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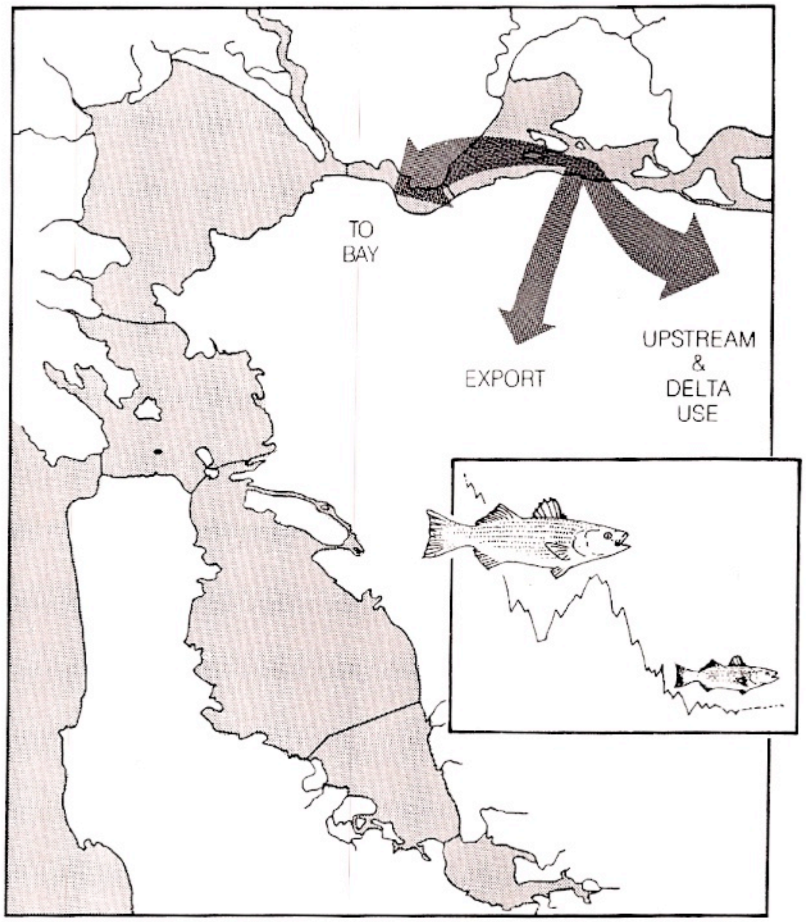
THE ROLE OF WATER DIVERSIONS IN THE DECLINE OF FISHERIES OF THE DELTA — SAN FRANCISCO BAY & OTHER ESTUARIES



September 1987

Michael Rozengurt, Michael J. Herz & Sergio Feld

With preface by Joel Hedgpeth

Technical Report Number 87-8

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THE ROLE OF WATER DIVERSIONS IN THE DECLINE OF FISHERIES OF THE DELTA-SAN FRANCISCO BAY AND OTHER ESTUARIES*

Michael Rozengurt, Michael J. Herz & Sergio Feld
(with Preface by Joel W. Hedgpeth)

* This research was supported by the San Francisco and Marin Community Foundations (Buck Trust).

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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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(This study follows our previous technical report, "Analysis of the Influence of Water Withdrawals on Runoff to the Delta-San Francisco Bay Ecosystem (1921-83)," as part of a series on the impact of water regulation on estuarine resources.)

PREFACE

JOEL W. HEDGPETH

San Francisco Bay is an estuarine system subjected to the combined stresses of urbanization, with its associated pollution, and diversions of water from its river systems. Since the quantity of river water that reaches the estuary is the prime environmental factor that influences the nature of the system, it is the increase or reduction of water that has the most immediate and obvious effect on the biological components of the estuarine system. Industrial or urban pollution is a biogenic complication that has more influence when the fresh water supply of the estuary is reduced.

In basic environmental conditions, however, estuaries are very similar all over the world, since the primary factors of salinity and nutrients are subject to similar ranges of variations. This is demonstrated by the ease with which species of plants, fishes and invertebrates have become colonized throughout the world so that we have the same or similar complexes, especially of phyto- and zooplankton, in estuaries everywhere.

The San Francisco Bay estuarine system has become a classic example of colonization by foreign species, either by the deliberate intervention of man, or inadvertent introduction by ocean traffic. At the present time, there are several hundred invertebrates classified as "introduced" (Carlton, 1979), in the

San Francisco Bay, and other species, once considered natives, are now suspected immigrants. Only recently we have become aware that several species of copepods, components of the zooplankton of the fresh water reaches of the Delta, are non-native from the Orient.

This report is concerned with two of the most successful introductions of fish in the history of deliberate introduction, the striped bass (Morone saxatilis), the American shad (Alosa sapidissima), and the native species of salmon (Oncorhynchus tshawytscha) that is possibly, in its occurrence so far to the south of its center of maximum distribution, a survivor of a more pluvial era. Now all of these species, especially the striped bass, our prime example of a naturalized species, are in trouble.

This report demonstrates that the population declines in these species are attributable to the changes being made in the estuarine system (and in the case of the salmon, to reduction of spawning grounds) by the human population, primarily resulting from the diversions of more than 30% of natural runoff (spring and annual) from the Delta system and the rivers. (The magnitude of these diversions is discussed in great detail in Rozengurt et al., 1987.)

The San Francisco Bay is not unique in this environmental alteration; it is occurring in many other estuaries of the world. The scale of change, however, especially in proportion to the entire system, may be greater than in other parts of the world. The basic reason for this greater impact is that the system of bays and river is small (on a worldwide basis), yet we are trying to use its fresh water to produce a mesophysic agricultural environment in a near desert region, where summer drought has been the prevailing factor in the climate. With respect to the fish population of the rivers, this effort is obviously beyond the range of tolerance, and promises, if continued, to have irreversible effects.

CHAPTER 1

INTRODUCTION

Runoff and Estuaries

Riverine-estuarine ecosystems are the parts of the shelf zones of the world's oceans where contact, interaction and interrelation between plants and animals and their environment occur tens to hundreds of times faster than in other areas of land and water. The influence of these changes on physical characteristics and biological productivity of coastal areas of the oceans and inland seas has been recognized by an international community of numerous hydrologists and oceanographers in the Northern and Southern Hemispheres (Pritchard, 1952; Reid, 1961; Hedgpeth, 1962; Ippen, 1966; Almazov, 1962; Lauff, 1967; Ricketts, Calvin and Hedgpeth, 1968; Simonov, 1969; Vendrov, 1970; Rozengurt, 1969, 1974; Schubel and Pritchard, 1972; Cronin, 1975; Officer, 1976; Wiley, 1976, 1977; White, 1977; Begg, 1978; Conomos, 1979; Hamilton and MacDonald, 1980; Olausson and Cato, 1980; Cross and Williams, 1981; Ketchum, 1983; Kennedy, 1982, 1984; Sckreslet, 1986). It is recognized that delta-estuarine ecosystems provide twenty times more food than the open sea (Zenkevich, 1963, Vinogradov, 1967).

Historically, the river inflow-delta outflow repels saltwater intrusion, flushes the natural and human-introduced wastes from the delta water body, and prevents salinization of estuaries (which may be detrimental to waterfowl and to migration, spawning and feeding of fish).

There are 850 estuaries in the U.S.A. whose total surface accounts for almost 10,000,000 hectares (NAS, 1983). From south to north along the Pacific Coast and north to south in the Atlantic Coast, the role of estuarine species in biological productivity and commercial and recreational catch is steadily increasing (Cross and Williams, 1981).

In the Pacific and the Atlantic coastal zones of the U.S.A., almost 15% and 85% of fishery resources, respectively, are composed of species whose life history stage depends upon a healthy estuarine environment (Singer, 1969). In the San Francisco Bay system salmon, striped bass, shad and sturgeon are typical valuable species of fish dependent on estuaries (Skinner, 1962, Moyle, 1976).

In general, 70% of the national landings of commercial fisheries and 65% of the national recreational catch are related to estuarine areas (or 4.4 billion pounds, McHugh, 1976).

In the Gulf of Mexico about 95% of the catch consists of estuarine-dependent stocks, of which shrimp are a large part.

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 national estuarine-adjacent coastal zone areas. The recreational expenditures were over $2 billion and the catch almost 1.6 billion pounds (Rote, 1981).

Any definition of estuaries should consider the origin of the hydrological, chemical and biological characteristics, and their spatio-temporal distribution in various climatological and geographical areas.

However, the one thing estuaries have in common is that their past, present and future environments depend first, upon the amount of fresh water discharged into the estuarine water body and the stochastic nature of runoff variables and second, on the stochastic-periodic nature of water and salt exchange between estuary and sea by runoff, tidal and wind action.

From this point of view, the ecological definition of estuaries may be determined as follows: 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, resulting in the development of specific mixed water masses and, related to them, spatio-temporal distribution of their regime and biochemical characteristics which provide for the unique biological productivity of estuarine organisms.

Thus, the major factor controlling brackish water regimes of estuaries is the volume of fresh and saltwater participating in the exchange between a river and sea. Fresh water, tidal flows, and winds are the moving forces of this exchange, which are responsible for development of specific circulation patterns in and out of estuaries (Hansen and Rattray, 1965, 1966; Fisher et al., 1979).

The interaction between controlling factors and the moving forces of estuarine water masses is responsible for the intensity of advection, mixing and spatio-temporal distribution of estuarine hydrological and biological characteristics--at the optimal levels required for the survival of the specific estuarine biota, regardless of the hydrophysical, geophysical and morphometric differences between estuaries which depend upon their origin.

At the same time, the changes taking place in the river watershed and the adjacent shelf zone also affect the estuarine regime. The distribution of surface, intermediate (transition) and deep layer physical (temperature, density, turbidity, transparency, currents, internal waves, vertical stability, etc.) and chemical (salinity, pH, oxygen, alkalinity, organic and inorganic matter, etc.) characteristics differ from season to season and year to year.

River discharges, tide oscillations and wind affect the vertical and horizontal mixing processes and the water and salt exchange between an estuary and adjacent coastal zone in different ways. These determine the majority of the characteristics of the water masses unique to each estuary.

The river discharges entrain many times the volume of estuarine waters and govern significant variations in mixing and velocity conditions as well as salinity distribution in the four universal transition zones characteristic of the river-delta-estuary-sea ecosystem (Rozengurt, 1964, 1967, 1969, 1974).

The role of the delta zone in the entire estuarine basin cannot be overestimated. Historically, any type of river delta is the heart of a rich, productive ecosystem that has been forming for thousands of years. A delta receives nutrients from upstream and produces, circulates, and processes an additional nutrient increment (about 70%) within its fresh-brackish water body which greatly influences the rich productivity of the estuarine area and the coastal zone (Almazov, 1962; Simonov, 1969).

This mixed estuarine water (one part of fresh water to ten or more parts of mixed waters) is carried away by 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. This is accompanied by a modification of temperature, as well as by many other physical, chemical and biological changes in estuarine regime characteristics (Ketchum, 1951, 1983).

Therefore, it is logical to assume that the kinetic energy of river flow, which overcomes friction, repels and entrains deep salty estuarine water and transports it toward the ocean, is a function of the volume of Delta outflow that as such, its flushing capacity depends on many natural (seasonal runoff fluctuations, estuarine zoning, etc.) and anthropogenic factors (runoff regulation, deepening of shipping channels).

