and regulated Delta outflow for this period.

However, the post-project period was characterized by a major difference in the extreme values (III.17) which averaged 1.5-2 times less than the values for the pre-project period. This is the direct result of water diversions which truncated the highest seasonal volumes typical for natural conditions of Delta outflow.

The average percent losses of water supply to the system for 5-year periods started to increase from 26% in 1941-45 to 56% in 1968-72, with the subsequent reduction to 31% in 1974-78 (the period of sub-normal wetness).

But, the predominant value of water withdrawals from the system in April for the 5-year periods between 1959 and 1978 was above 40%, or about 2 MAF on the average.

As mentioned earlier, the analysis of percentage of diversions should be followed by evaluation of absolute value of water withdrawal, inasmuch as the diversions undertaken in periods of low flow may yield a higher percentage than the same volume diverted under conditions of high flows.

For example in 1965-69, the reduction of NDO_5 was 2.2 MAF per year, or 44.3% of the NDO of 4.9 MAF; while in 1969-1973 the average losses of the NDO were equal to 2.2 MAF, or 55% of the natural Delta outflow of 3.9 MAF.

The gradual process of deflection of the trend of RDO_5 deviations can be seen from Fig. III. 51. While the predominant deviations of NDO_5 from normal ranged between ± 20% of normal, RDO_5 deviations have much greater negative deviations of -20 to -67%. This figure, as well as others, strongly supports the conclusion that upstream water withdrawals since 1944 have changed the average water supply behavior and its absolute values greatly.

It is likely that the pre-project period negative deviations of April NDO_5 and RDO_5 from normal to some reflect the influence of climatological factors (i.e., sub-normal and dry years), and that the highest and most persistent negative RDO_5 deviations of the the post-project period are mainly the result of intensified water withdrawals and diversions by multi-purpose project facilities. The precipitous decline and deflection of the curve of RDO_5 from normal appears to coincide closely with the beginning of project operations. Negative deviations of RDO_5 of normal for the post-project period were three to six times higher than those for the NDO_5. Diversions in April have paved the way (even more significantly than the preceding ones of winter) for the development of a chronic deficit in water supply to the Bay, compounded by even more significant values for May and June (as will be seen below) over the last three decades. This may degrade the ability of the system to maintain the normal dynamic equilibrium of its ecological characteristics.

It is important to emphasize that the probability of the highest RDO_5 for the post-project period corresponds to only 90% of the would-be NDO_5 (interval of recurrence of not less than one time in ten years, Table III. 20, Fig. III. 55), while the "new" normal of the RDO_5 of 2.8 MAF corresponds to only 95% of probability of exceedance (not less than one time in twenty years for the NDO_5) of the natural flow frequency curve (Fig. III. 53).

The minimum value of water supply between 1.6 and 0.6 MAF which characterizes the decade from 1968 to 1978 is beyond the 99% probability of exceedance of (not less than one time in 100 years) the NDO of 2.3 MAF, by itself a very rare event (Table III. 20).

In practice, for that decade RDO_5 was as much as 1.8 times lower than the NDO_5 (or only 45-60% of the potential NDO_5).

The histogram for April (Fig. III. 54) illustrates the shift from a high number of events of high ranges of NDO_5 to high frequency but low ranges of RDO_5. Here (as will be seen later for May) there is a leveling and reduction of the regulated water supply (RDO_5) to the Bay on a scale which has not been documented for NDO_5.

<u>MAY</u>

This month is characterized by more pronounced NDO_5 fluctuations than those for April due to the intensified snowmelt from the mountains and the subsequent increase in water supply to the system. Besides, this month illustrates better than April the existing periodicity of wet and dry phases. In this regard, one may arbitrarily define three sub-normal and three above-normal phases of wetness during which the prevailing range of the NDO_5 deviation from normal was equal to ± 20%, with the exception of periods of low wetness during the late 1920's.

During all the years of observation the ratio between the maximum NDO_5 and RDO_5 has changed very little, but the ratio between the minimum NDO_5 and RDO_5 increased almost two times (Table III. 17). The maximum RDO_5 observed corresponds to the 75% probability of occurrence in would-be natural conditions, and the minimum RDO_5 corresponds to a probability of occurrence beyond the theoretically acceptable limit of 99%.

It is no less interesting to stress that the average RDO_5 of 2.13 MAF for all the years of observations corresponds to only 51.5% of the normal NDO_5 for May of 1921-78. More to the point, this RDO_5 corresponds to probability of exceedance of 99%, i.e., recurrence of not less than once in 100 years of the would-be natural Delta outflow of May. However, such a low value for unimpaired Delta outflow is such a low probability event that it does not appear under natural conditions in the records kept since 1878.

The significance of this finding is that in RDO_5 for May, as was the case for April, there are new parameters of Delta discharges to the Bay which geographically belong to the Sacramento-San Joaquin Rivers basin, but geophysically describe a significantly modified regime of this river system.

The essential reduction of winter and April water supply to the Bay discussed earlier shows major decreases of RDO_5 from normal and NDO_5 fluctuations (Fig. III. 52) illustrate the degree of runoff transformation. It may support the hypothesis that the current decline in the ecological conditions of the Bay estuarine system is only the first indication of more severe modifications to the estuary yet to come.

For May, as in April, the estuarine system is forced to survive under unique new conditions. Not only are the negative deviations (since the late 1940's) several times higher than those of natural Delta outflow, but also the differences in water supply between the would-be natural and regulated conditions (which accounted for almost 3.7 MAF -1971-75, and 3.3 MAF - 1972-76) are also extremely high (almost -60 to -80%).

The histogram for May illustrates even more dramatic changes than in April in the RDO_5 distribution compared to NDO_5.

First, the NDO_5 discharges between 4.5-6 MAF were replaced by the predominant RDO_5 ranges of 1.0-3.0 MAF (Fig. III. 54).

Second. This shift of major ranges results in a striking resemblance of May RDO_5 to NDO_5 for June. Such transformation in the runoff regime should be considered in developing statistical or numerical models intended to explain or forecast the dependence of biological communities or any physical estuarine parameters on flow. This is especially important because even under natural conditions, average Delta outflow of 2.48 MAF for June was 1.7 times less than the normal Delta outflow in May.

It is possible that the cumulative consequences of this shift and the long-term, steady decline of water supply during April and May are responsible for the negative changes in the biological resources of the system (e.g., decline of fish catches, increases in salt intrusion and residence time). Similar relationships have been described in a variety of other estuaries and are therefore not unique to the Delta/San Francisco Bay estuary.

JUNE

This month, as with April and May, illustrates the same type of periodicity or alternation of periods of different wetness and the presence of significant differences between the deviations of natural and regulated Delta outflow for the 5-year running periods.

As in the case of May, the dominant range of the RDO_5 negative deviations (since the late 1940's) of 40-75% equals those observed during the late 1920's (Fig. III. 53). However, the length of the period in the 1920's was six to eight years, while the trend that started in the late 1940's has lasted for more than three decades.

It should be emphasized that it would be inappropriate to attempt to compare the impact of the naturally-occurring short period of dry years on the hydrophysical and biological properties of the San Francisco Bay with the more complicated, artificial long-term conditions of 1944-83 during which the scale of flow modification exceeded the natural trend of flow variables. During 1944-78, the value of mean RDO_5 for each 5-year period had a probability of occurrence between 90 and 99%, which would be observed under natural conditions one time in 10, or even 100 years. Only during 1967-78 did the RDO_5 correspond to a probability of 99% (or recurrence of not less than one time per 100 years) of the NDO_5 frequency curve (Fig. III. 54, Table II. 20).

Therefore, the recurrence of such dry-year intervals which would occur only rarely for the natural conditions became a constant feature of the water balance of the San Francisco Bay under conditions of impaired Delta outflow during April, May and June.

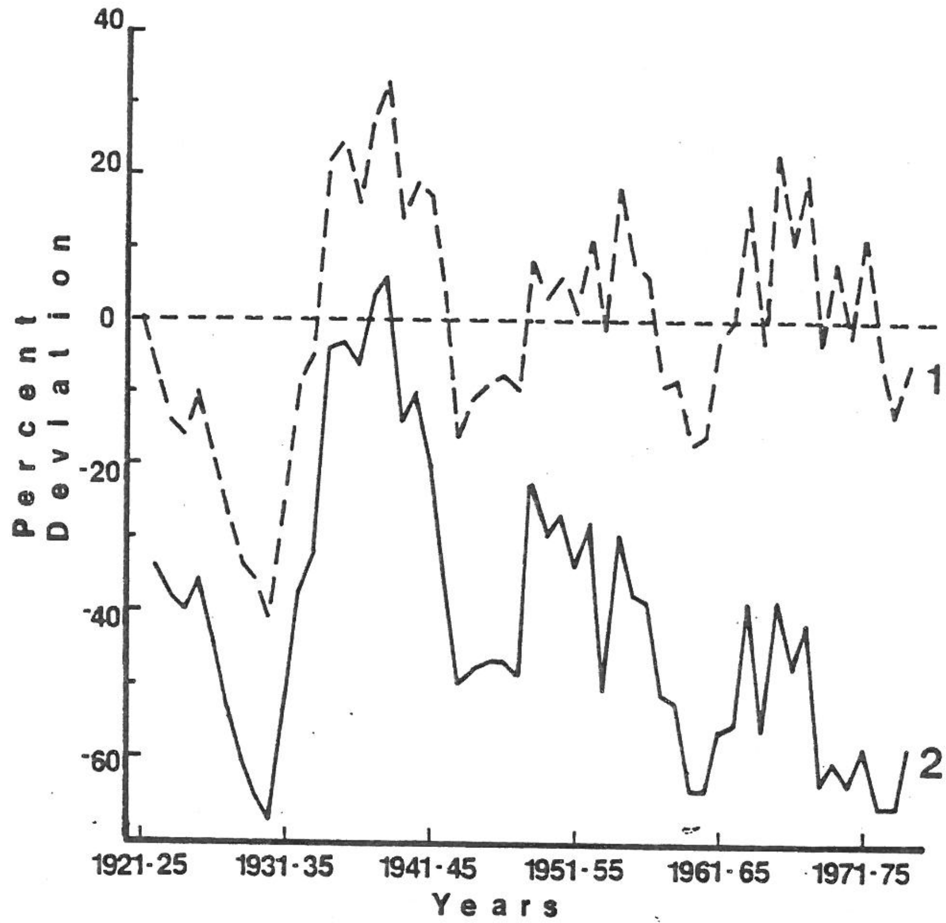


Fig.III.50. Deviations (in percentage) for the Spring in (1) Natural and (2) Regulated Delta Outflow from the Spring Natural Delta Outflow (Q = 3.59 MAF; 1921-78), calculated with 5-year running averages.

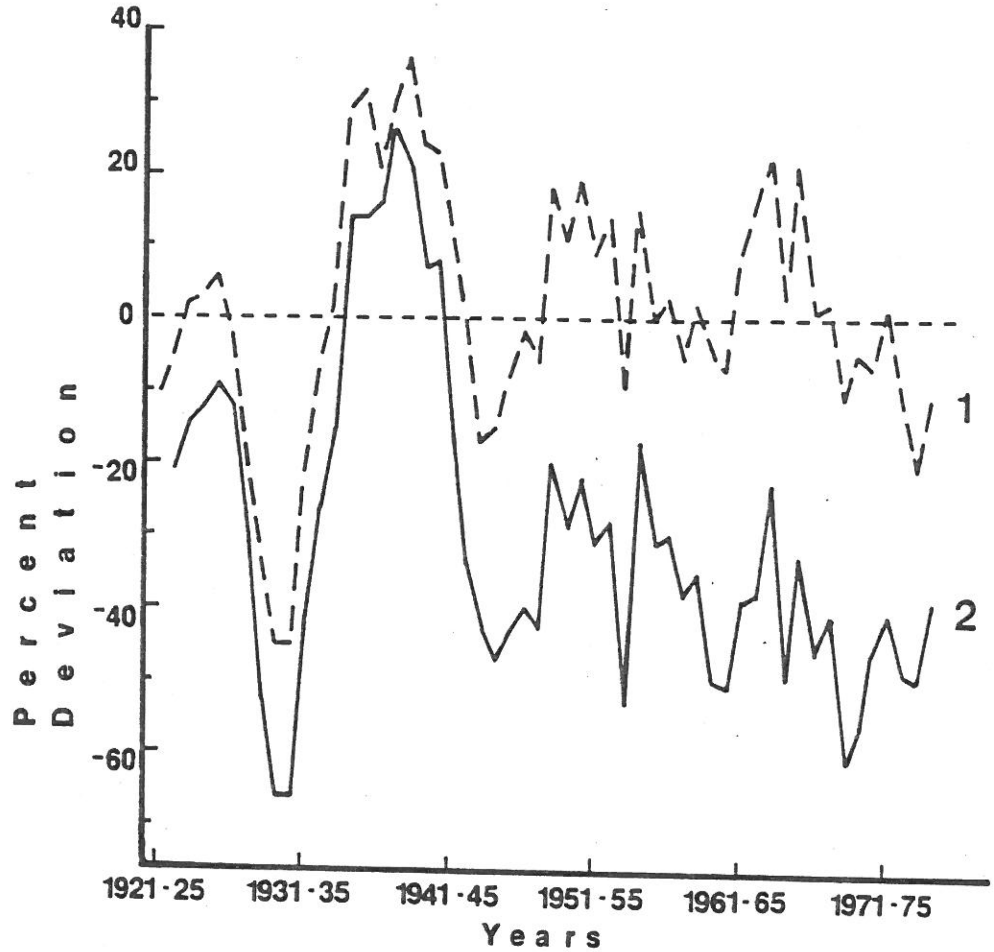


Fig.III.51. Deviations (in percentage) for the month of April in (1) Natural and (2) Regulated Delta Outflow from April Mean Natural Delta Outflow (Q = 4.14 MAF; 1921-78), calculated with 5-year running averages.