Some distance from the Delta, where inflowing sea water moving upstream on the bottom cancels out the downstream movement of fresh water on the top, a retardation of flows occurs (therefore a "null" zone) which results in development of an "entrapment" zone where the salinity is roughly 2-10 parts per thousand, compared to 34-35 parts per thousand in the ocean. Through a chain of very complicated biophysical, biochemical and hydrological interactions of different water masses, this area entraps, recirculates and produces organic and inorganic matter and serves as the nursery and feeding zone for many species of fish and other living resources. (This is one of the most productive parts, for example, of the upper San Francisco Bay where the high density of opossum shrimp each spring attracts the striped bass which feed on them.) There is much evidence for the importance of this zone in the preservation of biological productivity of the San Francisco Bay, as well of other estuaries the world over. There is no doubt among scientists that the past, present and future of the entrapment zone depends on certain volumes of freshwater discharges.

When there is very strong river outflow (e.g., 1986), the fresh water rushes forth from the Golden Gate Strait and forms a vast zone of fresh or brackish water at the surface out to the Farallon Islands, 5-20 miles in width along the shoreline to the north and south of the Golden Gate. 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 or weeks until the flood recedes. The tidal 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 two processes.

The salt composition of the river water differs sharply from the ocean water composition. Theory states and observation confirms that transformation of river water into sea water follows a hyperbolic law (Almazov, 1962), so that the main qualitative discontinuity takes place in the salinity range 1-2 g/l with mineralization of river water to 0.25 g/l (Khlebovich, 1974).

The chemical conditions of the media--as indicated by pH--change during mixing from values characteristic of river water to the high values of sea water. As deep salt waters with high pH values become involved in the mixing (Simonov, 1969), local extremes of pH, produced by dynamic causes, occur at the surface.

The content of suspended material in the river water is many times higher than that in sea water. Turbidity variation depends on the rate of runoff, sediment load and accumulation of sediment behind the dams, etc. Turbidity is directly proportional to the runoff volume and velocity (Krone, 1979) and decreases nearly exponentially with the distance from the river (Mikhaylov, 1969).

Estuaries have a higher index of photosynthesis than adjacent regions of the sea. The abundance of nutrient salts (thousands of tons) carried out to the sea by river water creates favorable conditions for the development of photosynthetic activity of green algae. The content of phosphate and other nutrient salts decreases with increasing salinity. With a decreasing phosphate content the amplitude of the daily variations of photosynthesis and oxidation processes decrease also.

Vertical and horizontal gradients of hydrochemical characteristics of estuarine waters are minimized under conditions of flow reduction. This type of dynamic behavior of estuarine characteristics and their ability to resist and to adjust to the temporary impact of natural external regime disturbances are based on <u>four major fundamental principles</u>:

1. The stochastic and stochastic-periodic nature of the estuarine environment including, but not limited to, runoff and fluctuations in water and salt balance elements induced by tides and winds,

2. The principle of dynamic equilibrium of water masses and their salt content,

3. The principle of ecological continuity of the river-estuary-sea ecosystem,

4. The principle of biological tolerance of the living resources of estuaries.

The following is a brief, simplified description of these principles:

1. <u>The fluctuations of natural estuarine regime characteristics are random (probabilistic) processes</u>. This statement implies that physical and biological parameters in the river-estuary-sea ecosystem are governed by the stochastic nature of hydrological process from the river side and the stochastic-periodic nature of ocean processes from an adjacent shelf zone. While some of the major oceanographic parameters (salinity, wind and tide induced currents, etc.) of estuarine water are known to be relatively stable under external disturbance for a long period, runoff variables are distinguished by a wide range of fluctuations during an exceptionally short span of time. The abrupt natural runoff decline during some years of one cycle of

wetness might be felt by large estuaries for several years to come.

The impact of runoff on estuarine waters is reflected in the annual and seasonal changes of estuarine regime characteristics. This is not to deny the significance of the wind and tide-induced circulation patterns for the dynamics of estuarine waters, but their variation will not, in the long run, produce essential changes in the hydrochemical and biological characteristics of an estuary.

Reduction of freshwater flow to estuaries due to natural causes or human intervention (such as extensive seasonal and annual water diversions) results in salinization, salt pollution of pre-delta and delta zones, and reduction of brackish nursery areas vital for migration, feeding, spawning and for eggs, larvae and fry survival (Rozengurt, 1971, 1974; Bronfman, 1977, 1985; Volovic, 1986).

It is now recognized that even though the behavior of living and non-living estuarine resources may superficially appear random, the dynamics of their variability are determined largely by fluctuations in runoff patterns. Those, in turn, are characterized by having natural limitations determined by physical and geographic dimensions of the river watershed (Vendrov, 1970, 1979; L'vovich, 1986).

Therefore, despite their stochastic nature, the amplitudes of runoff variables will be determined by the statistical probability of upper and lower limits of the watershed's natural water supply to the river basin. <u>This hydrologic phenomenon is</u> accepted by most water researchers who recognize <u>the fact that</u>

the magnitude and the renewability of the elements of any hydrologic regime of rivers is limited.

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.

This phenomenon 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.

2. The principle of dynamic equilibrium implies that estuarine hydrophysical, hydrochemical, and hydrobiological characteristics adapted over centuries of evolution to the stochastic nature of prevailing ranges of natural runoff fluctuation (e.g., probability of exceedence 25-50-75%) and related variables of salt and water exchange between the estuary and adjacent ocean coastal zone.

This process has contributed to the ability of estuarine organisms to recover from severely depressed population levels caused by extreme natural hydrological conditions which have very low probabilities of occurrence (like 95-99%; e.g., at least once per 20 to 100 years; e.g., drought produced, catastrophic declines in natural runoff leading to salt intrusion and salinization of the Delta-estuary ecosystem, sporadic algal blooms, anoxia, etc.).

Therefore, what makes an estuary an estuary is an adequate seasonal and annual water supply which provides and maintains the optimal conditions for the estuarine environment and its inhabitants.

A variety of investigations on a diversity of species have demonstrated significant relationships between resource abundance and magnitude of freshwater flow in numerous estuaries. An estuary is modified as more freshwater, normally serving to repel the inflow of saltwater from the ocean, is diverted. The resulting increase in salt intrusion will decrease the area of fresh and brackish entrapment zones as the seawater region increases, thus radically altering the resource potential of the entire estuary.

Salt pollution of estuaries has been observed and documented in many different areas where large-scale, artificial disruption of seasonal and annual flow has occurred (Almazov, 1962; Rozengurt, 1967, 1969, 1971, 1974; Rozengurt and Tolmazin, 1971; Aleem, 1972; George, 1972; Bronfman, 1977, 1985; Rozengurt and Haydock, 1981; Rozengurt and Herz, 1981). 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. This increase in vertical stability reduces the efficacy of entraining and mixing strength of freshwater discharges (Tolmazin, 1985).

3. The probabilistic nature of these processes under conditions of unimpaired runoff fluctuations is the foundation of the relative stability and continuity of physical and biological characteristics of estuaries. The same may be said about their

capability to self-adjust within the dominant rate of perennial and seasonal fluctuations.

In this context biological self-adjustment means the ability of estuarine organism populations to rebound from exceptionally low levels resulting from natural hydrological perturbations of estuarine ecosystems (e.g., drought), to near historical levels of productivity.

It should be noted that a catastrophic decline in natural runoff and subsequent salt intrusion are themselves exceptional phenomena, having a very low probability of occurrence under natural (unregulated) conditions. Therefore, whatever natural mechanisms are involved in the intrinsic and extrinsic regulation of diversity and density of estuarine species, natural periodic river outflow fluctuation emerges as the integral characteristic of the health of the estuarine environment, its sanitary conditions and biological productivity.

It therefore appears that the integral characteristics of the health of estuarine environments (biological productivity and pollution assimilative capacity) are determined by the natural periodic fluctuations in river outflow. When the range of natural fluctuation is exceeded, the process of deterioration of deltas and estuaries occurs, as has been documented in the Soviet Union where continuous diversions in excess of 30% and more of spring and annual runoff has destroyed the productivity of the deltas of the Amu-Darya and Syr-Darya (the Aral Sea), and the deltas of the Terek, Sulak, Volga, Ural (Caspian Sea); Don, and Kuban (the Sea of Azov), Dniester and Dnieper (the Black Sea), and the Nile Delta which evidence irreversible damage to habitats and fisheries resources (Rozengurt, 1967; Vinogradov and Tolmazin, 1968; Aleem, 1972; Rozengurt, 1974; Baidin, 1980; Rozengurt, 1983; Meleshkin et al., 1973; Vorovich et al., 1981; Bronfman, 1985; Volovic, 1986; Rozengurt and Hedgpeth, 1987).

4. The principle of tolerance means that at early life stages the living resources of an ecosystem can survive only within limited range of fluctuations (regardless of whether they are natural or regulated) of hydrological and hydrochemical characteristics of estuarine water masses (e.g., salinity, temperature, oxygen concentration, turbidity, circulation patterns, etc.).

In this regard, one of the special characteristics of mixed water masses which separates the estuarine biota into two different habitats is the 5 g/liter salinity concentration barrier (Khlebovich, 1974). Landward from this barrier lies the entrapment zone. The 5% water barrier and its low and high extremes on both sides represent natural boundaries of inner estuarine hydrological and biological hydrofronts. Its location, size and overall ecological coexistence depend mostly upon seasonal fluctuations and annual values of natural runoff and are modified by human activity, i.e., regulated river flow. In a well-mixed type of estuary under normal and above normal runoff conditions, the hydrofront in the upper part may be characterized by modest vertical salinity gradients and very small horizontal salinity gradients. From the biological point of view, this buffer zone type of salt stratification is the most favorable one for optimum growth of endemic and non-endemic species if enough

Successful spawning of semi-anadromous and anadromous fish can take place only if an appropriate volume of water and velocity of seaward flow in the Delta is maintained throughout the crucial 25-40 day (spawning) period (Skinner, 1986; Zenkevich, 1963; GOIN, 1972; Bronfman, 1973, 1977, 1985; Hedgpeth and Rozengurt, 1987).

The smaller the runoff, the less the buffer activities occur beyond the hydrofronts, i.e., inside of an entrapment zone. As a consequence, the size of this mixed buffer water zone becomes reduced. Relative to the magnitude of the decrease in runoff, the boundaries of the zone become increasingly saline and produce a very strong and persistent horizontal salinity gradient.

Under these conditions, even eggs and larvae that are tolerant to a small increase in salinity concentration may find themselves beyond the 5 g/liter critical barrier. In this case, there is insufficient time and space to allow for physiological adaptation to abnormal increases in salinity.

Salinity, as an integral value of dissolved constituents, has immense impact on spawning activities of fish, as well as on osmoregulation, metabolism, growth rate and survival of eggs, larvae and fry.