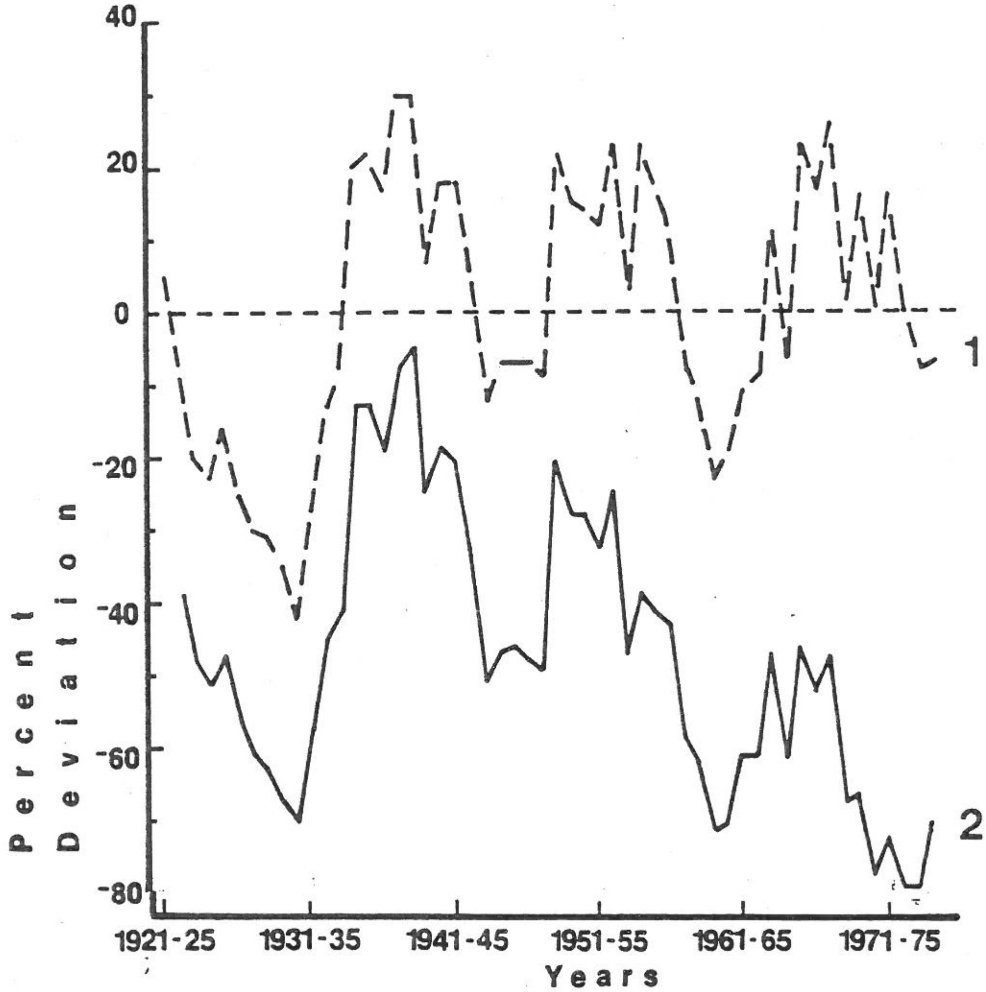


Fig.III.52. Deviations (in percentage) for the month of May in (1) Natural and (2) Regulated Delta Outflow from May Mean Natural Delta Outflow (Q = 4.14 MAF; 1921-78), calculated with 5-year running averages.

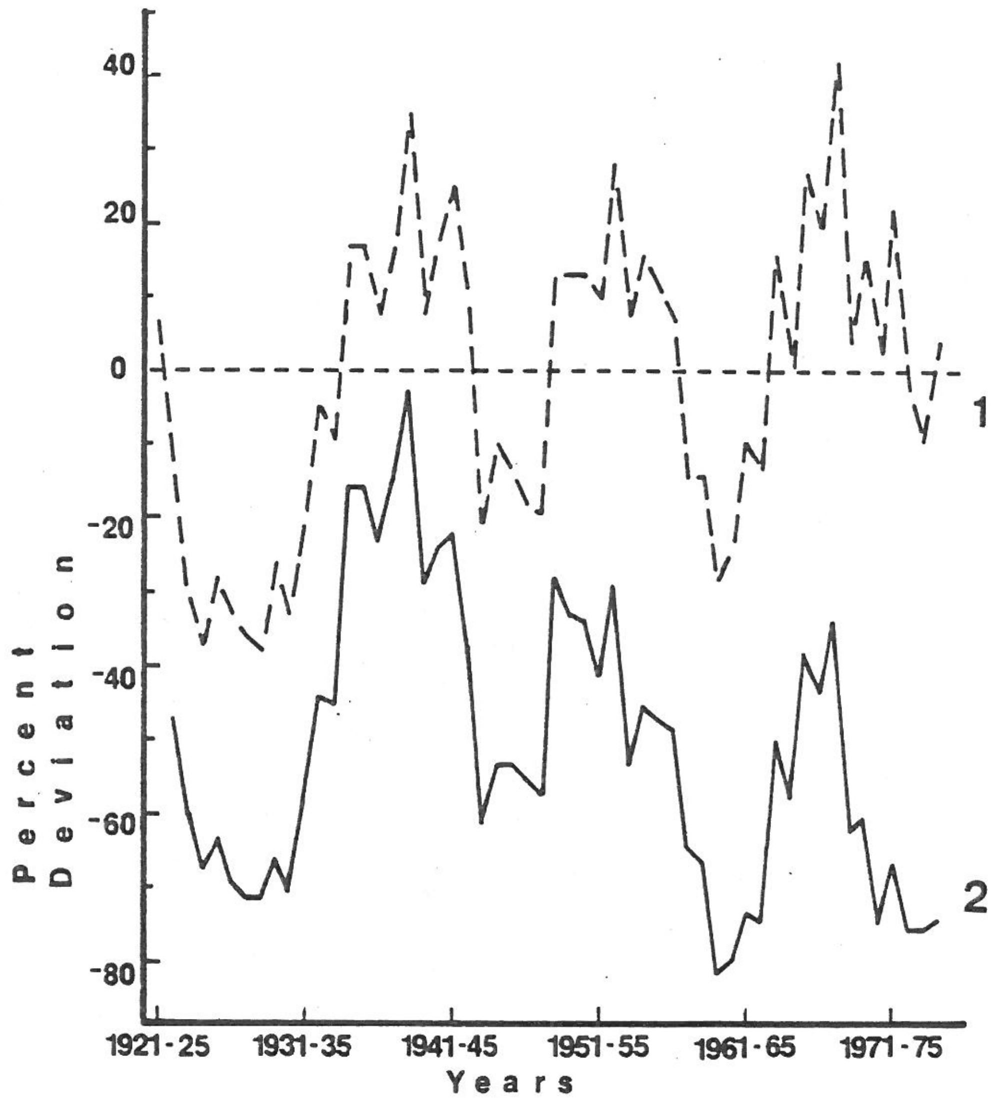


Fig.III.53. Deviations (in percentage) for the month of June in (1) Natural and (2) Regulated Delta Outflow from June Mean Natural Delta Outflow (Q = 2.48 MAF; 1921-78), calculated with 5-year running averages.

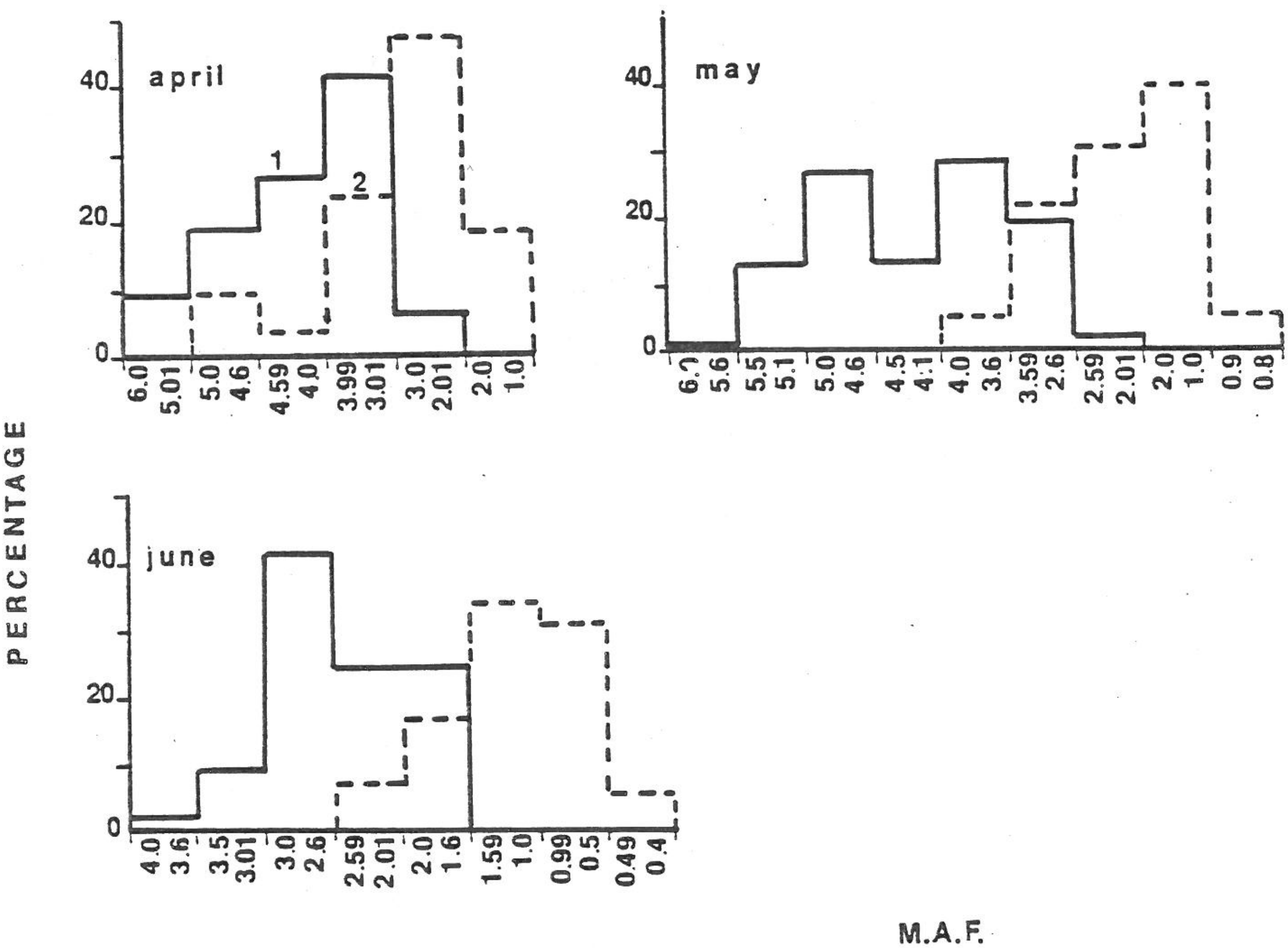


Fig. III.54. Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1922-82) Delta Outflow to the Bay for the Spring Months, calculated with 5-year running means.

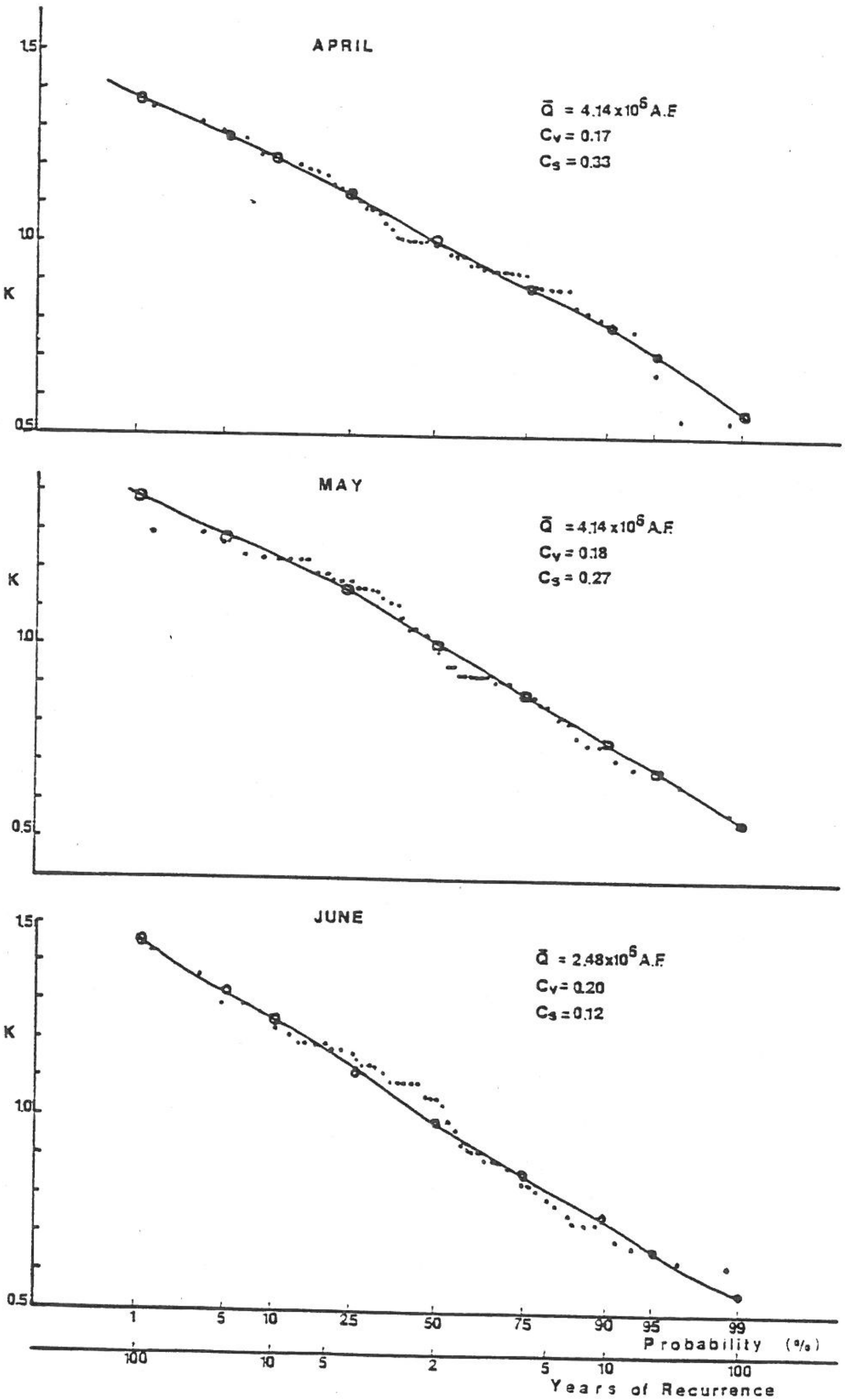


Fig.III.55. Probability Curve of the Natural Delta Outflow for the Spring Months, calculated with 5-year running means.

NDO_5 of 90% of probability of exceedance for June (Table II. 20) was observed only three times (1925-29, 1929-33, 1959-63, dry years) but the NDO_5 of 99% probability has not been documented at all. Moreover, the prevailing number of events of low regulated flow in the histograms of June (Fig. II. 54) is shifted to the category corresponding to the would-be natural outflow of July.

As mentioned above, the same kind of "shifting" process has taken place for April and May, i.e., the RDO_5 distribution of a given month resembles the predominant statistics (ranges and frequency) of the NDO_5 of the following month, but with pronounced low value of water supply. This striking result of runoff transformation, compounded with overall reduction of flow, may have long-term, relatively stable negative consequences on regime and water quality characteristics of the Delta-estuary system, the mitigation of which is beyond human capacity. Similar events are currently taking place in Russian estuaries (Baydin, 1986; Tolmazin, 1985; Volovic, 1986).

III.3.2.3 SUMMER
General Remarks

The fluctuations of normalized deviations for July and August are dissimilar and may reflect the complexity of the variables of Delta water supply to the Bay affected on the one hand (July), by the extensive water diversions and withdrawals from the Delta, and on the other (August) by the significant increase in returning water discharges, or presumably, emergency releases to the Delta system. It should be noted that while the NDO_5 and RDO_5 deviations fluctuations of July have practically the same trend for the entire 1921-78 period (Figs. III. 56, 57), nothing like that can be found for August since the inception of project operations.

JULY

Pre-Project Period (1921-43)

During this period, the predominant range of negative deviation of NDO_5 was -30 and -40% and the negative maximum in 1934 was equal to 50%.

At the same time, the negative deviations of RDO_5 from normal were two to three times greater than those for NDO_5, with a negative maximum of 90% in 1930-34 (Fig. III. 56,).

It is important to emphasize that running mean regulated Delta outflow (RDO_5) for the periods 1923-34 had a range of only 0.09-0.13 MAF which corresponds to one time in several hundreds of years for natural conditions.

At the same time, the would-be natural Delta outflow (NDO_5)

in the range of 0.50-0.65 MAF, corresponds to the probability of occurrence of 75-90%, and recurrence interval of once per 4-10 years. Hence, the regulation of water discharges, even on the relatively-reduced level of water development of 1924, triggered drought conditions for the Delta-Bay environment.

The predominant range of losses in water supply which the estuarine system sustained (i.e., water which has not reached the Bay) was equal to 0.4-0.5 MAF (on the average for 5 running years).

Post-Project Period (1944-78)

The deviations of the would-be NDO_5 were predominantly positive and the patterns of their fluctuations were characterized by the alternation of relatively small negative deviations of 4-35% for successive 5-6 years, and positive deviations predominantly in the range of 20-40% (maximum = 62%, 1967-71) during the successive 9 years (Fig. III. 56).

At the same time, the deviations of the RDO_5 from normal were all negative and had a prevailing range between 45 and 60%, with a maximum of 79% in 1959-63, and a minimum of 16% in 1967-71. Therefore, in most cases, RDO_5 was very low.

For example, the RDO_5 of 0.18 MAF (1959-63) does not fit even the lowest recurrence interval of the NDO_5 frequency curve, while the highest RDO_5 of 0.7 MAF (1967-71) corresponds to only a probability of only 75% (not less than once in 4 years).

For the majority of the years since project operations began, RDO_5 for July had a range of 0.30-0.46 MAF. However, these values correspond to only a 95-99% probability of exceedance under would-be natural conditions, i.e., very rare events with a recurrence interval of at least once in 20 or even 100 years (Fig, III. 58).

Therefore, since 1944 and with the exception of several 5-year periods, the San Francisco Bay estuarine system was subjected to successive 5-year periods of very low flow with values that would be considered as dry or critical dry years under natural conditions. Although the losses sustained in July are much less than those of the preceding spring months, the impact of even these small losses on the hydrological and biological properties of the entire estuarine system should not be ignored.

The histogram for July (Fig. III. 59) illustrates that the highest values of Delta outflow for this month were eliminated. Instead, these values were replaced by an increasing number of cases of very low flow in the range 0.1-0.5 MAF, which, as was mentioned above, would rarely be observed under natural conditions.

July did not benefit from water releases from project operations as did August and the two months of autumn.

<u>AUGUST</u>

The temporal variability of deviations of the 5-year running mean unimpaired and regulated runoff are different from each other for this month, and resemble the same type of water supply fluctuations as September and October, as we will see later.

As can be seen from Fig. III. 57, August runoff fluctuations present some new features.

During the pre-project period, the deviations of regulated water supply from the mean follow the familiar patterns until 1944 made up of predominantly high negative values in the range of -55 to -99%. These deviations were 2-7 times higher than the deviations for the 5-year running mean natural outflow.

During several 5-year periods between 1928 and 1934, the regulated Delta outflow was negligible (0.01-0.07 MAF, values which are within the range of standard deviations), NDO_5 was two orders of magnitude higher.

During 1922-44, regulated discharge to the Bay for August was within the range of measurement error of Delta runoff itself, i.e., the Bay was almost completely deprived of water supply.

In many years, the residual runoff was far beyond the computed probability, and its mean value for 5-year periods, 0.01 - 0.1 MAF had a recurrence interval under would-be unimpaired conditions of flow of not less than once in 100 or more years, while the natural runoff in and out of the Delta of 0.2-0.3 MAF had a recurrence interval of at least once in 3-10 years.

<u>Post-Project</u> <u>Period</u> (1944-1978)

Since the beginning of project operations, with the overall increase of water diverted for agriculture and the resulting increase of returning irrigation waters and storage releases discharged to the Bay, the deviations of regulated Delta outflow often evidenced a net increase. Gradually, the negative values changed to a high positive range of 60-80% (from 1966 to 1975, for example) and even higher for NDO_5. It should be noted that this RDO_5 to the Bay brought about such an increase in water quantity (but of low quality) that its value for the majority of years of observations was within the range of probability of exceedance of from 1 to 50%. This lies in the area of the curve of probability (Fig. III. 58) that would characterize the 5-year running mean natural outflow as "catastrophic wet", "critically wet", "wet" or "normal" years, with a recurrence of at least once per 4, 10, 20 and 100% which has not been observed very often

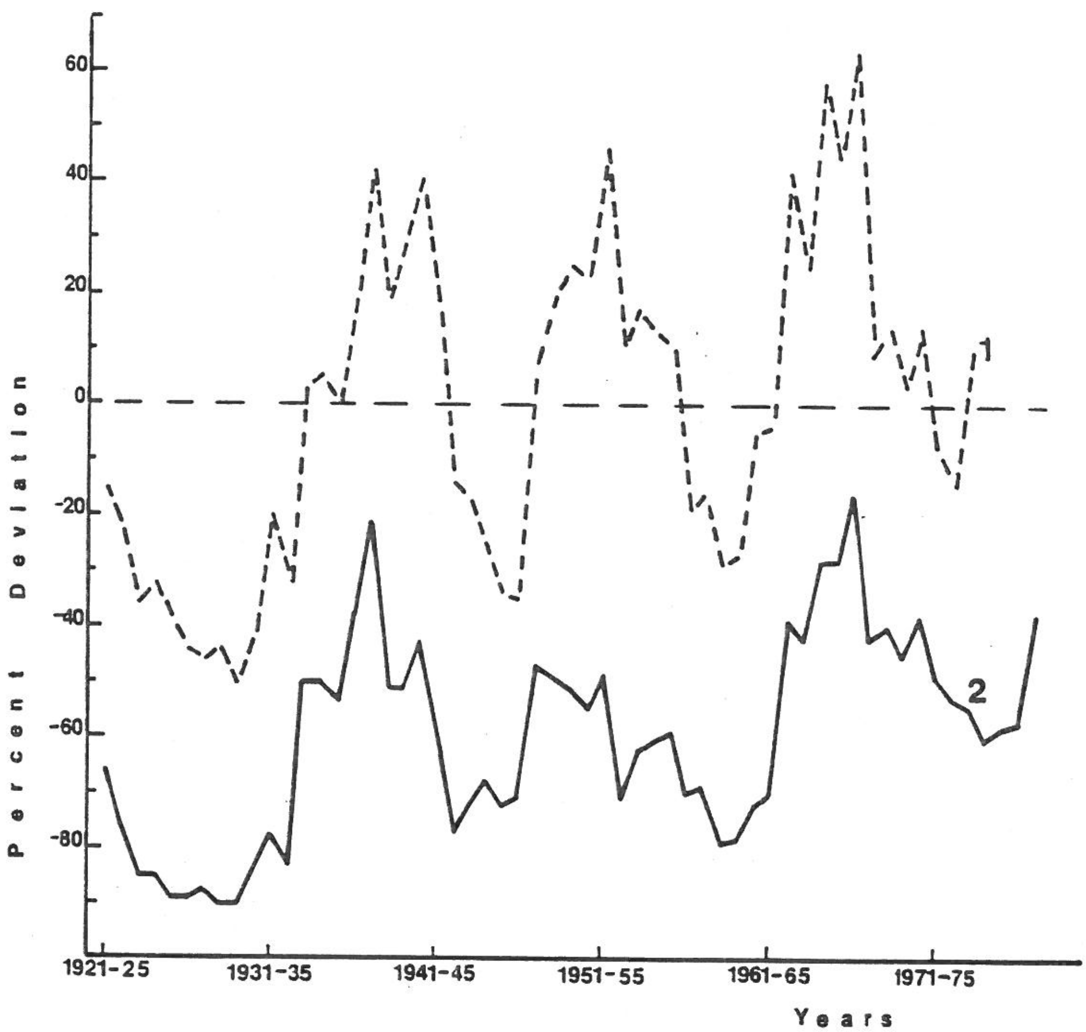


Fig.III.56. Deviations (in percentage) for the month of July in (1) Natural and (2) Regulated Delta Outflow from July Mean Natural Delta Outflow (Q = 0.83 MAF; 1921-78), calculated with 5-year running averages.

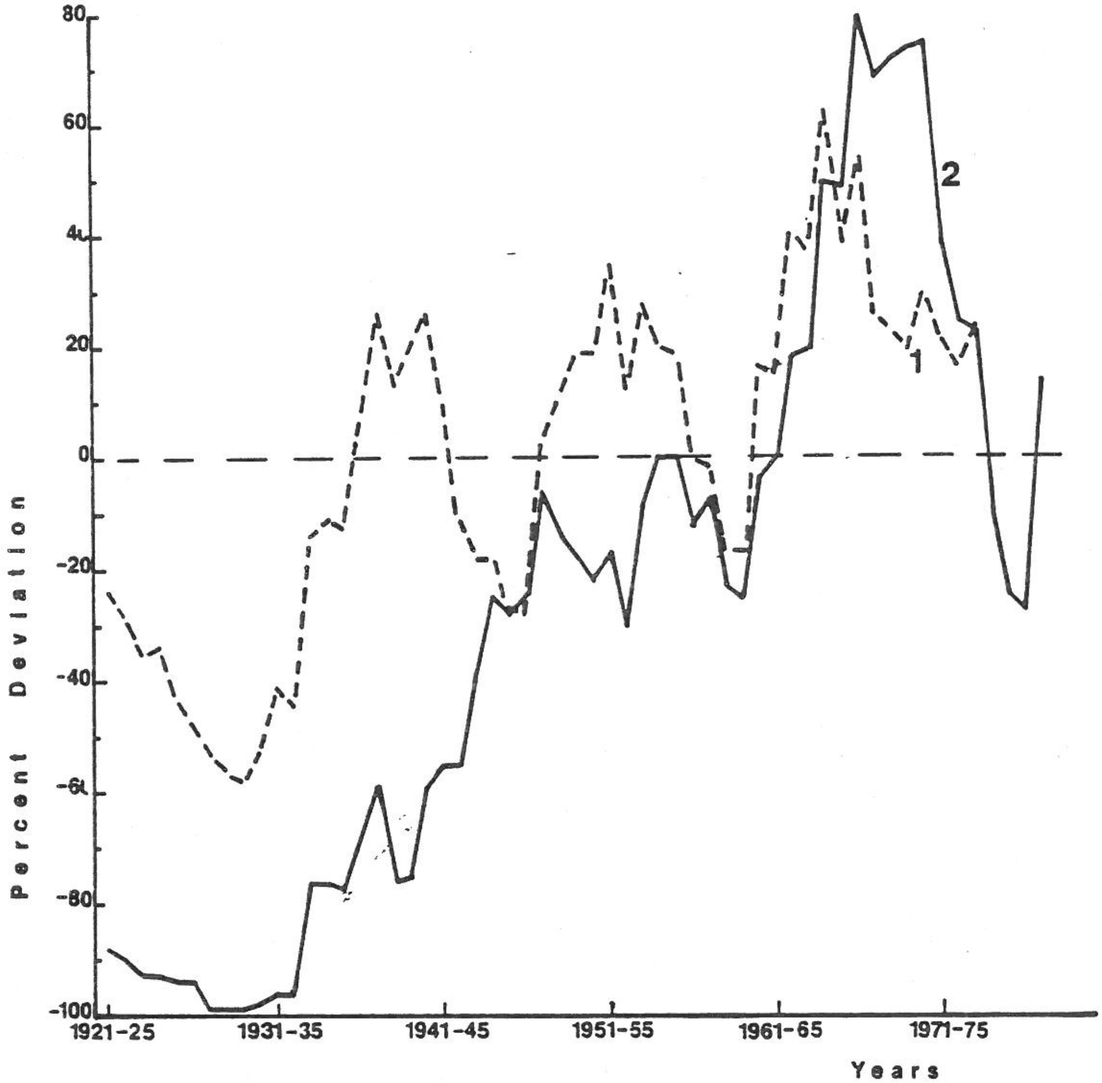


Fig.III.57. Deviations (in percentage) for the month of August in (1) Natural and (2) Regulated Delta Outflow from August Mean Natural Delta Outflow (Q = 0.32 MAF; 1921-78), calculated with 5-year running averages.

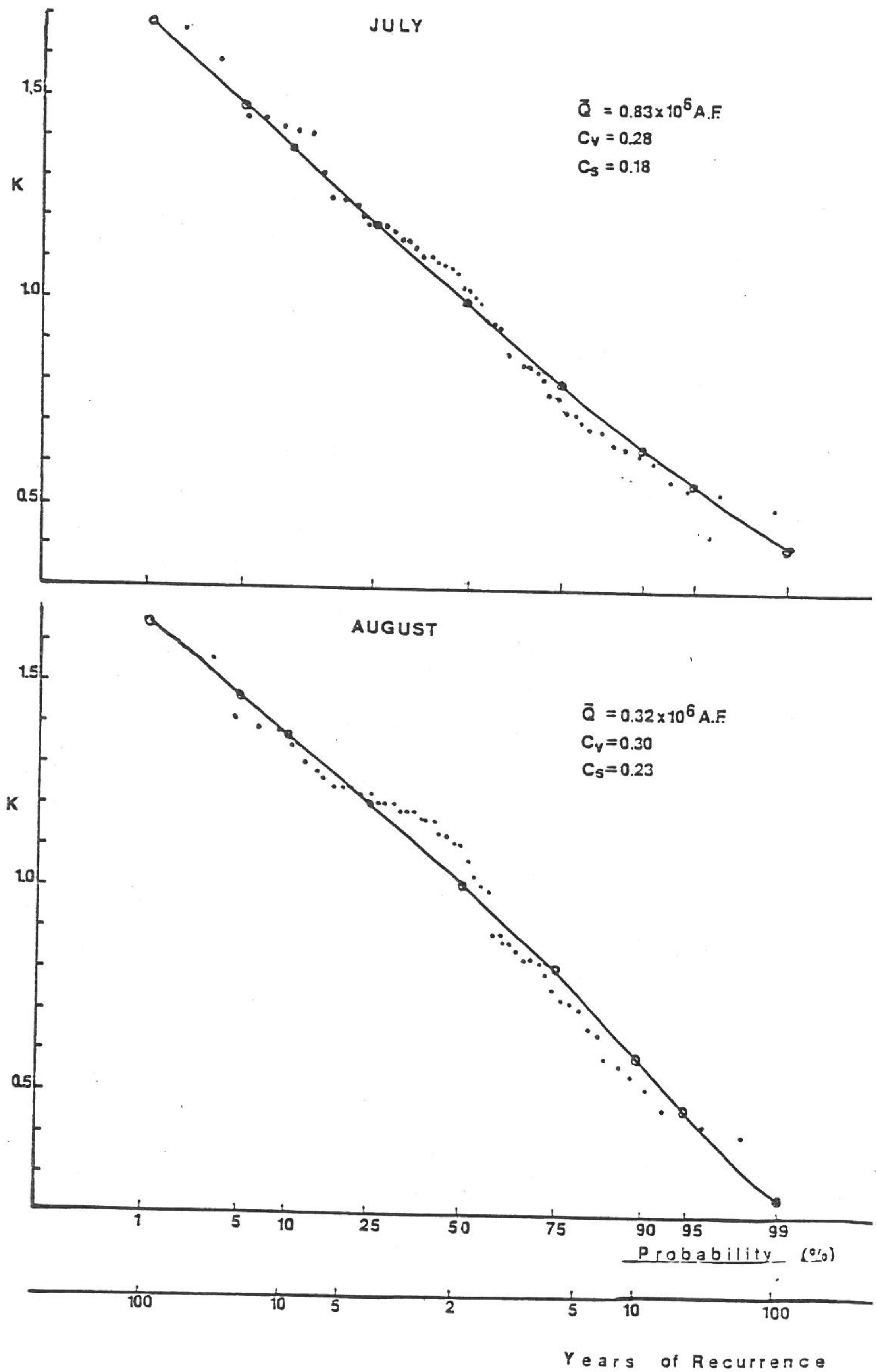


Fig.III.58. Probability Curve of the Natural Delta Outflow for the Summer Months, calculated with 5-year running means.