This was particularly true in the past, when the estuary was a "partially mixed" type, and contained a well-developed salt wedge. After successive dry years and drought, a noticeable transformation of the upper part of the estuary occurred which resulted in a negative impact on fisheries and other biological

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Numerous investigations on a diversity of species have demonstrated significant relationships between abundance of eggs, larvae, fingerlings, etc. and magnitude of freshwater flow and salinity concentration in a variety of different estuaries.

The factors shown to be responsible for damage to estuaries and their resources include:

1. Intensified upstream water withdrawals coupled with water siphoned from the Delta for agricultural uses, and major seasonal redistribution values of flow (White, 1977; Cross and Williams, 1981; Texas Deparment of Water Resources, 1980, 1981, Vorovich et al., 1981).

2. Returning water from agricultural fields saturated with chemicals (Baydin, 1980; Cross and Williams, 1981).

3. Industrial and municipal waste disposal, coinciding with overall reduction of runoff reducing dilution and flushing of polluted, high salinity water out of the estuary (Lauff, 1967; EPA, 1977; Komarov, 1980).

4. The deepening of channels, compounded with upstream irretrievable water withdrawals leading to the spatio-temporal increases in salt intrusion upward to the Delta, the heart of a river system (Orlob, 1977). This produces a negative salt balance exchange between estuary and sea (Hamilton and MacDonald, 1980).

5. Increased rate of the flushing time of estuaries which increases concentrations and exposure times of resident organisms to pollutants (Rozengurt and Tolmazin, 1974; Conomos, 1979; Fisher et al, 1979; Skreslet, 1986).

6. The distortion of spawning routes and zones of migration for anadromous and semi-anadromous species and drastic reduction of commercial and sport fish catch (Chadwick, 1971; Moyle, 1976; Chadwick et al., 1977; Herrgesell, 1981; Herrgesell et al., 1983; Thayer et al., 1983; Stevens et al., 1985).

7. The significant reduction of nutrient supply and overall negative changes in water quality and hydrophysical parameters of fresh and slightly brackish water bodies (Almazov, 1962; Simonov, 1969; Aleem, 1972; GOIN, 1972; Arthur and Ball, 1979; Alausson and Cato, 1980).

8. The migration of new species of biota (and perhaps less valuable ones) into the ecosystem (Hedgpeth, 1975, 1983, 1986; Volovic, 1986; Rozengurt et al., 1987).

Precise evaluation of the different factors, resulting from river impoundment and affecting environmental conditions of riverine-aestuarine ecosystems, is an extremely difficult task due to the dynamic complexity of ecosystems, the lack of special monitoring techniques and the absence of data characterizing the influence of each runoff transformation (natural and regulated).

In this report, we limit our efforts to an analysis of the role of water diversions on the fisheries of the San Francisco Bay ecosystem.

CHAPTER 2

BACKGROUND

Relationship Between Fish Catch and Fresh Water Flow in Estuarine and Coastal Zones

In estuaries which have a mean inflow significantly higher than their total volume, the prevailing fluctuations of mean freshwater supply vary within 25% of normal flow averaged over 50 to 60 years. (Rozengurt et al., 1987b) Hence, if diversions do not exceed the natural deviations from the average flow, the cumulative supply of the watershed may compensate for these water withdrawals. In such a case, the estuarine ecosystem will survive regulated water supply fluctuations because they are within the range of natural conditions. If diversions exceed these natural limits for prolonged periods, there will be little prospect of recovery because the natural but limited resilience of the system will be reduced, and deteriorating conditions will produce serious damage to its resources.

The Delta-San Francisco Bay ecosystem is the largest estuary on the West Coast of the United States. Like all major estuaries throughout the world it once received massive quantities of fresh water from free-flowing streams and rivers and supported rich and diverse living resources.

However, pressures from an ever-expanding human population and its development needs - the urbanization process - have radically modified this once productive ecosystem (Davis, 1981).

Historically, high winter-spring river discharges prevented saltwater intrusion into the Delta through its numerous tributaries. These discharges provided high volume flows for flushing which produced optimal conditions for migration and reproduction of fish, shellfish and waterfowl. Today, largely as a result of massive diversion of river water (up to 85% of total flow during the critical spring season in some years) for irrigation, salmon and striped bass catches and egg production are only 10-20% of what they were as recently as 25-30 years ago. (The reductions in spawning and fish catches may also be compounded by increased pollution levels associated with reduction in flushing action, and increase in the residence time of pollutant accumulations resulting from decreases in freshwater inflow, despite improvements in the treatment of municipal and industrial effluents).

<u>The purpose of this report is to</u>:

1. Document the relationship between freshwater inflow and fish catch for the pre- and post-project periods (CVP and SWP) of runoff discharges to the Delta-Bay ecosystem.

2. Demonstrate that there are threshold and optimal levels of inflow required to maintain the health of this estuary (or any other).

3. Define critical values of inflow which must occur in a specific period of a year to ensure optimal levels of living resource production. Some special recommendations for a threshold level of river discharges necessary to preserve commercial fisheries in the adjacent Bay Area coastal zone and in the river-Delta-San Francisco Bay ecosystem are also discussed.

Flow-Fisheries Relationships in Other Estuaries

A variety of studies have been performed on the relationship between inner inflow and the productivity of estuaries and coastal zones. Sutcliffe (1973) demonstrated the dramatic effects of the Miramichi River flow on the larval stages of lobster. His scatter diagram of the estimated average production of the American lobster (Homarus americanus) larvae (Stage one) in the northern Northumberland Strait plotted against June runoffs of the Little S.W. Miramichi River (1952-1963 "...one of the largest rivers in the general area of the larval sampling") shows almost linear regression ($r=0.95$, $p<0.01$). The result of this investigation led to the conclusion that the greater the discharge during lobster spawning the better the chances of larvae survival. (Fig. 2-1)

The Maryland Department of Natural Resources (cited in Stevens, 1977) found that the mean catch of young striped bass per seine haul in the Potomac River was highly correlated with mean April-May river flow ($r=0.865$ for 1961-1971) but uncorrelated with June-July flow ($r=0.059$).

Sutcliffe (1973) has further demonstrated the role of river inflow in biological productivity and catch in the Gulf of St. Lawrence. He found high positive correlation between monthly St. Lawrence River outflow and the annual catch of American lobster (Homarus americanus) and Atlantic halibut (Hippoglossus hippoglossus) from the Gulf of St. Lawrence with a lag time accounting for a mature age and commercial size. To match annual

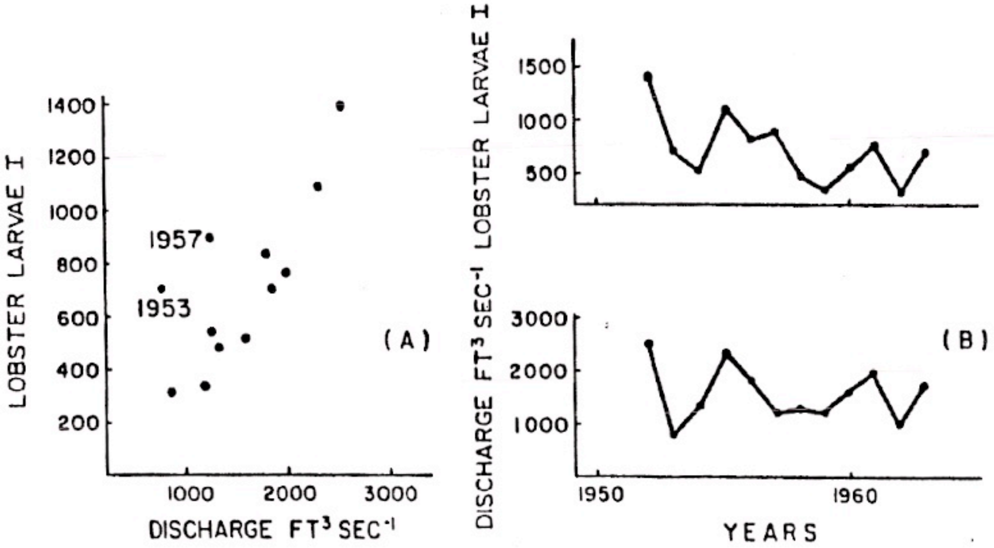

FIG. 2-1 Estimated average production of American lobster (*Homarus americanus*) larvae (I) in a towed area in northern Northumberland Strait, and June discharge of Little S. W. Miramichi River, 1952–63.

(From Sutcliffe Jr., 1973)

lobster catch of Quebec and Prince Edward Island for the period (1939-1970) to runoff, Sutcliffe used April and June river outflow with a lag time of 9 ($r=0.831$) and 8 years ($r=0.853$; $p<0.01$) for both, correspondingly. (Figs. 2-2 through 7)

Copeland (1966) found that fishery stocks in some Texas bays were higher in years when runoff was near or above mean values. A similar relationship was shown by Menzel et al. (1966) for oyster stocks in Apalachicola Bay, Florida.

The choice of these lags was based on the assumption that the cumulative effect of freshwater discharge for several preceding years is the major factor responsible for providing favorable conditions for fish and lobster larvae survival and their successive growth to harvestable sizes.

It is assumed that these correlations reflect an underlying relationship between river inflow and survival of eggs and larvae (strength of year class). It would then appear to follow that the young most affected by those flow conditions are the dominant year class represented in the catch occurring many years later.

Stevens' (1977) analysis of the Sacramento-San Joaquin striped bass party boat catch data and Schaefer's (1972) assessment of East Coast (Long Island Sound and Chesapeake Bay) information on the striped bass commercial catch indicate that the abundance of adults available to the fishery depends largely on survival during early life stages. Data from both coasts indicate that high survival coincides with "moderately high river flows".

There is also information indicating that there is a critical level of seasonal runoff below which biological

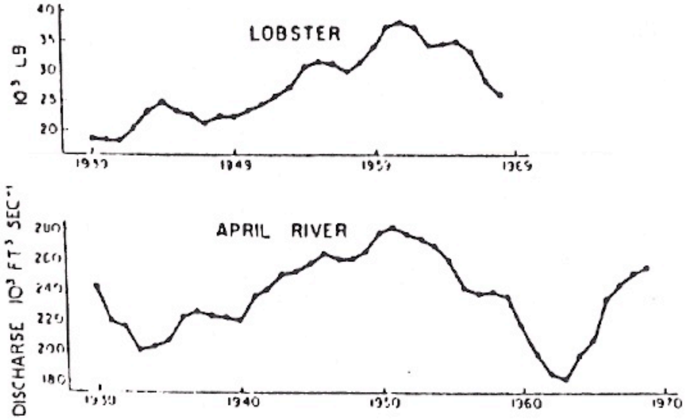

Fig 2–2 Annual lobster landing of Quebec, and April discharge of St. Lawrence River, both 3-year running means, year is first year of triad, $r = .831$, $P < .001$, 9-year lag.

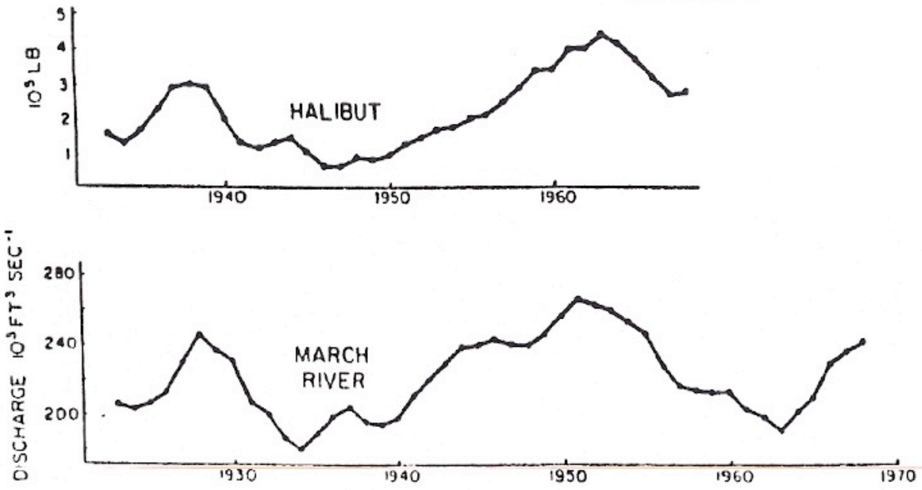

Fig 2–4 Annual halibut catch of Quebec with March discharge of St. Lawrence River, both 3-year running means, year indicated is first year of triad, 10-year lag.

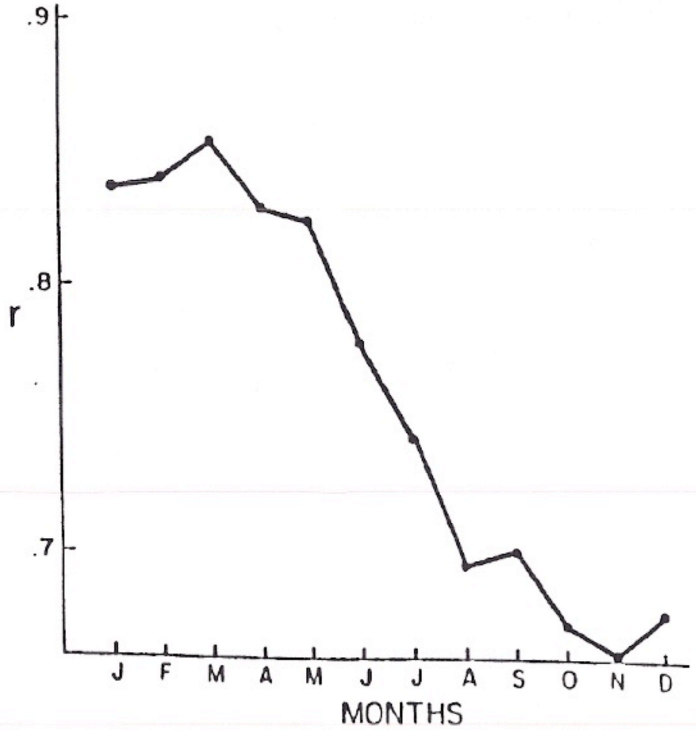

Fig.2-3 Correlation coefficient of annual Atlantic halibut (*Hippoglossus hippoglossus*) catch of Quebec and monthly discharge of St. Lawrence River, both 3-year running means, 10-year lag.

(From Sutcliffe Jr., 1973)

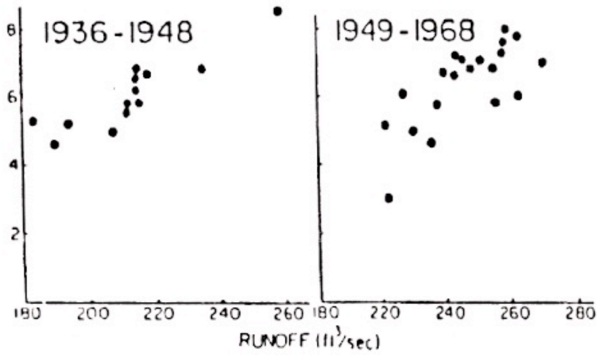

FIG. 2-5 Lobster pack of Quebec (× 10^3 cases) vs discharge St. Lawrence River (× $10^3 ft^3/sec$); 1936–1948 $r = .929$, $P < .001$; 1949–1968 $r = .751$, $P < .001$ no correlation 1929–1935. 6 year slip, 2-year running averages.

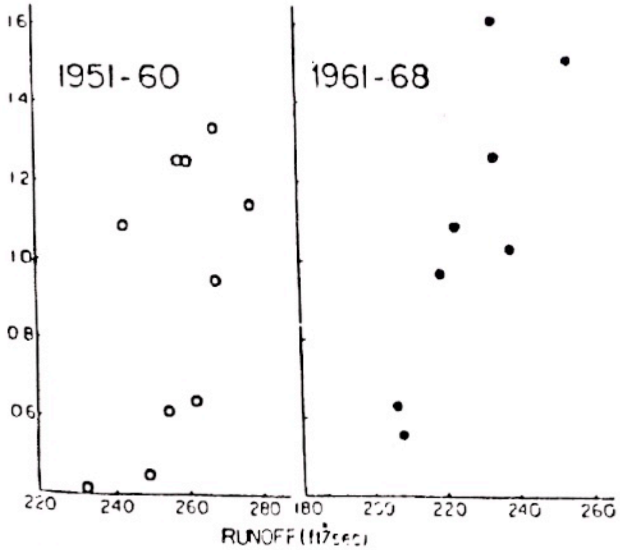

FIG. 2-7 Clam (soft shell) catch of Quebec (× 10^6 lb) vs discharge St. Lawrence River (× $10^3 ft^3/sec$); 1951–1960 $r = .576$, $P < 0.1$; 1961–1968 $r = .853$ $P < .005$. 5 year slip

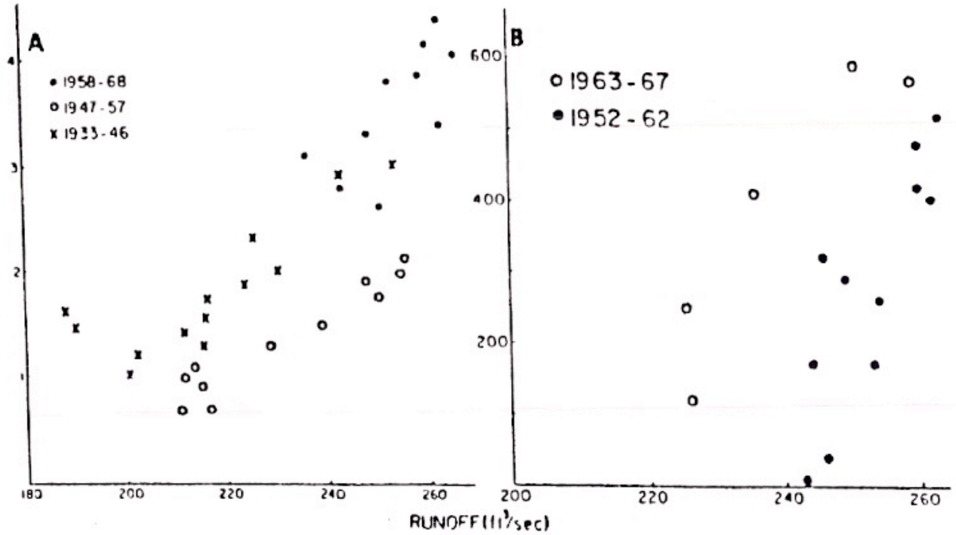

FIG. 2-6 (A), Halibut catch of Quebec (× 10^5 lb) vs discharge St. Lawrence River (× $10^3 ft^3/sec$) 1933–1968 $r = .797$, $P < .001$, 10 year slip, 3-year running averages. (B), Haddock catch of Quebec (× 10^3 lb) vs discharge St. Lawrence River (× $10^3 ft^3/sec$); 1952–1962, $r = .934$, $P = .02$; 1963–1968 $r = .773$, $P = .001$, 8 year slip, 3-year running averages.

(From Sutcliffe Jr., 1972)

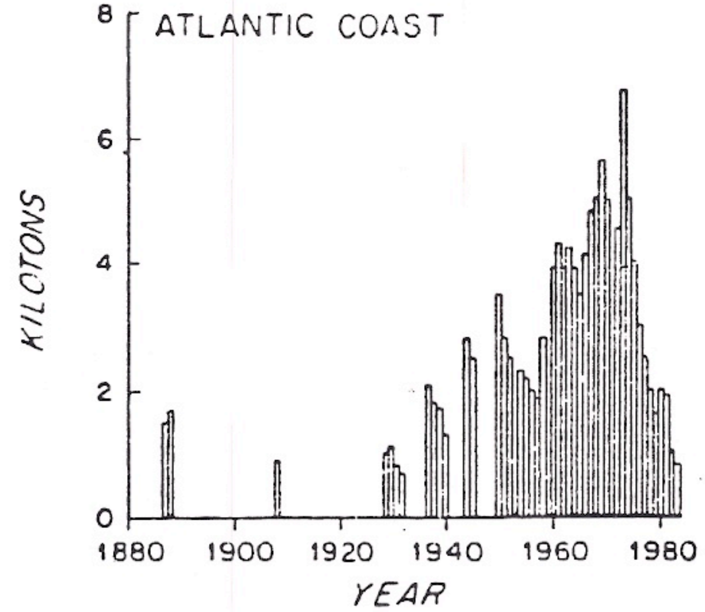

FIGURE 2–~~8~~ *Reported commercial landings of striped bass from Maine to North Carolina, 1887–1983, based on "Fisheries Statistics of the United States."*

(From Borman & Austin, 1985)

resources may begin to decrease or collapse. Reduction of runoff by about 40-85% during the spring spawning time for anadromous fish in the Sea of Azov (Bronfman et al., 1973) and the Caspian Sea (Hedgpeth and Rozengurt, 1987) has been followed by a reduction in valuable fish catch by 90-96%.

Statistical analysis of the dynamics of striped bass egg, larval, juvenile, and adult stages in the Potomac Estuary (which contributes about 20% of the striped bass stock in the Chesapeake Bay ecosystem) and flow discharges, temperature of water, phytoplankton and zooplankton population, etc., led Mihursky et al. (1981) to conclude "...that any significant diminution of springtime freshwater discharge to the estuary would tend to decrease the probability of substantial recruitment success." Although acknowledging that contaminants may be partially responsible for part of the reduction of striped bass harvest, these authors firmly demonstrated that spring flow fluctuation is the major environmental factor regulating (1) the spawning success and the size of area, where spawn takes place; (2) the food supply for larvae at the very critical first stage of growth and (3) the recruitment of adult fish for subsequent years. The same was found for the Sea of Azov (Rozengurt, 1983; Bronfman, 1985; Volovic, 1986).

Austin and Boreman (1985), basing their analysis indices of the annual production of striped bass (Morone saxatilis) young-of-the-year in the Chesapeake Bay (since 1969), Roanoke River-Albemarle Sound region (since 1955), and in the Hudson River, concluded that eggs and juvenile survival depend upon the cumulative effect of ecological conditions in freshwater bodies from North Carolina to Canada where the spawning takes place. (Fig. 2-8) They report the steady decline of juvenile striped bass abundance indices, expressed as percentages in given stock of the maximum value in the series, from 100 (1970) to 5-10 (1982). Commercial landings suffered a corresponding drastic decline (Table 2-1).