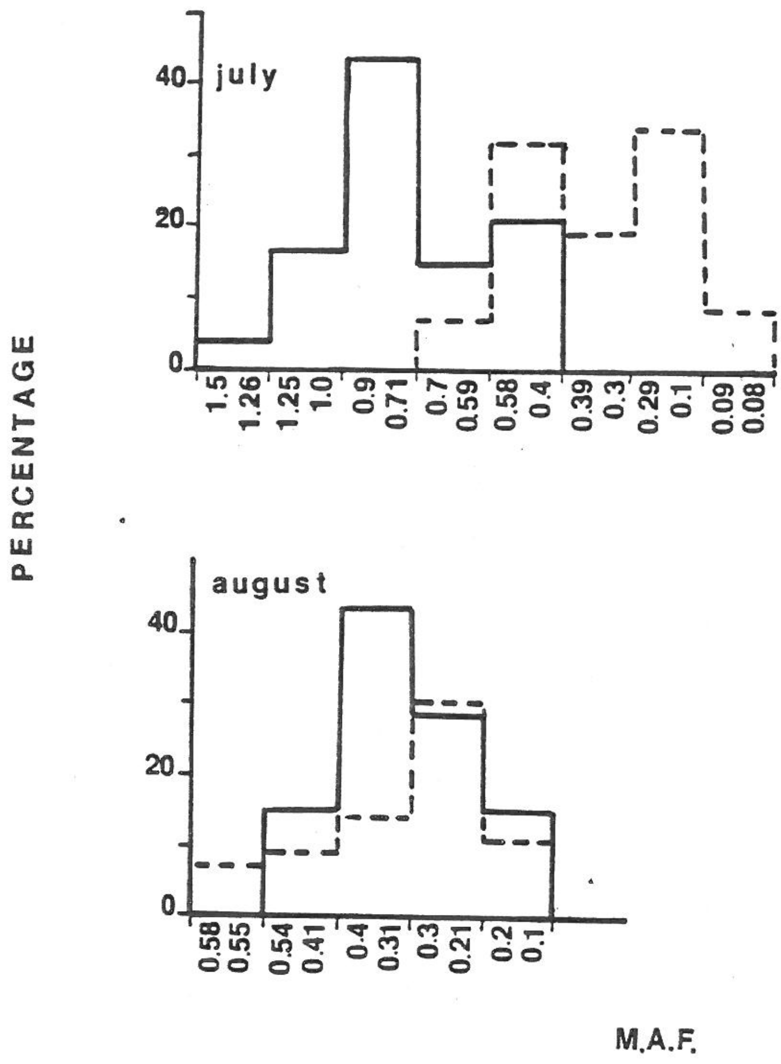


Fig.III.59. Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1922-82) Delta Outflow to the Bay for the Summer Months, calculated with 5-year running means.

under natural conditions.

More to the point, during the period 1967-76, the RDO_5 was as much as 1.2-1.5 times higher than the would-be natural. For example, for the 5-year period 1970-74, the RDO_5 and NDO_5 were 0.56 and 0.38 MAF, respectively, and only the successive period of low flow of 1974-81 once again yielded negative deviations from the mean.

The histogram for August illustrates some of these changes and shows the appearance of high values of RDO_5 which have not been observed under natural conditions (Fig. III. 59). However, the quality of this water, in terms of its impacts on biological resources/fisheries or municipal or industrial use is unknown.

III.3.2.4. AUTUMN

General Remarks

It is logical to expect that the changes in the RRI which took place during autumn due to upstream regulations are reflected, and to some extent compounded, in the regime characteristics of the regulated Delta outflow to the Bay. That is why the RDO_5 deviations from the normal, as well as absolute values of the NDO_5 and RDO_5 do not have much in common. They differ especially for September, since the water facilities of the CVP and SWP were completed.

SEPTEMBER

Following August, the first month of autumn has experienced even greater outflow changes (Fig. III. 60).

As in the case of August, the chronological trend of deviations and RDO may be divided into two distinctive periods:

1. The pre-project period of 1921-43, when the quantity of returning water from agricultural fields and other discharges was relatively small and there were no storage releases. The RDO_5 deviations were similar to the NDO_5.

2. The post-project period, when the overall amount of returned water, which may coincide with emergency releases from storage to provide dilution of agricultural runoff, increased the value of RDO_5 far beyond reasonable probability levels for NDO_5 volume. For example, from 1965-69 to 1974-78, the means of the successive 5-year periods of the RDO_5 (ranging 0.6-0.94 MAF) were almost double that of NDO_5 (ranging from 0.34-0.43 MAF). RDO_5 for September was much higher than that of July or August; but the RDO_5 September nearly reached the level of natural discharges typical for July.

Since 1944-48, RDO_5 has had no negative deviations from normal, and was much higher than NDO_5 (Fig. III. 60).

For example, in the 5-year running periods between 1965 and 1975, regulated Delta outflow was as much as 1.9 - 2.6 times higher than the would-be natural Delta outflow.

Positive deviations of the RDO_5 from normal for this period were in the range of 150-215%, while the NDO_5 positive deviations from normal were in the range of 13-43%. This suggests that on the average, the Delta and the Bay received 0.6 to 1.0 MAF of returned water (of unknown quality), which is almost equal to the volume of Suisun Bay and the Delta, respectively.

This artificial increase of water supply resulted in modification of the probability of exceedance of regulated Delta outflow such that its values for wettest and wet years of different recurrence are much higher than they would be for the NDO_5.

For September (as was shown for August), such volumes of runoff, i.e., RRI_5 and RDO_5, have not been documented since records began in 1878. More to the point, from August through September, Delta outflow may be considered as having hydrological characteristics of a new small river within the Delta.

The histogram for September (Fig. III. 63) illustrates what kind of major changes took place in different ranges of Delta outflow. The predominant range of the RDO_5 periods between 0.49-0.95 MAF was not documented before, which shifted the NDO_5 regime from predominantly low to prevailing high values of RDO_5.

In some reports, it is stated that this increase of Delta outflow (consisting primarily of returning waters) has improved the ecological conditions of the Delta, Suisun Bay and even the San Francisco Bay ecosystems. The available information on the effect of returning waters from agricultural fields, enriched with different types of chemicals, organic and inorganic matter, which are not usual components of the natural system, casts doubt on the veracity of these statements.

Meanwhile, numerous publications on other estuaries provide conclusive evidence that the returning waters from agricultural fields, saturated with herbicides and pesticides, cannot mitigate the water losses sustained by estuarine systems for the preceding spring and summer seasons, or improve water quality. More to the point, the returning water itself requires at least 6-10 volumes of water of high quality for its dilution (L'vovich, 1979).

<u>OCTOBER</u>

High negative deviations of natural and regulated Delta outflow from the normal during <u>1922-43</u> were predominant for both types of flow, while the differences between the two types of flow were small (Fig. III. 61). For <u>1944-78</u>, positive deviations were predominant for both flows. However, from 1969-78 the positive deviations of RDO_5 above normal were 3-5 times higher than the deviations of NDO_5 (which may be explained, as in the case of September, by the increased value of returning water and upstream releases).

As in the case of the NRI_5 and RRI_5, the differences between the deviations of the NDO_5 and RDO_5 from normal have become significant since the late 1960's. The absolute value of RDO_5 discharges to the Bay was 1.2-1.6 times higher than what it would be under natural conditions. That is, the dominant range of the NDO was 0.42-0.69 MAF while RDO ranged 0.6-0.9 MAF.

The striking result of release is that October's RDO_5 for the post-project period was close to the mean NDO_5 of July.

The maximum positive deviation of the RDO_5 above normal was 105% (1963-67) and the maximum negative deviation, -27% (1977-81). (For the pre-project conditions all deviations were negative and the predominant range was 20-50%.) Therefore, if the water quality and other regime characteristics are not considered, it might be claimed that the post-project conditions have had a positive influence by providing a water surplus to Delta outflow during months of normal or above-normal wetness. Under conditions of sub-normal wetness, there is no additional water supply originating in the drainage network and the system must rely entirely upon emergency releases from storage facilities if there is to be enough water discharged to the system.

RDO_5 of October is characterized by the relatively moderate redistribution of ranges of RDO_5 (Fig. III. 63). The presence of a relatively low frequency of high values of Delta outflow and overall increase in the number of events with values of the RDO_5 close to the probability of 50% (or not less than once per two years, 0.55 MAF) are typical for this month (Fig. III. 64).

<u>NOVEMBER</u>

Upstream and downstream runoff to the estuary during this last month (Fig. III. 62) of autumn does not show the same dramatic discrepancies between natural and regulated flows which were the outstanding features of late summer-first part of autumn.

Regulation truncates the extremes of maximum and minimum water supply to the Bay. During sub-normal and wet periods the differences between the NDO_5 and RDO_5 are moderate and range between 0.2-0.4 MAF for the post-project period, especially since 1960-64, which corresponds to a percentage of diversion of 18-24%. At the same time, due to climatological factors (rainy weather, reduction of evapo-transpiration, etc.), the value of

RDO_5 for November is as much as 1.2-2 times higher than for September or October. From 1965-69 to 1974-78, the range of RDO_5 was about 1.0-1.8 MAF while the NDO_5 ranged between 1.2-2.3 MAF.

Maximum diversions for the pre-project period were observed during 1928-37, in the negative range of -57 to -68%; for the post-project period of 1976-1981, the negative diversions ranged between 61-62%. Thus, for November, as for October, the maximum negative deviations (i.e., the lack of water supply to the Bay) coincided with the years of low flow probability of 80-95% of natural Delta outflow (i.e., these events under natural conditions would occur one time per 6 or 20 years).

The histogram for November (Fig. III. 63) illustrates the relatively moderate changes in the probability of occurrence between natural and regulated Delta outflow. Thus, November Delta outflow and river inflow may be considered the least transformed runoff in comparison to all other months of the hydrological year.

The differences between the values of impaired and unimpaired Delta outflow for different probabilities of exceedance lie within the limit of precision in the calculation of these characteristics.

In summary, the autumn may be characterized as the season during which the system is under a relatively neutral dynamic equilibrium, with September and October gains almost balancing the losses experienced by the system during November, although this may be true only from the standpoint of absolute values of freshwater input-output, and not from the perspective of water quality, circulation patterns and living resources of the Delta/Bay ecosystem.

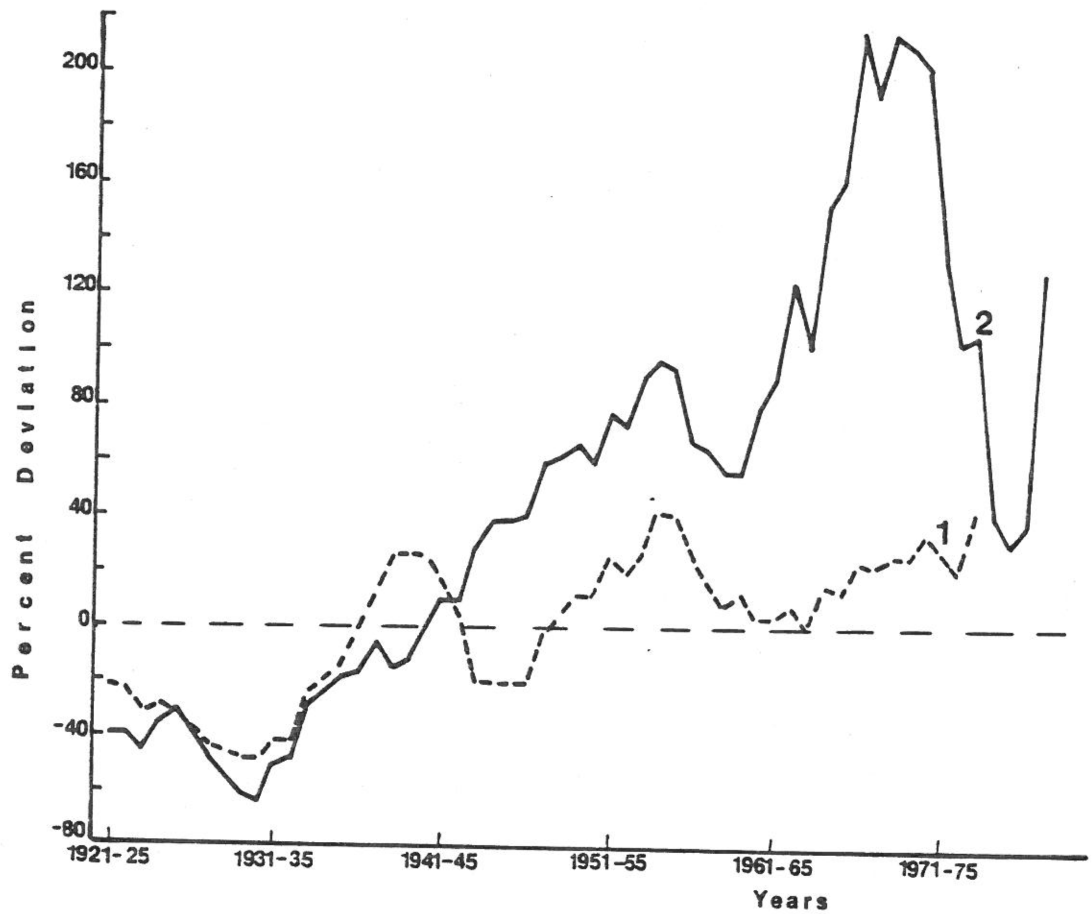


Fig.III.60. Deviations (in percentage) for the month of September in (1) Natural and (2) Regulated Delta Outflow from September Mean Natural Delta Outflow (Q = 0.3 MAF; 1921-78), calculated with 5-year running averages.