Table 2-1

Percent Decline in Striped Bass Commercial Landings Along the Atlantic Coast, 1973-1983. *

	Region	% Decrease
1.	North Carolina	- 80
2.	Chesapeake Bay	- 93
3.	Middle Atlantic Region (NY, NJ, DE)	- 89
4.	New England Region (MN to CT)	- 79
5.	The Atlantic Coast	- 82

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* (Compiled from Austin and Boreman, 1985)

This decline in commercial fishing has been attributed to overall reduction of juvenile production in Chesapeake Bay, which contributes 90% of the stock for the fishery in Atlantic Coastal waters, 2-5 years earlier. (Kumar and Van Winkle, 1978; Berggen and Lieberman, 1978).

The cumulative nature of the interrelation between physical (e.g., flow) and ecological characteristics of estuaries provides strong support for the notion that any attempts to relate major elements of primary and secondary productivity and fishery success in estuaries on a year-to-year or a seasonal basis may fail to work. The latter can be seen from the attempt to use the striped bass juvenile abundance Index as a tool to predict subsequent recruitment and commercial landings in some estuarine areas of the Atlantic and Pacific of the U.S.A. in the given year.

The juvenile abundance Index for the young-of-the-year striped bass (Morone saxatilis) was introduced by the Maryland Department of Natural Resources in 1954 to predict subsequent landings. The values of the juvenile Index were obtained by averaging the striped bass young-of-the-year caught on some stations in four major spawning areas during summer in the Chesapeake Bay.

However, the statistical re-evaluation of these data undertaken by Goodyear (1985) showed that one single prior year's estimate of juvenile abundance did not predict adequately the landings in any given year. This is because recruitment into the stock and harvesting in any one year are characterized by cumulative values of fish matured during the years prior to the catch. Goodyear (1985) found for the period 1959-1983 that in Maryland waters of Chesapeake Bay the juvenile abundance Indices might predict the striped bass landings with high efficiency if the lag time between them ranged from 3-5 years.

In the case of the striped bass juvenile abundance Index for the San Francisco Bay since 1959 (Turner and Chadwick, 1972) the presumption has been based on there being a relationship between the Index for the Delta and Suisun Bay versus mean regulated Delta outflow to the Bay and the amount of water diverted from the Delta for the period of May and June in a given year.

Stevens (1977) found that this assumed relationship was an artificial one. As a result, the relative deviation between observed and predicted juvenile Index ranged between -40 and -80% (1978-1984) and reached almost -90% in 1985.

More to the point, this questionable relationship has led to a series of erroneous recommendations about permissible levels of spring and annual water diversions on which water management practice in the Sacramento-San Joaquin River watershed has been based since the late 1960's.

Various studies have shown that there is a critical level of seasonal runoff below which the biological resources and productive biomass may experience declines in production, leading inevitably to the elimination of some fish and shellfish from the estuarine and coastal fishery. Such examples can be seen from available fish statistics for coastal zones of northern Africa, the western part of the Black Sea, the Sea of Azov, and the Caspian Sea.

Before the Aswan Dam on the Nile River started to impound between 50-80% of the annual volume of flood waters (about 35 km^3, mid-August to December), the fisheries of the coastal zone of the Eastern Mediterranean and some of the brackish lakes of the Nile Delta produced about 120,000 tons of fish per year (Aleem, 1972). The annual landings of pelagic fish such as <u>Sardinella</u> ranged between 10,000 and 20,000 tons; and for demersal fish, the catch was about 29,000 tons. Such production reflected the highly successful primary biological productivity which depended heavily upon river-borne detritus and dissolved organic materials (as was the case in the Black Sea and Sea of Azov shelf areas before major impoundments and diversions).

However, since 1965 (the first year of the operation of the Aswan Dam), there has been a 96.4% decrease in the catch of Mediterranean Sardinella (Aleem, 1972). In the shallow shelf zone of the Black Sea and Sea of Azov basins, the decrease in valuable commercial fish catch has been 92-95%. In the San Francisco Bay region striped bass and salmon sport catch decreased 90 and 80%, respectively.

In the Delta-Bay system, where annual freshwater flows have been reduced as much as 35-55% (Rozengurt and Haydock, 1981; Rozengurt et al., 1987a), fish populations have declined radically: the striped bass population is down to 20% and egg production is at 10% of levels of the 1960s (Striped Bass Working Group, 1982); salmon (Chinook) population has declined to 30% (Kjelson et al., 1982).

The Sea of Azov provides one more comparative example of the impact of water withdrawals on the physical and biological characteristics of its water body.

In the enormous literature produced in the Soviet Union since the 1920s, the Sea of Azov is cited as the most productive low-salinity region in the world. According to Zenkevich (1963, p. 465) the total fish catch was 80 kg/hectar "in some years" with an average annual fish harvest of 100,000-300,000 tons. The case history of the Sea of Azov is strong evidence in support of the concept that freshwater inflow (from two main rivers, the Don and Kuban) plays a major role in maintaining the biological productivity of the Sea and its estuarine system (Goin, 1972; Bronfman, 1977; Komarov, 1980).

In 1980 these problems were examined by the National Symposium on Freshwater Inflow to Estuaries in San Antonio, Texas. The more than 400 estuarine experts in attendance concluded:

> Published results regarding water development in rivers entering the Azov, Caspian, Black and Mediterranean Seas in europe and asia all point to the conclusion that no more than 25 to 30 percent of the historical river flow can be diverted without disastrous ecological consequences to the receiving estuary. Comparable studies on six estuaries by the Texas Water Resources Department showed that a 32 percent depletion of natural freshwater inflow to estuaries was the average maximum percentage that could be permitted if subsistence levels of nutrient transport, habitat maintenance, and salinity control were to be maintained. (Clark, 1981, page 524)

Unprecedented changes in ecological conditions have appeared 5-7 years after a period of 10-15 years of relatively stabilized seasonal redistributions of flow patterns and increasing diversion of 30-60% of the mean historical spring and annual water supply. This reduction in runoff has resulted in increased salt intrusion from the Black Sea into its major estuaries and the Sea of Azov and the consequent salinization of their water bodies, leading to radical declines in the both economic and recreational development since the 1970s.

In this report we will limit our discussion to three anadromous species inhabiting the River-Delta-Bay Ecosystem: striped bass, King or Chinook salmon and American shad. Although these three species differ in taxonomy, their life cycles in the estuarine environment and their interrelation with runoff show many similarities: 1) They are seasonal migrants; 2) Their migration and spawning success depends upon quantity and quality of freshwater discharge; 3) They migrate in schools; 4) Their nursery grounds appear to be related.

For our studies we choose runoff as the indicator for two main reasons: 1) The spatial-temporal distribution of major estuarine characteristics and prognosis of their behavior require consideration of runoff as the primary variable of estuarine environment; 2) Runoff modification and reduction are considered to be the major present and future problems for the preservation of estuarine ecosystems.

The intermediate links of complex systems of river-estuary-sea types react most keenly upon quantitative and qualitative changes of water balance caused by intensifying agricultural, industrial, and municipal water consumption (EPA, 1977). Water policy decisions have often been based upon the demands of water users who disregard the natural limits of freshwater sources, thus creating irreversible damage to previously healthy ecosystems.

Description of the Central Valley and State Water Projects

The State of California consists of approximately 158,000 square miles, equal to three times the size of England or New York State.

Northern California streams carry more than two-thirds of the state's available supply of water: twenty-five major rivers and five hundred large streams which are fed by rain during winter and melting snow from late spring through fall.

At the same time, about two-thirds of the state's present demands for water originate in the southern part of the state (San Joaquin Valley and that portion of the state south of the Tehachapi Mountains), and also south of the Sacramento-San Joaquin Delta near Stockton. To satisfy this demand for water, the Central Valley and the State Water Project systems were completed during 1944-1971.

The principal elements of the present system are the Trinity River system, the Sacramento River system, the Feather River system, the American River system and the San Joaquin River system. The Owens Valley system, the Hetch-Hetchy system, and the two Colorado River systems are major components of the state's total water resources development. (Figs. 2-9 through 2-12)

Central Valley Project

In 1927-30 the State of California defined a comprehensive statewide water development program. (The description of projects had been compiled from Hall and Dracup, 1970; Gilbert et al., 1977; Dennis, 1981.) A basic feature of the program was the

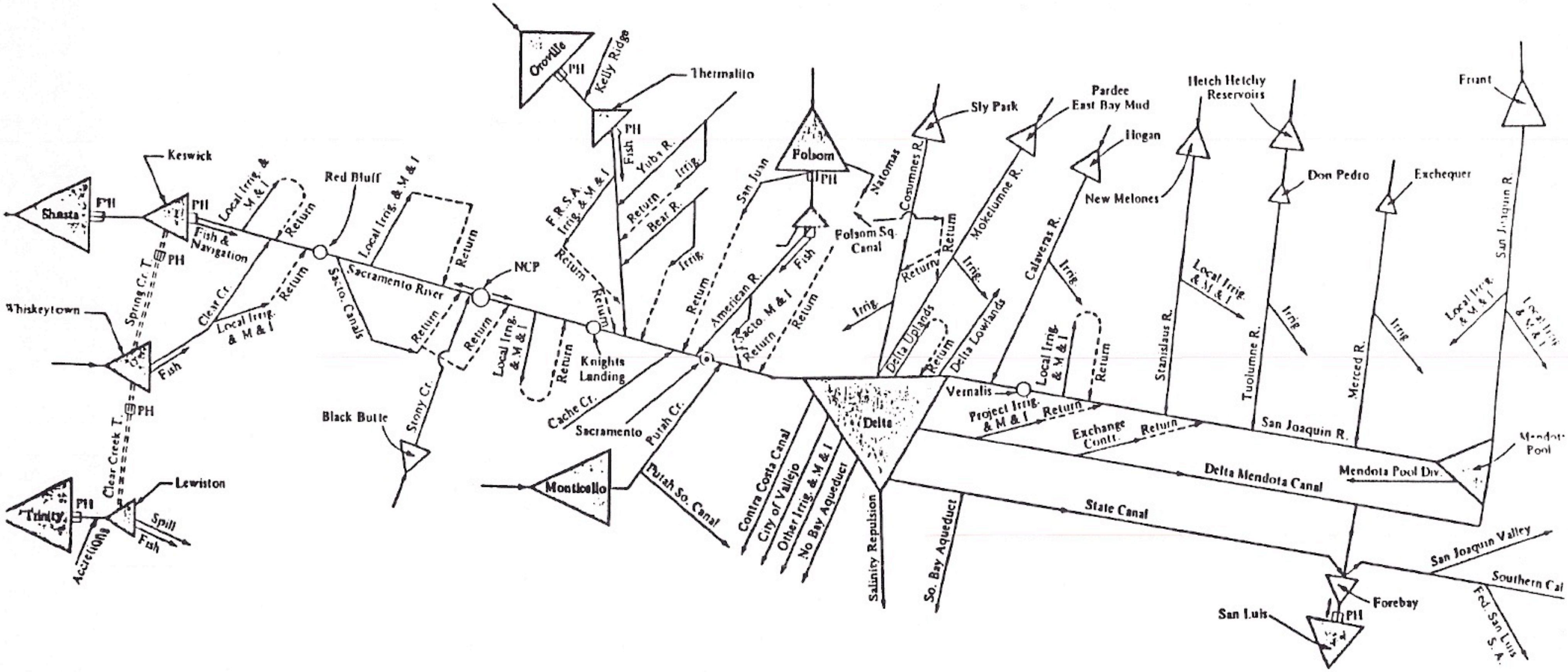


Fig. 2-9 . Schematic diagram for combined federal-state operation studies (modified after Hall and Dracup, 1970)

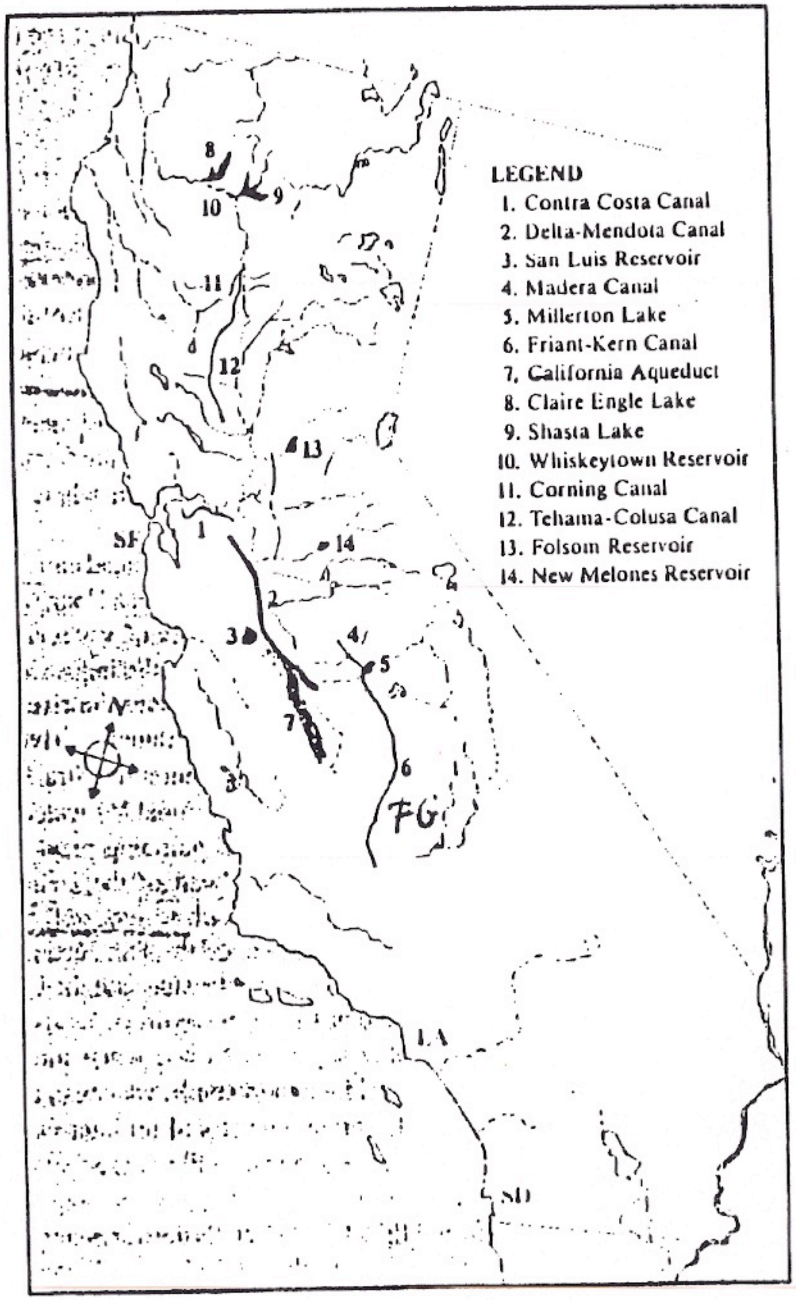


Fig. 2-10 Central Valley Project

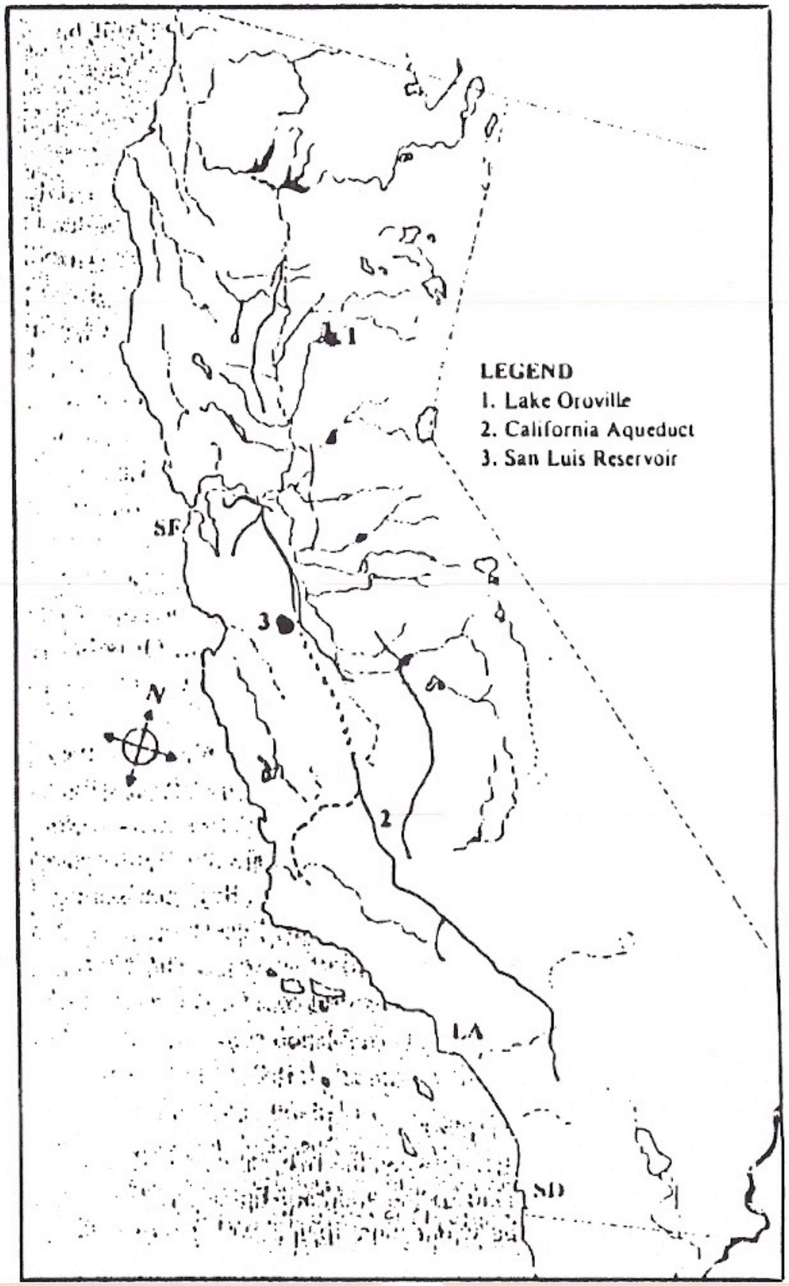


Fig. 2-11 State Water Project

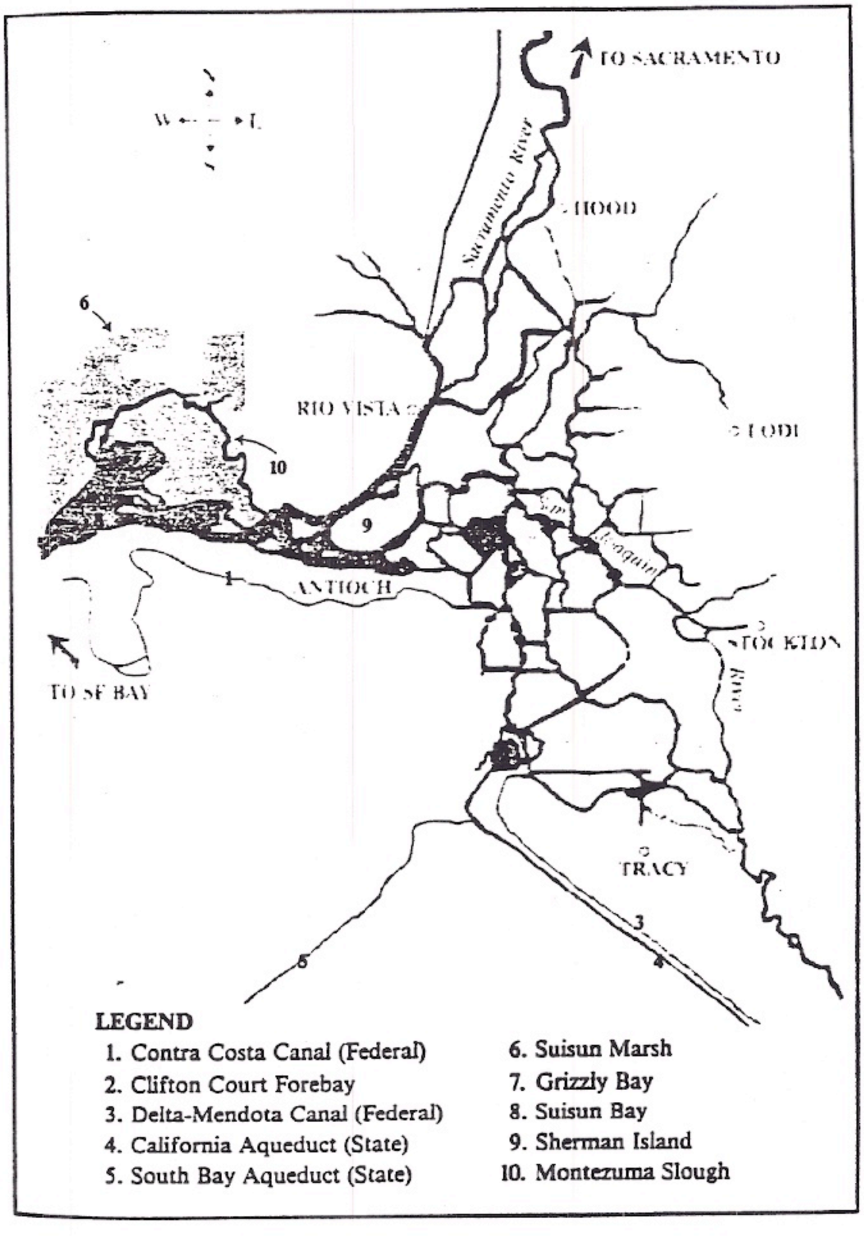


Fig. 2-12 The Delta. (taken from Dennis, 1981)

Central Valley Project (authorized by the Federal Government in 1935 and assigned to the U.S. Bureau of Reclamation in 1937).

<u>The Central Valley Project (CVP)</u>, constructed and operated by the Bureau of Reclamation, is a multi-purpose development designed to supply water for irrigation, municipal, industrial, and other uses; improve navigation of the Sacramento River; provide adequate flows to maintain suitable water quality in the Sacramento-San Joaquin Delta; control floods in the Central Valley; and to produce hydroelectric energy.