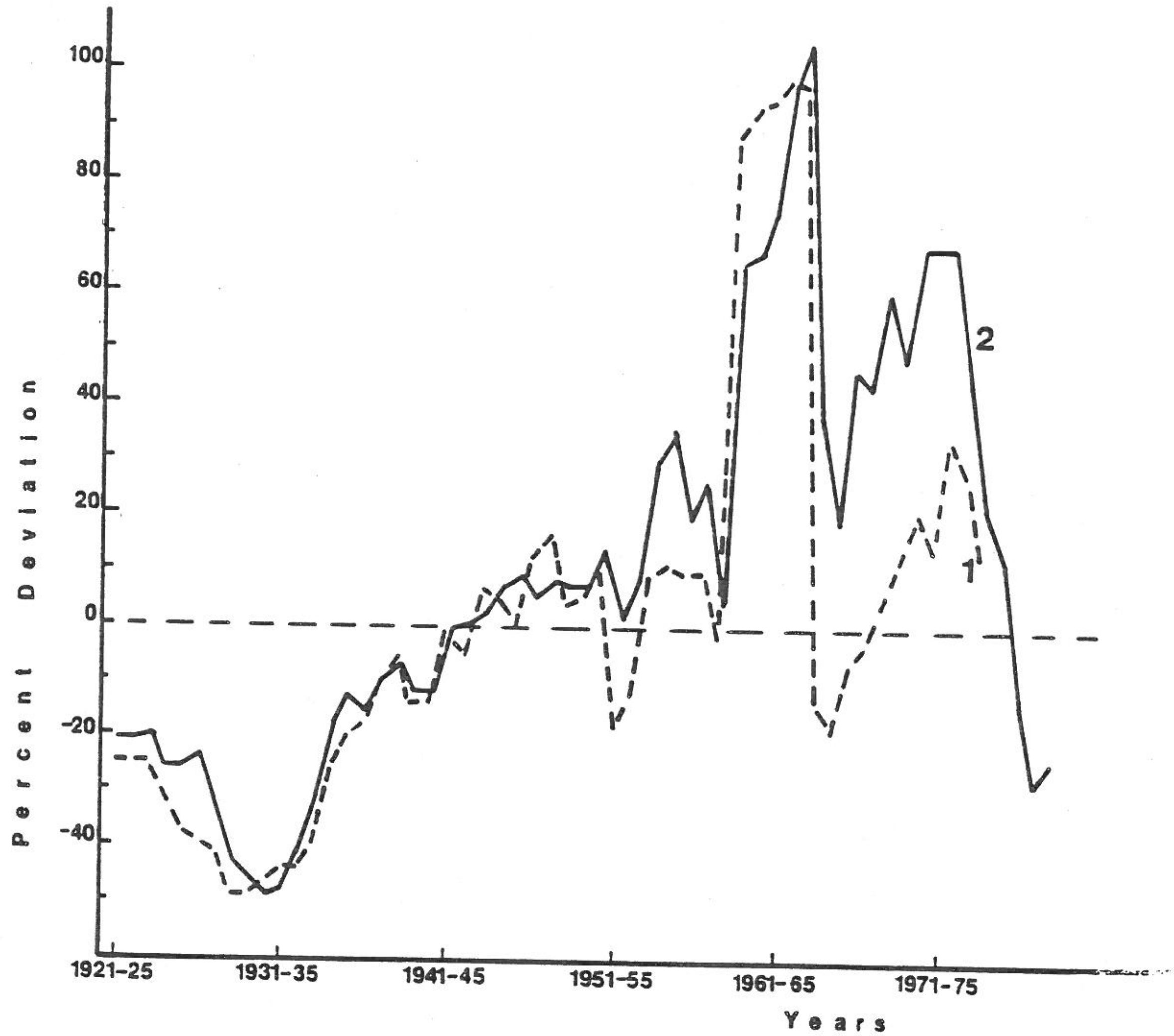


Fig.III.61. Deviations (in precentage) for the month of October in (1) Natural and (2) Regulated Delta Outflow from October Mean Natural Delta Outflow (Q = 0.52 MAF; 1921-78), calculated with 5-year running averages.

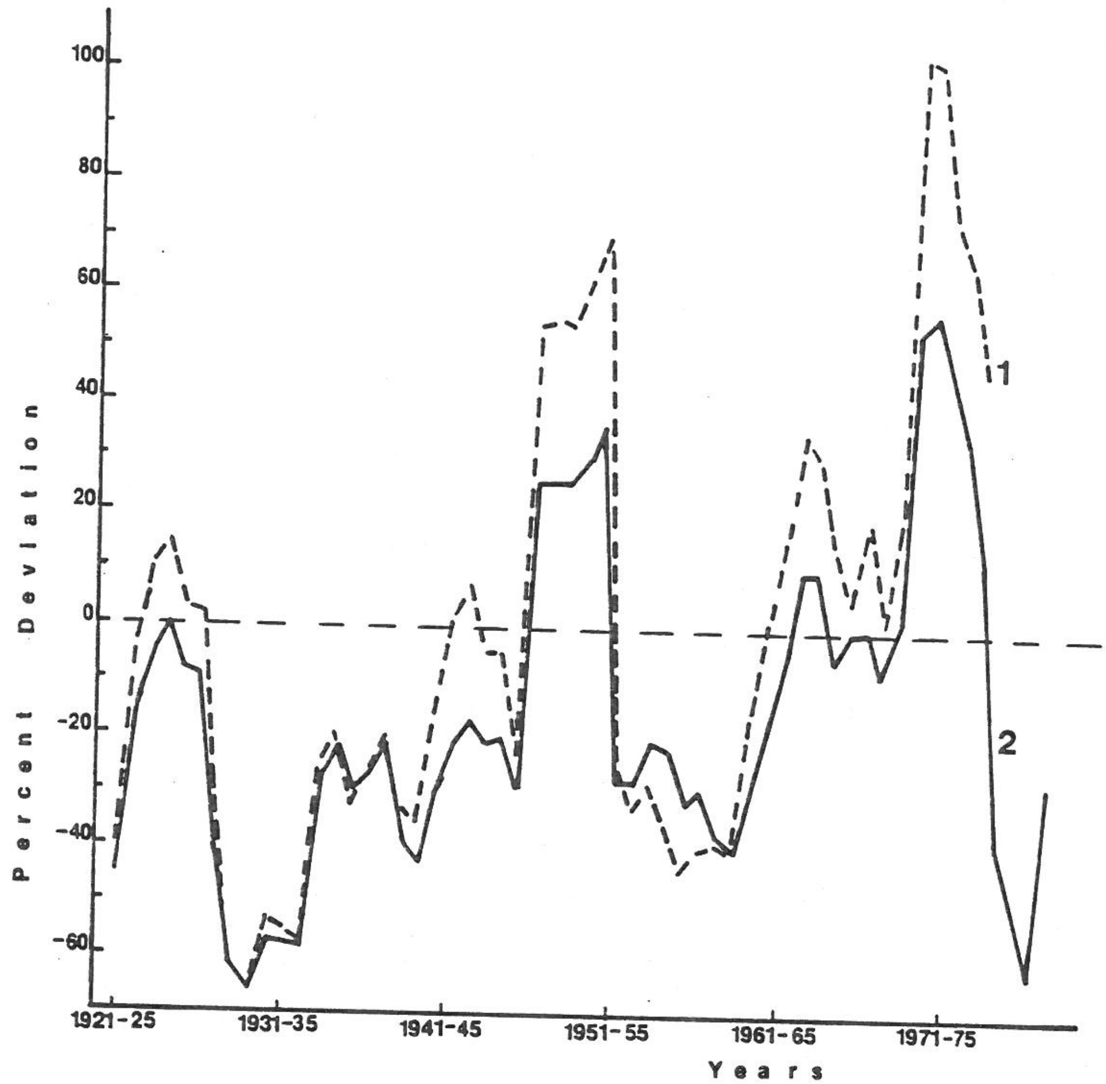


Fig.III.62. Deviations (in percentage) for the month of November in (1) Natural and (2) Regulated Delta Outflow from November Mean Natural Delta Outflow (Q = 1.15 MAF; 1921-78), calculated with 5-year running averages.

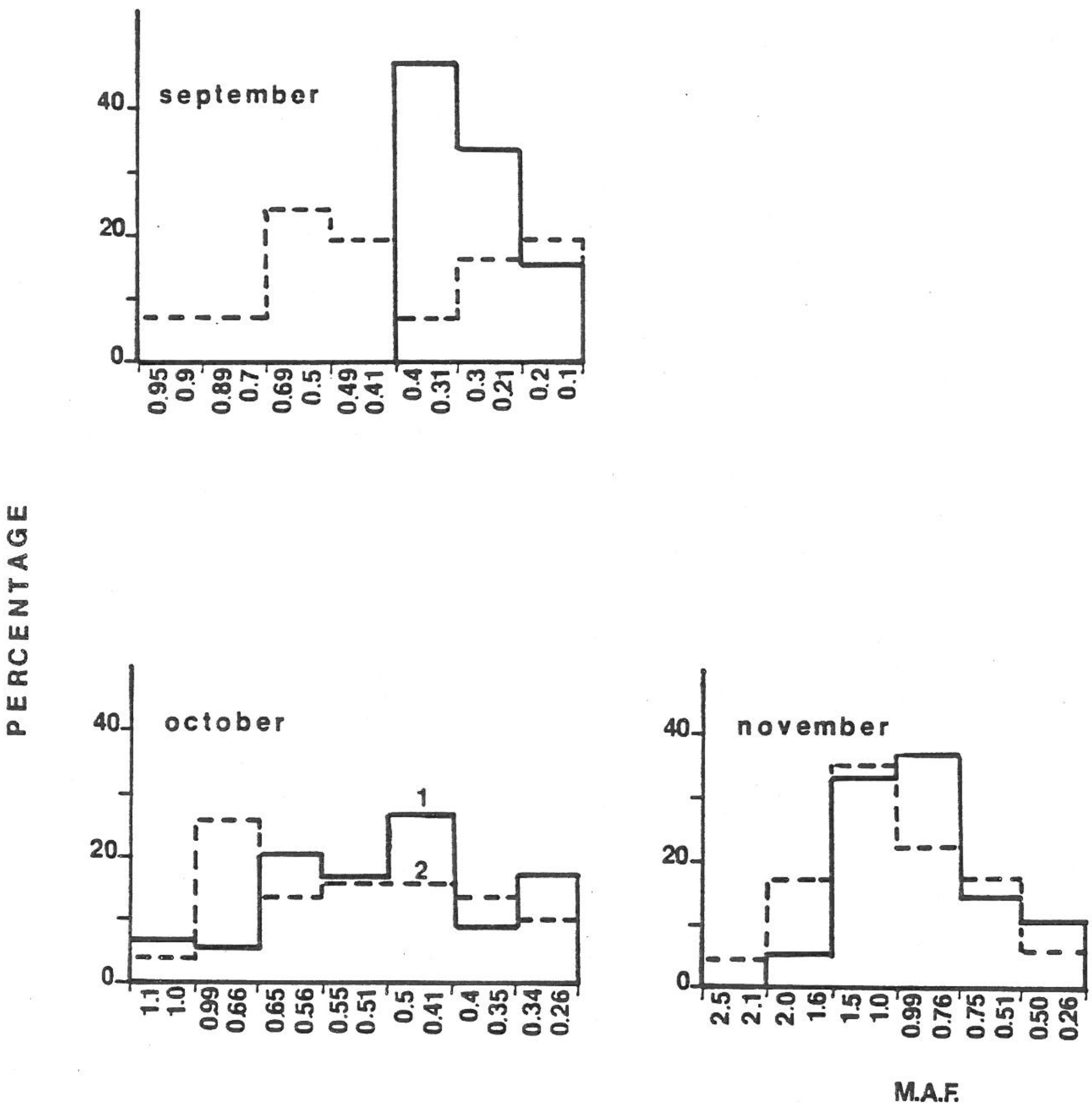


Fig.III.63. Histograms of Occurrence of (1) Natural (1921-78) and (2) Regulated (1922-82) Delta Outflow to the Bay for the Autumn Months, calculated with 5-year running means.

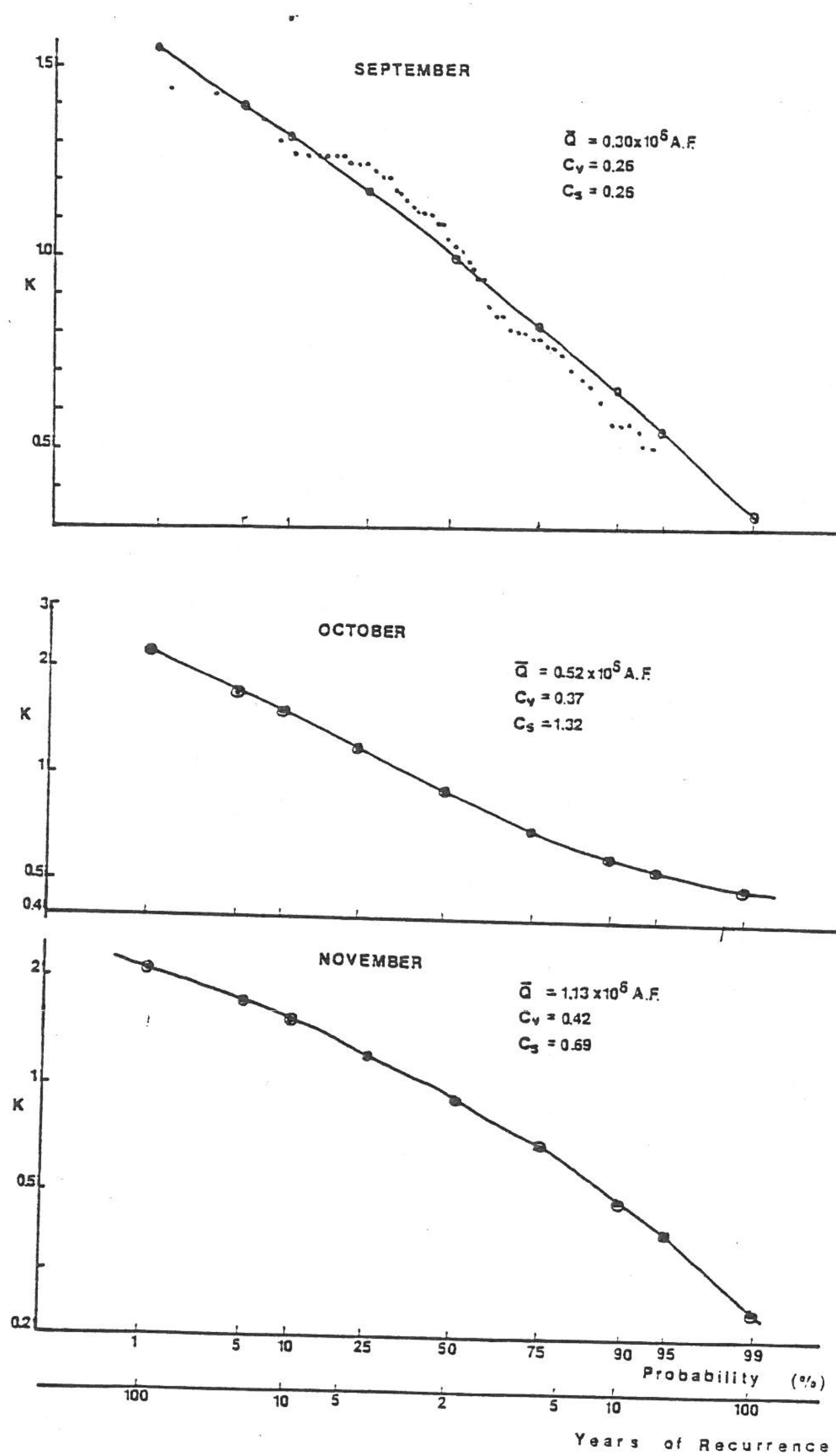


Fig.III.64.Probability Curve of the Natural Delta Outflow for the Autumn Months, calculated with 5-year running means.