The service area encompasses twenty-eight counties and is about 400 miles long and 45 miles wide.

The main elements of the Central Valley Project are Shasta Dam, Friant Dam Folsom Dam, Trinity Project, the Delta-Mendota Canal, and San Luis Reservoir (Figs. 2 & 3). The latter is also an element of the State Water Project.

1. <u>Shasta Dam</u> (1945) is the major unit of the CVP, storing headwaters of the Sacramento River (Table 2-2). Releases from this reservoir pass through hydroelectric plants at Shasta Dam and Keswick Dam. Keswick Dam and Power Plant, nine miles downstream from Shasta, has a fish elevator which salvages upstream migrating salmon and trout before they reach Shasta Dam. Keswick Reservoir is augmented by additional water brought through the Spring Creek Tunnel from the Trinity River.

Releases from this sub-system flow down the Sacramento River to the Delta. From the Delta, this water, as well as water from Folsom Dam and the Trinity Project, is pumped to the Delta-Mendota Canal for use on the west side of the San Joaquin Valley or for storage in San Luis Reservoir.

2. Friant Dam on the San Joaquin River and the Madera and Friant-Kern Canals supply lands on the east side of the San Joaquin Valley in Madera, Fresno, Tulare, and Kern Counties. These diversions from the San Joaquin River are partly replaced by Sacramento River waters at Mendota Pool to supply certain former users of San Joaquin River flows under an exchange contract.

3. Folsom and Nimbus Dams on the American River provide storage for irrigation and flood protection for the Sacramento area, and also send surplus waters to the Delta for transportation southward. Power plants at Folsom Dam and at Nimbus Dam (Lake Natoma) downstream furnish additional power for the Central Valley Project system.

4. The Trinity Project (1964) consists of Trinity (Clair Engle Lake), Lewiston and Whiskeytown Reservoirs, four power plants, and two tunnels. This project is a series of interconnected features which divert Trinity River water into Keswick Reservoir on the Sacramento River for use in the Central Valley Project. Power generated at the hydroelectric plants feeds into the Central Valley Project transmission lines.

5. The Delta Cross Channel, thirty miles south of Sacramento, helps to provide for the regulated passage of Sacramento River water through the Delta channels to the pumping plants of the Delta-Mendota Canal and Contra Costa Canal.

6. The Federal pumping plant at Tracy, on the south side of the Delta, lifts water out of the Delta to the head of the Delta-Mendota Canal, which carries as much as three million acre-feet of water down the western edge of the San Joaquin each year.

7. The Delta-Mendota Canal delivers water 117 miles south to the San Joaquin River where it replaces the natural flows of the river. These replacement flows are also diverted for irrigation so that only a small percentage of the original San Joaquin River flows are stored by Friant Dam and Reservoir in the Sierra Nevada foothills northeast of Fresno, from which water is distributed to the north and south by the Madera and Friant-Kern Canals.

8. The Federal Modesto and Friant-Kern Canals deliver water to farmers along the south and east edges of the San Joaquin Valley. The Friant-Kern Canal carries water south about 150 miles to near Bakersfield. The Madera Canal carries water about 30 miles northwest.

9. The San Felipe Canal delivers water to farms and homes in the Santa Clara Valley, south of San Francisco Bay, from San Luis Reservoir.

10. New Melones Dam on the Stanislaus River (CVP).

11. On the west side of the Delta, Contra Costa Canal carries water from the Delta to the highly-industrialized areas along the nearby Carquinez Straits. When large amounts of water are flowing out of the Delta to San Francisco Bay, the industries that line the Straits draw their water directly from the river. During the summer and fall, though, the Sacramento River slackens, allowing saltwater from the Bay to enter the Straits. The industries then turn to the Contra Costa Canal for water.

12. The Contra Costa Canal extends 48 miles from the Delta.

13. San Luis Dam and Reservoir and its associated pumping, generating, and storage facilities are joint-use facilities of both the Federal Central Valley Project and the State Water Project. Water diverted from the Delta is pumped into San Luis Reservoir (60 miles south of the Delta) during the winter and early spring for release to service areas during the summer and fall.

State Water Project

In 1957, the Department of Water Resources submitted the California Water Plan to the state Legislature.

In accordance with this plan, the Legislature in 1959 passed the Burns-Porter Act of the State Water Project, part of the State Water Plan. The SWP, as the CVP, is a multi-purpose development for firming local water supplies, providing flood protection in the Feather River area, generating hydroelectric power, and exporting surplus waters available in the Sacramento-San Joaquin Delta to areas of deficiency in the San Joaquin Valley, San Francisco Bay area, and Southern California.

The basic elements of this project are Lake Oroville Dam on the Feather River, the California Aqueduct, and San Luis Reservoir. (Fig. 4, Table 2-3) The inflow of water into Lake Oroville is partially regulated by three small completed reservoirs in Plumas County.

Water is released from Lake Oroville to an underground hydroelectric power plant. A short distance downstream, a series of smaller dams and reservoirs store water for the pump-storage operation, and regulate the releases into the Feather River.

1. A power plant at Oroville Dam operates in conjunction with an offstream plant downstream at Thermalito. The hydroelectric plants at Oroville and Thermalito have the ability to reverse their action and pump water that has been previously released back into the Oroville reservoir. During hours of peak demand the plants generate power and during off-peak demand (when power can be purchased at a low rate) the plants pump water back into Oroville reservoir, where it is stored and then re-released during the next period of peak demand.

Water released from the Oroville complex flows down the Feather River into the Sacramento River and then into the network channels of the Sacramento-San Joaquin Delta.

2. Near the northern edge of the Delta, North Bay Aqueduct delivers water to Napa and Solano Counties. Interim facilities in operation at present by the State serve some supplemental water to Napa county with water made available by the U.S. Bureau of Reclamation's Solano Project.

3. At the southern edge of the Delta, water is lifted 244 feet by the Delta Pumping Plant into the California Aqueduct and into the Delta-Mendota Canal, if excess capacity is available in the Delta-Mendota Canal after diversions of Central Valley Project water.

4. The 444-mile long California Aqueduct is the principal water transportation facility of the overall project which now includes twenty dams and reservoirs, five power plants, and seventeen pumping plants, as well as an additional one hundred miles of branch aqueducts.

5. The south aqueduct branches off the California Aqueduct at this point and delivers water as far west as San Jose.

Water is conveyed by the California Aqueduct to the San Joaquin Valley and southern California. Additional storage is provided by the Federal-State San Luis Reservoir west of Los Banos.

6. The San Luis unit consists of San Luis Reservoir, two pumping-generating plants, and a forebay for the main plant. This facility is utilized jointly by the U.S. Bureau of Reclamation as an extension of the Central Valley Project and by the California Department of Water Resources as a basic unit of the State Water Project. The San Luis Reservoir provides storage for excess water which is pumped through the California Aqueduct and the Delta-Mendota Canal during the winter and spring months and released during the summer months. The complex will also operate as a pump-storage power-generation facility.

South of San Luis Reservoir, the California Aqueduct transports the water southward. The Dos Amigos Pumping Plant raises the water 125 feet, sufficient to provide gravity flow to Buena Vista. As water flows south in the San Joaquin Valley, three more pumping plants raise it an additional 968 feet to the A.D. Edmonston Pumping Plant at the northern base of the Tehachapi Mountains.

The A.D. Edmonston Pumping Plant lifts aqueduct water nearly 2,000 feet up the Tehachapi Mountains to an elevation of 3,165 Feet above sea level. At that elevation, water crosses the mountains through a series of four tunnels connected by siphons, a total of about nine miles in length.

South of the Tehachapi Mountains, the Aqueduct divides. The West Branch, which carries the bulk of the water, passes through Pyramid Reservoir and terminates at Castaic Lake northwest of Los Angeles. The East Branch delivers water to contracting agencies in the Antelope Valley and in 1973 delivered the first water into Lake Perris in Riverside County which is the terminal reservoir of the aqueduct system.

The city of Vallejo exports water from the Delta (Cache Slough) for municipal and industrial use, and transports it in a pipeline to its Fleming Hill water treatment plant. In addition to supplying its citizens, Vallejo sells raw water to the city of Fairfield and Travis Air Force Base and treated water to Mare Island Naval Shipyard.

Water Diversion, Economics and Environment

The multi-purpose Central Valley Project (CVP) provides water supply not only to major water users in the Central valley but also controls floods, produces hydroelectric power, maintains navigational depth on the Sacramento River and, to some extent, water quality in the Sacramento-San Joaquin Delta.

The State Water Project (SWP) started delivering water in 1957 to 31 service agencies, which include one quarter of California's arid land and more than two thirds of the state's population. Its main construction is the Oroville Dam and some other facilities which transfer water from the northern reaches of the Upper Feather River as far south as San Diego, covering almost 600 miles. The first phase of the SWP was completed by 1973 and yields about 2.3 MAF/year.

Water supply has a direct effect on the following major areas of economic and human resources (Smith, 1979):

1. Agriculture and food
2. Employment, population and economic growth of regions
3. Sanitary conditions and recreational use of water bodies
4. Fisheries and wildlife
5. Storage, hydroelectric power stations, including flood control facilities
6. Strategic branches of the national economy: oil refineries, electronic and metallurgic production, chemical manufacturing, drinking water supply and conveyance facilities.

Water supply has an indirect effect on:

1. Birth rate and population growth
2. Immigration and character of the work force (agricultural or industrial workers, engineers or scientists, and other human resources). The current population growth in Southern California accounts for 100,000 per year.

California uses 15.0 MAF of ground water per year (40% of the state water needs). California water facilities generate about 32.0 x 10^{12} kwh (1/5 of the total state needs).

Flood prevention measures saved $339 million (1950-1974) in the Central Valley.

In 1950, California's total water needs were 21.1 MAF; in 1979, 34 MAF; by 2000 they are projected to be 41 MAF.

of the upper Sacramento River watershed, have been dammed. Nearly 1,300 dams have been built on 21,000 miles of fresh waterways (Collins, 1982).

In the Central Valley alone, 5,700 out of the 6,000 miles of nursery grounds for salmon that existed as recently as 1900 are no longer available for spawning due to dams and other water distribution systems. As a result, in some areas, like the San Joaquin River, the salmon population has declined more than 40 times from its historical level of 300,000.

The striped bass, shad and Dungeness crab have experienced almost the same level of decline. Since 1957 up to 1986, losses sustained by the recreational fishery account for 1.5 billion dollars. (Meyer, 1985)

The commercial fishery in the Bay has ceased to exist since 1957 and future recreational fishery and other resources, as well as the water quality of the Delta-San Francisco Bay ecosystem and commercial fishery in the adjacent coastal zone, are in question.