III. 4 Dynamics of Annual Water Losses (or Gains) Sustained by the Combined Sacramento-San Joaquin River Runoff for 5-Year Periods

III. 4. 1 Upstream Water Diversions
Pre-Project Period

The average annual diversions for this period were around 4.8 MAF (for 1925-29 until 1940-44, Table III.21). The minimum was observed in 1935-39, while for all other 5-year periods diversions were above 4.0 MAF. Therefore, excluding the diversions for the period 1912-25 during which water losses of river inflow were within the range of 2-4 MAF, for the rest of the pre-project period the Delta received about 18% less water per year than would be possible under natural conditions for the same 5-year periods.

In sum, the amount of water that did not reach the Delta in total for the pre-project periods equalled to 96 MAF (assuming 4.8 MAF as the average per period).

Post-Project Period

This period, as expected, is characterized by a pronounced increase in the means for all 5-year periods of upstream water diversion. The mean, maximum and minimum are equal to 6.6 MAF, 7.8 MAF and 15.5 MAF, respectively. That is the mean, maximum and minimum increased 1.5, 1.6 and 1.7 times, respectively, in comparison with the same characteristics of the previous period.

Therefore, the total amount of water which did not reach the system for the 5-year periods (and the last incomplete 4-year period) was 257 MAF. If the losses sustained by the system during four periods of the pre-project period (1925-1944) are compared with the four periods of the post-project period (1945-1964), the average upstream losses increased 1.3 times.

It should be emphasized that the period 1975-79, which includes two of the driest years of the present century (1976, 1977), was characterized by almost the same mean upstream diversions as four other periods like 1950-54, 1955-59, 1960-64 and 1970-74, despite the fact that the wetness of these periods under natural conditions was quite different.

From the comparison of the amounts of water diverted for periods of different wetness it follows that the diversion for each of the 5-year periods was based on contractual obligations rather than on the availability of water to be diverted according to the wetness of the period.

For example, the average NRI_5 of the period 1975-79 was equal to 18.6 MAF which corresponds to a dry period of 95% probability of exceedance (Fig. III.17, Table III.16), or

Table II.21 The mean volume of upstream diversions for 5-year periods between 1925 and 1983 (in thousand acre feet)

Year Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Annual	Average NRI
1925–29	+66.2	-333.6	+30.8	-206.4	-509.2	-535.6	-543.2	-1295.2	-890.8	-449.6	-220.4	-34.8	-7001.0	24.6
30–34	+48.2	+62.4	-286.6	+128.0	-233.4	-483.0	-909.6	-1188.8	-909.8	-391.2	-222.4	-50.4	-4436.6	16.0
35–39	+73.0	+112.6	+8.4	-29.0	+222.0	+106.2	-789.8	-1396.6	-829.8	-468.0	-244.2	-28.6	-3253.8	30.6
40–44	+41.8	+31.2	-467.6	-376.4	-123.0	+123.6	-73.6	-1581.4	-1050.6	-658.4	-310.4	-63.2	-4560.4	35.8
45–49	+55.4	-120.4	-178.8	+255.0	-387.6	-818.2	-1478.2	-1664.2	-981.2	-317.0	-10.0	+175.6	-5489.6	22.8
50–54	+50.8	-173.4	-352.6	-294.4	+111.4	-688.4	-1753.4	-1879.2	-1164.2	-599.8	-109.2	+159.6	-6758.4	33.4
55–59	+201.0	+197.6	-1023.4	-136.4	-692.4	-302.8	-1290.0	-2258.2	-1367.4	-494.0	+58.0	+234.4	-6661.0	31.8
60–64	+5.4	+74.2	-106.6	-414.2	-861.8	-756.6	-1667.0	-1919.0	-1149.6	-87.8	+245.2	+363.2	-6259.6	22.8
65–69	+399.2	-107.0	-1099.0	-1060.0	+212.6	-686.4	-2033.8	-2552.4	-1375.0	-444.6	+240.6	+567.0	-7784.6	36.0
70–74	+514.8	-429.2	-292.8	-700.8	+407.4	-2240.8	-1334.0	-2826.2	-1450.0	+84.8	+616.2	+811.4	-6753.0	35.3
75–79	+635.9	+365.6	+147.0	-716.2	-696.6	-1235.0	-1320.2	-2377.0	-1418.8	-26.8	+421.8	+440.8	-6018.8	18.6
*80–83	+230.2	-704.0	-434.5	-718.3	-981.0	-127.5	-1341.8	-2689.3	-1825.0	-311.0	+574.7	+824.0	-7128.5	47.4

Note: The positive values denote that RRI>NRI, which means that the river received an additional supply of water from storage releases.

*This period for four years only.

recurrence not less than once per twenty years. However, the upstream water withdrawals at this period were 6.0 MAF, or almost 30% of the average NRI_5 for 1975-79.

For the period 1970-74 the average annual upstream diversion was equal to 6.7 MAF, but the average NRI_5 was almost twice as high as the NRI_5 for 1975-79 (35.3 MAF), a diversion of 19.2%.

Therefore, despite the strong difference in the wetness of the periods 1970-74 (wettest year) and 1975-79 (dry year), the diversion was almost the same.

It is possible to obtain the same results if the 1945-49 period is compared to the 1950-54 period or if the period 1955-59 is compared with 1960-64.

Therefore, it is logical to assume that if the wetness of the period is disregarded by water developers, then the riverine-estuarine system may experience strong ecological disturbances due to its long-term deficit in water supply.

In our opinion, the annual as well as the seasonal upstream water withdrawals should proceed from an evaluation of wetness which may eliminate excessive water withdrawals or enforce other conservation methods.

III. 4. 2. Inner Delta Diversions

As in the case of upstream water withdrawals, there are significant differences between the pre-project and post-project conditions (Table III.22).

Pre-Project Period (1921-1944)

During this period, the mean inner Delta diversion was equal to 0.85 MAF per period with a maximum of 1.84 MAF in 1925-29 (period of sub-normal wetness) and minimum of 0.4 MAF in 1940-44 (wettest period), more than 125% of normal for 1921-78). During this period, approximately a total of 70 MAF was diverted from the Delta, almost thirteen times the volume of the Delta, or almost two volumes of the San Francisco Bay.

However, since the implementation of the project facilities, the inner Delta diversions began to grow gradually.

Post-Project Period

During the first twenty years, i.e., from 1945-1964 (Table III.22) the average inner Delta diversion was 1.4 MAF which is 1.6 times higher than the average for the pre-project period.

Table II.22 The mean volume of water diverted from the Delta for 5-year periods between 1925 and 1983 (in thousand acre feet)

Year Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	Spring	July	Aug	Sept	Annual
1925-29	-99	209	-64	183	-248	526	-113	-91	-127	-110	-208	-193	-146	166
30-34	-116	-79	5	61	92	-0	-61	-79	-151	-100	-152	-133	-143	-903
35-39	-102	-126	-104	110	-22	179	5	-161	-157	-104	-200	-184	-144	-1091
40-44	-111	-60	73	201	-814	104	-551	-73	-161	-264	-233	-217	-151	-403
45-49	-91	-44	-175	-4	56	100	-56	-88	-168	-100	-248	-227	-158	-1081
50-54	-123	-1	103	171	78	142	17	11	-157	-42	-246	-226	-160	-524
55-59	-148	-81	121	174	175	4	-3	-114	-260	-129	-380	-349	-207	-1257
60-64	-189	-67	-68	35	60	-84	-198	-306	-416	-307	-541	-493	-313	-2732
65-69	-286	-71	-0	32	124	-242	-203	-400	-404	-330	-483	-497	-317	-2821
70-74	-315	-74	-180	-236	98	117	-343	-506	-627	-491	-694	-665	-415	-3926
75-79	-399	-300	-361	-318	-371	-515	-371	-436	-507	-436	-574	-698	-573	-5588
*80-83	-442	-592	-378	-1225	-366	-201	-378	-29	-502	-304	-612	-752	-471	-5054

Note: The positive values denote that RDO > RRI, which means that the Delta received an additional supply of water from any type of discharges and precipitation.

*This period for four years only.

In the post-project period, the maximum diversion of 2.7 MAF took place in 1960-64 (sub-normal wet years), and the minimum of 0.5 MAF was observed in 1950-54 (wettest period).

For the 1965-83 period, average inner diversions (4.4 MAF) increased 3.1 times in comparison with the average of 1945-64 with a maximum of 5.6 MAF (1975-79-dry period) and a minimum of 0.5 MAF (1950-54-wettest period).

The steady increase of inner Delta diversion started in 1964 and more than doubled during the following twenty years. The total inner Delta water withdrawals for this 5-year period (1945-49 to 1980-83) equalled 103 MAF, which is 79 times higher than the volume of the Delta itself, or 3.8 times higher than the combined natural river inflow to the Delta.

It should be noted that even from this approximation of the water losses sustained by the Delta as a result of inner Delta diversions, it is likely that the Delta environment of the Delta has been deprived of millions of tons of organic and inorganic matter (including sediments and nutrients).

Moreover, for the last two decades inner Delta diversion reached almost 6.0 MAF which is 4.5 times the volume of the Delta itself, so it is not surprising that circulation patterns in the Delta changed greatly (increased frequency of occurrence of landward currents carrying salty and brackish water into the Delta channel).

This, as well as many other changes in regime characteristics in the Delta, e.g., turbidity, light penetration, temperature and pH, oxygen concentration, etc. may be attributed to cumulative, subtle developments in the Delta that may ultimately effect the migration, spawning and feeding of fish.

III. 4. 3. Total Upstream and Delta Water Diversions

San Francisco Bay is the final link which has been directly effected by upstream water withdrawals and Delta diversions (Table III. 23).

Pre-Project Period (1921-44)

The mean volume of total withdrawal from the NDO_5 discharged to San Francisco Bay for this period was 5.3 MAF, with a maximum of 8.2 MAF (1925-29-sub-normal wetness), and a minimum of 3.8 (1935-39-wet period).

The average diversion constitutes 20% of the average NDO_5 of 26.3 MAF for the same period. The total average losses for four 5-year periods equals 106 MAF which is as much as thirteen times the volume of the Bay itself, but this amount of water is much

Table III.23 The mean volume of the combined upstream and Delta diversions for 5-year periods between 1925 and 1983 (in thousand acre feet)

Year Period	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Annual	Average NDO
1925-29	+27.4	-173.0	+31.8	-66.8	-870.4	-31.2	-633.4	-1279.8	-879.6	-444.0	-192.0	-18.6	-8186.0	23.9
30-34	+14.6	+6.0	-376.0	+91.8	-210.4	-491.6	-883.8	-1163.0	-915.6	-330.0	-133.0	-33.2	-4572.0	15.2
35-39	+41.0	-14.6	-166.2	-18.6	+27.6	+169.4	-736.0	-1442.6	-841.8	-455.2	-207.0	-14.4	-3835.8	30.1
40-44	+5.6	-85.4	-499.4	-366.8	-1080.8	+165.0	-608.8	-1547.8	-1063.8	-678.0	-305.0	-112.6	-4522.4	35.4
45-49	+17.0	-180.8	-430.6	+248.2	-371.8	-726.2	-5952.0	-1649.4	-1003.8	-351.8	-14.6	+179.6	-5794.0	22.1
50-54	+8.0	-381.8	-368.4	-247.8	+164.8	-583.6	-1683.0	-1752.2	-1177.2	-632.8	-114.2	+179.8	-6632.4	32.8
55-59	+132.4	+136.8	-1006.8	-123.8	-641.4	-314.0	-1271.0	-2279.8	-1479.0	-603.4	-69.6	+163.0	-7366.6	31.2
60-64	-129.8	-169.4	-178.0	-445.0	-889.0	-878.0	-1807.8	-2108.0	-1405.6	-416.4	-26.8	+210.2	-8246.0	22.1
65-69	+198.4	-238.4	-1198.2	-1212.8	+275.4	-950.8	-2191.4	-2829.6	-1275.0	-715.8	-42.8	+411.6	-10049.4	35.4
70-74	+251.0	-589.4	-589.2	-1074.2	+468.6	-2153.4	-1604.0	-3214.4	-1934.4	-400.4	+173.4	+553.4	-10109.0	33.7
75-79	+20.0	+143.8	-122.2	-1948.6	-871.0	-1447.4	-1515.4	-2673.6	-1791.4	-490.6	-116.4	-3.8	-9720.0	22.1
*80-83	-115.7	-1221.0	-738.0	-1895.1	-1298.2	-287.0	-1620.7	-1506.2	-2201.3	-790.2	-50.5	+464.8	-11079.3	46.3

Note: The positive values denote that RDO>NDO, which means that the system received an additional supply of water from storage releases.

*This period for four years only.

less than what was diverted from the system in the following post-project period.

Post-Project Period (1945-83)

From the first 5 years of this period (1945-49) to the end, total water diversions increased almost two times, and in 1980-83 were equal to 11.1 MAF. This amount of water constitutes almost 41% of normal and should be considered a typical example of long-term major water withdrawals. It should be remembered that the predominant natural deviations of the water supply to the Bay for 5-year running periods is only $\pm$ 25%.

The gradual increase in total water losses for San Francisco Bay began in 1945-49, and the average diversion, 7.0 MAF, for the following twenty years was 1.3 times higher than for the preceding twenty years of the pre-project period but as much as 1.5 times less than the mean total withdrawals of 10.2 MAF in the following nineteen years (1955-83).

It is important to note that during the period of sub-normal wetness of 1945-49, the average NDO_5 equalled 22.1 MAF and the total diversions were 5.8 MAF, but for the period of sub-normal wetness of 1960-64 (NDO_5 = 22.1 MAF) the total diversion was 8.3 MAF, or 1.4 times higher than for the period of the same wetness category discussed above.

In 1975-79, with the same wetness conditions, even higher withdrawals took place (Table III. 23). Therefore, as in the case of upstream water withdrawals, the gradual increase of total water diversions for these 5-year periods, regardless of their wetness category, was based, in our opinion, on the needs of different water users. Thus, the San Francisco Bay was subjected to a gradual increase in water supply deficit.

The total water withdrawals from 1945-1983 equalled 333 MAF. This amount of water is equal to more than forty times the volume of San Francisco Bay.

The high levels of diversion that have occurred over this 39-year period appear to have exceeded the natural resiliency of the system which has evolved over many centuries of highly variable freshwater inflow. It is our opinion that these large flow reductions are a principal source of the major water quality and biological resource problems that have been increasing over the past several decades, e.g., Delta salinity intrusion, collapse and disease problems of fish populations, reduced flushing and circulation.

PART IV

SUMMARY

Runoff Cyclicity

1. Analysis of the 1921-78 data on water flow (DWR's period of record) reveals cycles of approximately 14-year duration , each with two phases (rise and fall) that varied within ± 30% of the mean (normal) natural inflow to the system for the 58-year period (28.3 MAF). (Such cycles were also demonstrated to be present in other river basin systems in the U.S., USSR and Europe.) The existence of these cycles is important because without this information, planning and distribution of water is based only on year-to-year estimates and data which results in deficits of water for distribution during phases of fall for such cycles and overly conservative diversion during the phases of rise.

Comparative Analysis of Natural & Regulated Runoff

Annual Variability of Natural & Regulated Runoff

1. For 56% of years of the 1921-78 period of record natural runoff was within ± 30% of normal for the period. Natural runoff was above normal for 30% of the years and 13% of the years were "critically dry" (natural river inflow less than 28.3 MAF, natural Delta outflow = 27.2 MAF). The majority of years had natural runoff which would have occurred once every 2.4-3.3 years (flow probability of exceedance = 30-54%).

2. However, regulated flow (both river inflow, 22.1 MAF, and Delta outflow, 20.4 MAF) was above normal values in only 15% of the years (half of the level for natural flow) and 30% of the years were "critical dry" (twice as many as for natural flow for the same period. The predominant range of annual flow remaining after upstream and downstream diversions would have occurred under natural conditions at least once every 5-20 years (p = 75-95% - sub-normal wetness or below).

3. Gradual substantial annual increases of upstream, downstream and total diversions during the post-project period (1944-83) in comparison with the pre-project period (1921-43) have resulted in significant modification of the Sacramento-San Joaquin River water supply to the Delta-Bay estuarine system to conditions never before observed.

4. The number of sub-normal, dry and critical dry years of regulated river inflow and regulated Delta outflow increased 1.3-2 times, while the number of wet and normal years in comparison

with natural river inflow and natural Delta outflow decreased by half.

5. As a result, the San Francisco Bay ecosystem experiences chronic deficits in water supply up to 60%, particularly for years of normal, subnormal and critical natural water supply.

6. The predominant range of annual upstream, Delta and total water diversion since the 1960's (up to 1983) was 6-12 MAF, 4-6 MAF and 9-13 MAF, respectively. (In 1978, more than 20 MAF were diverted.)

7. As a general rule, the highest percentage of diversions before and after CVP and SWP completion occurred in years of subnormal and critical dry categories of wetness. The highest volume of water was diverted in wet and normal years following years of subnormal or low wetness.

8. In general, the persistent increases in annual upstream, downstream (inner Delta consumption and export) and total water diversions from the Sacramento-San Joaquin River system (which are many times higher than those documented for the pre-project period) support the conclusion that the entitlements of different water users has been the factor governing the management of this system. It is our contention that in order to maintain the health of the Delta-Bay estuarine system, decisions regarding water diversions should take into consideration the natural limits of the water resources and wetness of the year (for a series of years) based upon data on past and present flow regimes.

Seasonal & Monthly Natural & Regulated Runoff

In addition, examination of the changes which have occurred in seasonal and monthly natural river inflow to the Delta and Delta outflow to the Bay because of regulation offers further insight into the human intervention process.

1. As a result of upstream and Delta diversions the highest values of natural runoff have been truncated for all but autumn months. Comparison of typical pre- and post-project years further illustrates this point.

2. In a typical "normal" pre-project year (1936-37), most of the water removed from the system (equal to 14% of the annual flow for the year) was diverted during the spring months while for a comparable post-project "normal" year (1961-62), major diversion occurred during eight months of the year (35% of annual flow).

Regulated river inflow and Delta outflow during all post-project winter and spring months were 2-5 times lower than they were for the pre-project period. The resulting regulated discharge to the Bay would have occurred once every 5-10 years under natural flow conditions (p = 75-95%; recurrence interval of at least once per 5-20 years).

3. Similar comparisons for typical "wettest" years 1937-8 (pre-project) and 1968-69 (post-project) indicate that in all months, diversions were 2-10 times higher for post-project. For typical "critical dry" years, 1976-77 (56% diversions; post-project), withdrawals were four times higher and residual flows were negligible, representing only half of the levels of the comparable pre-project year (1923-44) during which outflow from the Delta (RDO) for the entire year was less than half the total volume of San Francisco Bay.

4. For the post-project period, the trend of upstream diversions, regardless of the type of water year, appears to have been more a reflection of contractual obligations than of wetness of years. For some spring months, the predominant range of diversions was 50-60% (up to 85% in some worst case months) and residual inflow to the Delta and outflow to the Bay would have occurred normally at least once every 20-50 years (p = .95-.98). This suggests that low flow events, which happened only rarely under unregulated conditions, have now become the predominant events for the system, and are occurring on an almost annual basis except in very wet years. The impact of such continuous low outflow to the Bay is thought to be one of the causes of many of the symptoms of deterioration of the system.

Cumulative Monthly and Annual Losses

Between 1955 and 1978, the period after completion of the CVP and SWP, diversions amounted to a total of 240 MAF of freshwater, equivalent to 40 times the volume of the San Francisco Bay. Of this, 164 MAF was diverted from the rivers for irrigation and domestic water supply and 76 MAF was removed from the Delta for agricultural and other needs. For 23 years, an average of 7.1 MAF/year was withdrawn from river inflow (Sacramento and San Joaquin) to the Delta, yielding a total of 10.4 MAF/year that never reached the Bay. Cumulative losses of such magnitude are believed to be one of the major factors responsible for salt intrusion and salinization of the Delta and Bay as well as for serious modification of flushing, fish migration and spawning conditions, and reduction of nutrients and sediment load.

Mean Runoff Fluctuations (for 5-Year Periods)

Dynamics of Wetness

1. Review of more than 100 years of precipitation and 60 years of runoff records reveals the existence of similar climatological cycles in widely separated geographic regions. Analysis of 50-60-year periods of natural runoff in the all of

these basins reveals the existence of cycles, each with a rising and falling phase, with annual deviations of running 5-year means that vary within a predominant range of 20-30% of the average (normal) for the period.

2. Superimposed on these natural phases of wetness which are due primarily to climatological factors, there are large negative annual runoff deviations (predominant range = 35-60% of normal) which reflect human intervention, i.e., regulation.

Annual Wetness Dynamics (for 5-Year Periods)

1. In more than 60% of the 5-year periods between 1921 and 1978, natural river inflow varies within 30% of normal, except for the critically dry years of the late 1920s.

2. During the same time , the number of subnormal and dry periods for regulated river inflow and Delta outflow increased more than 5 times and more than 40% of the 5-year periods were subnormal.

3. Up- and downstream regulation (post-project) has led to a significant increase in the number of periods of low wetness which is not attributable to natural conditions. The resulting reduction in water supply for 5-year periods is unprecedented in the period of record.

Monthly Wetness Fluctuations (for 5-Year Periods)

1. Water regulation for the winter season is characterized by an overall decrease in the number of 5-year periods of high and normal wetness and by an increase in the number of periods of subnormal wetness.

2. These trends both continue into into the spring months where they reach their peaks, e.g., June - no wet periods, April- 8-10 times more 5 year periods of subnormal wetness than before project operations began.

3. The increases in late summer and fall runoff (most likely the result of returning agricultural drainage flows and/or releases from storage facilities) are small relative to the large runoff deficits for late winter and spring (by nearly an order of magnitude).

Whereas before project operations, there were significant numbers of critical dry and very few wet periods, the projects were followed by an elimination of dry periods and a significant increase in the number of wet periods (especially for August).

4. Similar increases in the number of wet 5 year periods were observed for early autumn (September and October) following the beginning of project operations but November showed decreases

in the number of wet and increased dry periods.

5. In the absence of data on the quality of returning flows, it is impossible to determine whether the increase in flows and wet periods, and the decrease in dry periods for late summer and early autumn, created a net improvement in conditions for estuarine organisms.

Annual River Inflow to the Delta (for 5-Year Periods)

1. For Delta inflow, upstream diversions reduced the number of periods of above normal river flow as much as five times.

2. The lowest ranges of regulated river inflow to the Delta characterized by the predominant range of 10-15 MAF became a permanent new feature of low water supply to the system.

Seasonal and Monthly River Inflow and Delta Outflow (for 5-Year Periods)

1. The average natural water supply to the Delta for 5-year periods was reduced 30% for the winter and 60% for the spring.

2. Especially for the period beginning in the late 1950's, the Delta-Bay system did not receive more than one third of the historic winter river inflow.

3. For January and February, regulated Delta outflow is regularly characterized as sub-normal runoff or below, except in wet years.

4. Since the 1960's, March has had the highest diversions for the winter period and regulated Delta outflow discharge corresponds to subnormal periods while natural Delta outflow for the same period could be characterized as wet.

5. For the post-project period, deviations from normal spring monthly average regulated river inflow/Delta outflow ranged from -35% to -85% while for the worst pre-project period (1924-34) they were only -45%.

6. Regulated Delta outflow deviations have been higher than regulated river inflow and for the majority of springs, regulated Delta outflow has shifted to below normal and sub-normal wetness categories of would-be natural flow. Since the late 1960s, discharges to the Bay have been predominantly sub-normal as a result of upstream and Delta diversions.

7. The extreme high values of spring river inflow which were observed before project operations were reduced 1.5 to 3 times for the post-project period.

8. For the post-project period, mean spring natural river inflow had a predominant range of ± 25% of normal while regulated river inflow deviations ranged from -35% to -70%, (an increase of 1.5 to 2.8 times).

9. For spring, under natural conditions the prevailing range of natural river inflow was 3-4 MAF. The current regulated spring river inflow to the Delta has a predominant range of 1.5 to 2.5 MAF (conditions of sub-normal wetness and below), or reduced 1.6-2.0 times.

10. Spring and winter conditions have led to average losses (for 5-year periods) of at least 7 MAF. These values are highest for periods preceded by 5-year periods that are dry or critical dry.

11. The predominant range of regulated river inflow observed for the spring months between the 1965 and 1978 corresponded to events which would occur at least once per 10-20 years while natural river inflow for the same period would have a recurrence interval of once per 2-4 years. This shift has made a rare occurrence into a nearly permanent feature of the system.

12. For late summer and early fall periods of the past 20 years, there has been no deficit in water supply, primarily as a result of the volume of returning agricultural drainage flows. Since the completion of the projects the average river inflow for some of these months has increased to more than 1 MAF (an increase of nearly 100%).

13. July regulated river inflow deviation patterns were similar to those for regulated Delta outflow, but with predominantly negative deviations of -45 to -80% and regulated Delta outflow does not reflect the influence of returning flows.

14. August and especially September demonstrated significant overall increases in 5-year regulated Delta outflow (compared to natural Delta outflow), with maximum positive deviations up to +200% above normal, presumably as a result of return flows.

<u>Delta Outflow to San Francisco Bay (for 5-Year Periods)</u>

<u>Annual Deviations</u>

1. The same trend of decreasing water supply was observed for 5-year periods between 1958 and 1982. Therefore periods of low would-be natural Delta outflow to the Bay which occurred once per 10-20 years now occur once per 2-4 years.

2. Since 1955, minimum average diversions for 5-year periods have not been lower than 7 MAF and reached a maximum of 11 MAF (1974-78).

Annual Losses for Running 5-Year Periods

1. Between 1945 and 1983, 333 MAF of total upstream and Delta water which would have reached San Francisco Bay was diverted from the system.

2. Since the beginning of project operations, the mean, minimum and maximum upstream diversions have increased 1.5, 1.6, and 1.7 times.

3. Cumulative losses for all 5-year periods between 1925 and 1944 = 70 MAF, and for the post-project 1945-64 period = 112 MAF, an increase of 1.6 times, the same ratio as between pre- and post-project losses for spring.

Summary, Conclusions and Recommendations

The foregoing analysis and evaluation has focused on natural and regulated flow characteristics and variability in order to estimate the impact of diversions on the flow patterns and water supply to the Delta-Bay estuarine system.

1. The results indicate that current annual diversions result in 35-55% reductions in flow to San Francisco Bay. Even in some wet years, regulated river inflow and Delta outflow correspond to natural flows of dry years.

2. The major cause of these persistent decreases in annual runoff is that diversions in <u>winter</u> range between 15 and 45% and for <u>spring</u> between 30 and 80% or more.

3. Upstream diversions in the post-project period (predominant range of 8-12 MAF per year) are 6-8 times higher than before the CVP and SWP were completed (1-2 MAF per year). Upstream diversions are currently 1.5-3 times higher than downstream withdrawals which illustrates that the water facilities are not capable of holding and releasing excess water to benefit the Delta and Bay in years of critical wetness.

4. In the post-project period, diversions take place throughout the year, with major exports (upstream) beginning in February and March. Downstream diversions in some years (e.g., 1975) are as great as upstream, a phenomenon never observed in the pre-project era when diversions took place primarily in the spring.

5. As a result of regulation, the frequency of subnormal or dryer months (for the late winter and spring) is 1.3-2 times higher for the post-project than for the pre-project period.

This means that the Delta-Bay system currently is regularly and persistently subjected to conditions of sub-normal wetness with the exception of critical historic wet years such as 1983.

6. Annual Delta diversions are currently more than 5 times the volume of the Delta, often resulting in entrainment and circulation of salty water from Suisun Bay through the Delta toward the export facilities.

7. In normal and subnormal years, regulated runoff (primarily as a result of returning agricultural drainage flows) for July, August and September (especially the latter two) is equal to the volume of spring flows. This artificial augmentation of flow is an entirely new feature of the system which has distorted the natural cycle of river discharge to the Delta and Bay. The result appears have been the gradual salinization of the basin, modification of conditions for fish migration and spawning, presumably, pollution (from drainage constituents).

8. Analysis indicates that for the majority of 5-year periods, the mean regulated runoff is much less than normal and has been replaced by volumes corresponding to subnormal and dry conditions. This water supply is 35-50% less than natural mean Delta outflow (27.3 MAF). (These 5-year periods reflect phase of precipitation and are responsible for the cumulative water supply to the estuary which is the determining factor for fish production, salinity, residence time and flushing.)

Despite our appreciation of the fact that the welfare of California depends on the freshwater from the North being supplied to the South through one of the world's most sophisticated distribution systems, the results of our evaluation clearly indicate that the limits of the Delta-Bay ecosystem have been reached and exceeded. We now face a choice between recommendations that will result in only 2.8-5 MAF per year remaining for discharge to the Delta and Bay after meeting future contractual obligations and a more balanced distribution of water which can meet some of the needs of agriculture (and other municipal and industrial users) as well as those of the Delta-Bay ecosystem.

Based on the experience of 1924 and 1976-77, we wish to emphasize that under natural conditions, residual runoff to San Francisco Bay of 3-5 MAF would occur only very rarely (once per 100 or more years). If such extreme conditions were to occur on a regular frequency, or even releases of 7 MAF (critical dry or drought) to 14 MAF (dry conditions) per year the Delta-Bay system would cease to function as an estuary and ultimately would be incapable of meeting the water needs of either California agriculture (including the Delta) or the resources of the Delta and San Francisco Bay.

We share the Metropolitan Water District's conclusion that

"Unfortunately, the State Water Project was not formulated to recognize all of these weather problems explicitly. The project was organized using the concept of 'annual entitlements.' These are specific amounts of water for each year that are set forth in each of the 31 contracts between the State and local water agencies." (MWD, 1979, page 30) This means that the delivery of fixed quantities of water to meet contractors entitlements (for the CVP as well as the SWP) regardless of natural climatological limitations will ultimately lead to overdraft of the water supply.

We suggest consideration of any or all of the following alternatives:

1. Passive measures

A. Rescheduling and reducing seasonal water diversions. For the spring, especially May and June, provide for the release to the Delta and Bay of volumes equal to at least 75% probability of exceedance (by definition, a subnormal volume) for at least 2-3 successive years.

B. Accumulation during the winter of sufficient water to provide flows adequate for maintaining or improving conditions for Delta and Bay water quality and living resources, especially when regulated river inflow and Delta outflow both correspond to lower than subnormal seasonal wetness.

C. To return to conditions of seasonal distribution of runoff more closely resembling natural patterns which are now distorted by reduction of spring flows and artificial increases in late summer and fall flows.

D. Re-examine plan to increase Delta pumping capacity based on the fact that current exports have been 3-5 times higher than the volume of the Delta itself for the past decade. Current exports already exceed the volume of San Joaquin River outflow and may be considered responsible for serious reverse flow conditions in the Delta resulting in its gradual salinization.

E. Evaluate the potential value of water conservation, recycling, increased efficiency of use (industrial, agricultural, and municipal), marketing and trading for reducing demand before increasing entitlements or developing new facilities.

2. Direct measures

A. Construction of retarding basins to accumulate winter and spring flows for discharge into the Delta and Bay to maintain adequate conditions for repelling salt intrusion, flushing, fish migration and reproduction, and improving water quality.

B. Increase storage capacity of existing reservoirs to increase yield in wet years for release to the estuarine system (and not for export) in dry years.

Managers of California water must recognize the lessons learned from other estuaries in the United States and abroad--that we can never return productivity of the estuary to the level of pre-regulated conditions. Improvement in water quality and resource health and productivity in the riverine-estuarine system resulting from any of these proposed alternatives should be a good indication that the alternatives are useful.

PART V

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Appendix 1 Statistics of the Mean Monthly and Annual Natural River Inflow to the Delta - 1921-1978

Months	Range Q MAF	Mean Q MAF	Cv	Cs	Standard Deviation MAF
October	0.32- 3.29	0.58	0.42	1.95	0.24
November	0.34- 6.04	1.13	0.88	2.66	1.00
December	0.40-12.67	2.44	1.00	2.30	2.44
January	0.56-14.44	3.39	0.94	2.20	3.18
February	0.53-10.92	3.80	0.61	1.10	2.32
March	0.63-11.08	3.85	0.54	1.13	2.08
April	0.77- 8.80	4.15	0.47	0.60	1.94
May	1.01- 8.79	4.26	0.45	0.56	1.93
June	0.47- 6.31	2.65	0.54	1.08	1.44
July	0.32- 2.93	1.04	0.53	1.12	0.55
August	0.28- 0.94	0.54	0.31	0.73	0.17
September	0.27- 0.83	0.45	0.24	0.77	0.11
ANNUAL	6.75-56.53	28.30	0.44	0.88	12.50

Appendix 2 Variables of a theoretical curve of probability of exceedance of mean monthly and annual Natural River Inflow to the Delta, 1921-1978 (MAF).

Probability of exceedance, %	1	5	10	25	50	75	90	95	99
Years of recurrence	100	20	10	4	2	4	10	20	100
October	1.45	1.01	0.90	0.68	0.51	0.41	0.36	0.39	0.33
November	5.04	3.16	2.36	1.40	0.78	0.48	0.39	0.38	0.37
December	14.90	7.95	5.54	3.01	1.57	0.82	0.55	0.48	0.29
January	15.90	9.80	7.50	4.50	2.36	1.40	0.71	0.57	0.31
February	11.10	8.26	6.99	5.11	3.41	2.11	1.27	0.84	0.27
March	10.30	7.79	6.64	5.00	3.48	2.31	1.56	1.21	0.73
April	9.76	7.66	6.70	5.34	3.93	2.73	1.80	1.32	0.48
May	9.50	7.67	6.77	5.45	4.09	2.90	1.96	1.45	0.60
June	7.05	5.35	4.56	3.42	2.41	1.59	1.06	0.82	0.48
July	2.73	2.08	1.22	1.34	0.95	0.64	0.43	0.33	0.19
August	1.01	0.85	0.76	0.64	0.52	0.42	0.34	0.30	0.23
September	0.75	0.65	0.60	0.52	0.45	0.38	0.32	0.28	0.26
ANNUAL	65.03	51.42	45.00	35.38	26.49	19.19	13.98	11.40	7.50

Appendix 3 Statistics of the Mean Monthly and Annual Regulated River Inflow to the Delta - 1921-1978

Month	Range MAF	Mean MAF	Cv	Cs	Standard Deviation MAF
October	0.29- 2.73	0.76	0.60	1.75	0.46
November	0.36- 4.16	1.06	0.68	2.00	0.72
December	0.52- 7.97	2.09	0.85	2.20	1.77
January	0.62-11.62	3.14	0.78	1.90	2.45
February	0.49-10.40	3.63	0.68	1.55	2.48
March	0.44-11.60	3.26	0.70	1.65	2.28
April	0.37- 8.96	3.00	0.80	1.85	2.40
May	0.29- 7.34	2.32	0.74	1.63	1.72
June	0.11- 4.96	1.45	0.72	1.44	1.05
July	0.00- 1.68	0.69	0.59	0.51	0.41
August	0.04- 1.60	0.61	0.65	0.63	0.40
September	0.18- 1.89	0.71	0.60	1.50	0.42
ANNUAL	5.57-55.76	22.12	0.51	0.99	11.34

Appendix 4 Variables of a theoretical curve of probability of exceedance of monthly and annual regulated river inflow to the Delta, 1921-1978

Probability of exceeding	1	5	10	25	50	75	90	95	99
Years of recurrence	100	20	10	4	2	4	10	20	100
October	2.33	1.66	1.36	0.96	0.63	0.43	0.32	0.29	0.26
November	3.70	2.53	2.01	1.35	0.86	0.65	0.42	0.57	0.35
December	8.63	5.68	4.35	2.72	1.51	0.86	0.58	0.52	0.48
January	11.84	8.01	6.34	4.12	2.42	1.38	0.88	0.74	0.60
Feburary	11.91	8.42	6.90	4.76	3.05	1.82	1.16	0.87	0.58
March	11.06	7.73	6.29	4.29	2.67	1.60	1.03	0.80	0.58
April	11.45	7.74	6.18	3.99	2.33	1.27	0.78	0.60	0.47
May	8.14	5.68	4.59	3.11	1.89	1.07	0.62	0.44	0.26
June	5.80	3.77	3.01	1.94	1.23	0.71	0.39	0.26	0.12
July	1.79	1.45	1.26	1.40	0.92	0.53	0.28	0.12	0.07
August	1.73	1.37	0.80	0.69	0.54	0.28	0.14	0.08	0.04
September	2.16	1.55	1.28	0.94	0.63	0.39	0.28	0.22	0.13
Annual	56.18	43.36	37.16	28.31	20.35	13.94	9.29	7.30	4.20

Appendix 5 Statistics of the Mean Monthly and Annual Natural Delta Outflow to the San Francisco Bay - 1921-1978

Month	Range Q MAF	Mean Q MAF	Cv	Cs	Standard Deviation MAF
October	0.22- 3.37	0.51	0.48	1.92	0.24
November	0.29- 6.15	1.15	0.97	2.65	1.12
December	0.26-13.03	2.52	1.02	2.40	2.57
January	0.58-14.73	3.54	0.88	2.10	3.12
February	0.33-11.23	3.88	0.58	1.20	2.25
March	0.64-11.25	3.89	0.55	1.14	2.14
April	0.69- 8.36	4.10	0.46	0.44	1.89
May	0.94- 8.67	4.15	0.47	0.55	1.95
June	0.33- 6.19	2.51	0.57	1.14	1.43
July	0.11- 2.72	0.83	0.65	1.30	0.54
August	0.06- 0.73	0.32	0.55	1.10	0.18
September	0.11- 0.68	0.30	0.40	0.85	0.12
ANNUAL	5.81-56.26	27.18	0.45	0.90	12.23

Appendix 6 Statistics of the Mean Monthly and Annual Regulated Delta Outflow to the San Francisco Bay, 1921-1982

Months	Range QI MAF	Mean Q MAF	Cv	Cs	Standard Deviation MAF
October	0.13- 2.70	0.56	0.67	1.80	0.28
November	0.22- 4.32	0.97	0.74	1.95	0.71
December	0.26- 8.30	2.11	0.84	2.00	1.83
January	0.27-11.90	3.14	0.82	1.85	2.58
February	0.27-10.3	3.53	0.60	0.90	2.12
March	0.19-11.92	3.25	0.60	1.20	1.95
April	0.18- 9.23	2.85	0.80	0.80	2.28
May	0.23- 6.92	2.16	0.79	1.70	1.71
June	0.00- 4.80	1.20	0.93	1.39	1.12
July	0.00- 1.44	0.35	0.94	1.44	0.33
August	0.00- 0.82	0.24	0.90	1.01	0.22
September	0.03- 1.54	0.45	0.71	1.40	0.32
ANNUAL	2.53-52.97	20.41	0.54	0.95	11.02

Appendix 7 Variables of a theoretical curve of probability of exceedance of mean monthly and annual Regulated Delta Outflow, 1922-1982

Probability of exceeding, %	1	5	10	25	50	75	90	95	99
Years of recurrence	100	20	10	4	2	4	10	20	100
October	1.88	1.31	1.06	0.72	0.45	0.29	0.21	0.18	0.15
November	3.54	2.41	1.90	1.26	0.76	0.46	0.32	0.29	0.23
December	8.48	5.65	4.41	2.73	1.56	0.84	0.50	0.42	0.36
January	12.22	8.23	6.53	4.21	2.42	1.29	0.75	0.57	0.40
February	9.78	7.52	6.46	3.18	3.07	1.91	1.09	0.81	0.32
March	9.32	7.00	5.85	4.26	2.83	1.50	1.10	0.68	0.32
April	9.01	7.12	6.10	4.50	2.36	1.00	0.31	0.23	0.17
May	7.83	5.40	4.30	2.85	1.67	0.91	0.48	0.33	0.21
June	4.87	3.48	2.80	1.78	0.90	0.36	0.20	0.07	0.00
July	1.43	1.02	0.82	0.54	0.26	0.09	0.00	0.00	0.00
August	0.98	0.67	0.53	0.34	0.18	0.08	0.02	0.00	0.00
September	1.48	1.06	0.87	0.60	0.38	0.22	0.12	0.08	0.04
ANNUAL	53.27	41.02	35.11	26.53	18.57	12.45	7.76	5.72	2.55

Appendix 8 Statistics of the 5-Year Running Mean Monthly and Annual Regulated Inflow to the Delta - 1922-1978

Month	Range Q MAF	Mean Q MAF	Cv	Cs	Standard Deviation MAF
October	0.38- 1.31	0.76	0.35	0.70	0.26
November	0.47- 1.92	1.05	0.33	0.66	0.35
December	0.75- 3.26	2.10	0.34	0.68	0.72
January	1.11- 6.38	3.15	0.45	0.90	1.42
February	1.48- 6.71	3.59	0.34	0.68	1.21
March	1.86- 6.39	3.26	0.34	0.68	1.11
April	1.43- 5.54	2.95	0.33	0.99	0.97
May	1.31- 4.09	2.34	0.32	0.64	0.74
June	0.86- 2.60	1.48	0.30	0.47	0.44
July	0.24- 1.22	0.69	0.37	0.74	0.26
August	0.13- 1.29	0.59	0.57	1.26	0.33
September	0.25- 1.39	0.70	0.47	0.94	0.33
ANNUAL	11.46-35.81	22.75	0.24	0.02	5.56

Appendix 9 Variables of a theoretical curve of probability of exceedance of 5-years running mean monthly and annual Regulated River Inflow (MAF).

Probability of exceedance, %	1	5	10	25	50	75	90	95	99
Years of recurrence	100	20	10	4	2	4	10	20	100
October	1.51	1.24	1.12	0.92	0.73	0.57	0.44	0.38	0.28
November	2.02	1.68	1.51	1.26	1.01	0.80	0.64	0.56	0.42
December	4.11	3.40	3.05	2.53	2.02	1.58	1.25	1.08	0.79
January	7.35	5.78	5.05	3.95	2.94	2.11	1.52	1.24	0.80
February	6.93	5.73	5.15	4.26	3.40	2.67	2.11	1.83	1.36
March	6.38	5.27	4.74	3.92	3.13	2.46	1.95	1.69	1.25
April	5.90	4.78	4.25	3.48	2.80	2.24	1.86	1.65	1.42
May	4.42	3.70	3.35	2.78	2.25	1.80	1.45	1.26	0.96
June	3.56	3.03	2.77	2.48	1.94	1.56	1.25	1.09	0.81
July	1.42	1.15	1.04	0.84	0.66	0.50	0.39	0.33	0.24
August	1.68	1.25	1.06	0.77	0.53	0.35	0.23	0.18	0.12
September	1.70	1.38	1.14	0.88	0.66	0.46	0.33	0.26	0.16
ANNUAL	35.49	31.62	29.60	26.39	22.75	19.11	15.70	13.88	10.24

Appendix 10 Statistics of the 5-Year Running Mean Monthly and Annual Regulated Delta Outflow to the San Francisco Bay - 1922-1978

Month	Range Q MAF	Mean Q MAF	Cv	Cs	Standard Deviation MAF
October	0.26- 1.06	0.57	0.34	0.56	0.19
November	0.39- 1.81	0.97	0.35	0.58	0.34
December	0.65-- 3.34	2.02	0.38	-0.03	0.76
January	1.14- 6.15	3.14	0.44	0.41	1.40
February	1.56- 5.63	3.53	0.32	-0.01	1.12
March	1.76- 7.08	3.26	0.38	1.54	1.22
April	1.37- 5.18	2.79	0.34	0.74	0.94
May	0.87- 3.94	2.13	0.38	0.41	0.81
June	0.43-- 2.44	1.18	0.42	0.48	0.50
July	0.09- 0.69	0.38	0.42	0.30	0.15
August	0.001-0.58	0.28	1.00	2.00	0.28
September	0.11- 0.94	0.44	0.53	1.20	0.23
ANNUAL	10.67-34.88	20.79	0.27	0.26	5.58

Appendix 11 Variables of a theoretical curve of probability of exceedance of 5-years running mean monthly and annual Regulated Delta Outflow (MAF)

Probability of exceeding, %	1	5	10	25	50	75	90	95	99
Years of recurrence	100	20	10	4	2	4	10	20	100
October	1.10	0.92	0.83	0.69	0.55	0.43	0.34	0.29	0.20
November	1.91	1.58	1.43	1.17	0.93	0.73	0.56	0.48	0.33
December	3.78	3.27	3.01	2.53	2.04	1.52	1.03	0.75	0.22
January	6.75	5.97	4.96	4.02	3.05	2.17	1.44	1.04	0.35
February	6.18	5.37	4.98	4.27	3.53	2.79	2.08	1.69	0.88
March	7.27	5.64	4.92	3.88	3.00	2.35	1.96	1.79	1.60
April	5.50	4.52	4.07	3.35	2.68	2.12	1.67	1.45	1.09
May	4.26	3.56	3.20	2.64	2.07	1.55	1.13	0.92	0.51
June	2.50	2.05	1.83	1.49	1.14	0.83	0.58	0.44	0.21
July	0.79	0.65	0.59	0.48	0.37	0.27	0.18	0.13	0.04
August	1.29	0.84	0.64	0.39	0.19	0.08	0.03	0.02	0.00
September	1.15	0.86	0.74	0.55	0.39	0.26	0.18	0.15	0.10
ANNUAL	34.93	30.35	28.07	24.32	20.58	16.84	13.93	12.06	8.94