Table 2-2 Central Valley Project Storage Facilities

Storage Reservoir	Stream	Capacity (1,000 acre-feet)	First Year of Operation
Shasta Lane	Sacramento River	4,552	1944
Clair Engle Lake	Trinity River	2,448	1960
Lewiston Lake	Trinity River	15	1963
Whiskeytown Lake	Clear Creek	241	1963
Spring Creek Debris	Spring Creek	6	1963
Keswick	Sacramento River	24	1948
Red Bluff Diversion	Sacramento River	4	1966
Black Butte	Stony Creek	160	1963
Jenkinson Lake	Cosumnes River	41	1955
Folsom Lake	American River	1,010	1955
Lake Natoma (Nimbus)	American River	9	1955
Contra Loma	unnamed stream	2	1963
San Luis*	offstream	2,039	1967
O'Neill*	offstream	28	1966
Los Banos*	Los Banos Creek	17	1966
Little Panoche	Little Panoche Creek	7	1966
Millerton Lake	San Joaquin River	520	1944
Auburn	American River	2,326	--
New Melones	Stanislaus River	2,400	1981

*Joint use facilities with State Water Project

Source: Department of Water Resources Bulletin No. 160-74; Gilbert & Assoc., 1977.

Table 2-3 State Water Project Major Storage Facilities

Storage Reservoir	Stream	Capacity (1,000 acre-feet)	First Year of Operation
Frenchman Lake	Feather River	55	1968
Antelope Lane	Feather River	23	1968
Lake Davis	Feather River	84	1968
Abbey Bridge	Feather River	45	1984
Dixie Refuge	Feather River	16	1984
Lake Oroville	Feather River	3,538	1968
Thermalito Diversion	Feather River	13	1968
Thermalito Forebay	Feather River	12	1968
Thermalito Afterbay	Feather River	57	1968
Clifton Court Forebay	Old River	29	1968
San Luis*	offstream	2,039	1967
O'Neill*	offstream	28	1966
Los Banos*	Los Banos Creek	17	1966
Little Panoche*	Little Panoche Creek	7	1966

*Joint use facilities with Central Valley Project

Source: Department of Water Resources Bulletin No. 132-74, Gilbert & Assoc., 1977.

CHAPTER 3

HYDROLOGIC CONDITIONS BEFORE AND AFTER THE CENTRAL VALLEY AND STATE WATER PROJECTS OPERATION

Dynamics of Wetness and Regulated Annual and Seasonal Runoff Fluctuations (5-year Running Periods)

The analysis and comparison of long-term variables of monthly and annual unimpaired runoff (Rozengurt, et al, 1987) provided us with the following information on the dynamics of changes in water supply to the system brought about by human activities before and after CVP and SWP operations.

We consider that controlled discharges and cumulative water losses sustained by the Sacramento-San Joaquin River basin since 1944 have played the major role in transforming the riverine-estuarine system from the category of relatively moderate water supply to one of predominantly subnormal annual and lower than subnormal spring water supply.

As a result, annual and seasonal regulated river inflow/Delta outflow patterns and their statistical parameters have been subjected to such significant alterations that we are dealing with a new, artificially managed river watershed and water statistics.

In connection with the latter, it should be noted that our probablity estimates for residual annual and monthly river discharges to the Delta and the Bay (e.g., how often a given volume of regulated runoff would have occurred under conditions of unimpaired flow) are based on unimpaired total Sacramento-San

Joaquin River flow statistics and their frequency curves (Rozengurt et al. 1998a).

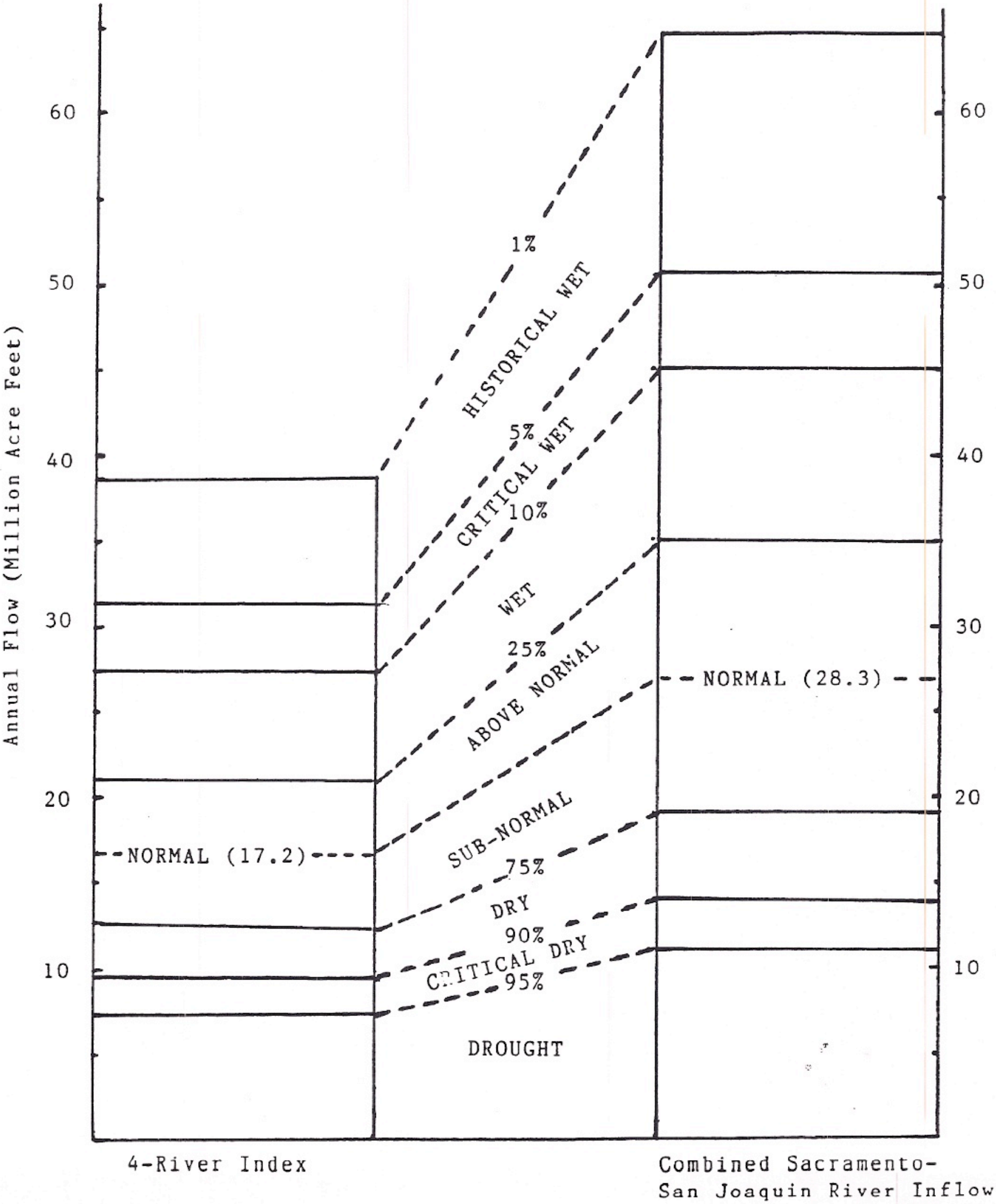
In other words, our statistics such as historical wet, critically wet, wet, etc. (Fig. 3-1) characterize the combined river discharges from all areas of the Sacramento-San Joaquin River watershed (100%), opposed to runoff statistics utilized by the DWR but only from 75% of the area of the watershed (Four River Index).

As can be seen from Fig. 3-1, the differences in absolute values of runoffs for the same categories of wetness are not only significant, but their use in estimates of water available for diversions and determination of category of wetness of residual inflow to the Delta Bay ecosystem may give rather different results.

For example, under the Four River Index water year-type classification system, regulated annual inflow in the range of 17.3-20.0 MAF will correspond to the conditions of above normal wetness. However, if the classification system is based on combined Sacramento-San Joaquin River Inflow, the same discharges will correspond to subnormal and even lower than subnormal wetness (Fig. 3-1).

This illustrates how the Four River Index Water year-type classification system, on which D-1485 is based, biases potential decision-making by classifying dry years as normal or wet, thereby minimizing the significance of alarming low outflows to the Bay over the last decade, and promoting an erroneous conclusion about the existence of water surpluses when there are none.

Fig. 3-1
Comparison of Combined Sacramento-San Joaquin River Inflow and 4-River Index Water Year-Type Classification Systems. (% = probability of occurence)



Therefore, in this report, as the previous one, (Rozengurt et al., 1987a) we use the Combined Sacramento-San Joaquin River Inflow year-type classification in determinations of the probability of occurrence of various values of regulated seasonal and annual runoff.

We consider it imperative for the SWRCB and other resource agencies to re-evaluate the use of the Four River Index.

1. Under would-be unimpaired runoff almost 90% of the 5-year means of natural river inflow (NRI_5) and Delta outflow (NDO_5) to the San Francisco Bay have varied within 30% of their normals (NRI = 28.2 MAF and NDO = 27.2 MAF for the period of 1921-1978), except for the critically dry years of the late 1920's (pre-project period).

2. However, due to water diversions, especially since the start of operation of major water facilities of the CVP (1944) and SWP (1955) the natural water supply of any of the 5-year periods have been reduced to the levels below those normally observed for unimpaired flows.

3. As a result of these changes, the 5-year mean residual water supply to the Delta (Regulated River Inflow, RRI_5) and to the Bay (Regulated Delta Outflow, RDO_5) have been transformed from predominant categories of wetness, which might be considered as favorable for the preservation of living resources of the Delta-Bay ecosystem (25-50-75% probabilities of exceedence), to the current prevailing unfavorable categories of wetness (e.g., subnormal and lower than subnormal; 75-99% of probabilities of exceedenceif the natural river annual and monthly discharges are

used as the basic for a statistic analysis). In otherwords, the rare events, like years of subnormal wetness of unimpaired runoffs, have become almost permanent features of the regulated runoff.

4. The practical implication of this runoff alteration can be seen from comparison of relative deviations of natural and regulated water supply to the Delta-Bay ecosystem from their normals:

a. While the deviations of the annual RRI_5 and RDO_5 from their normals (28.3 and 27.1 MAF, respectively) fluctuate within the range of -35% to -65%, the deviations of natural water supply, i.e. NRI_5 and NDO_5, fluctuate around +/-15-25% (Rozengurt et al., 1987a).

b. While the deviations of the spring RRI_5 and RDO_5 from their normals (NRI = 3.72 MAF and NDO=3.53 MAF, respectively) fluctuate between -40% and 85%, NRI_5 and NDO_5 around +/- 15-25%. (Fig. 6-11)

Because winter (rainy season) and spring (snow melt and rain) produce almost 90% of annual runoff, the transformation of their water supply, especially spring discharges, play the major role in the total reduction of runoff as well as in alterations of categories of seasonal wetness.

5. Winter water withdrawals for the recharging of major federal and state reservoirs (located in the Sacramento-San Joaquin River watershed) reduced the number of the 5-year period of high and normal wetness and signficantly increased the number of subnormal wetness (especially for March).

However, for the spring months, when an additional recharging of storage facilities and conveyance of water to the South both operate simultaneously, the resulting increases of dry over wet and normal periods have posed greater threats to fisheries and other water uses.

As a result of diversions of up to 2/3 of the spring runoff, the number of periods of subnormal and lower than subnormal wetness (1-2 MAF of regulated monthly discharges compared to prevailing natural flow of 3-5 MAF) increased for April and May 8-10 and 4-5 times, respectively, and 2-3 times for June (runoff less than 1.0 MAF).

6. At the same time (i.e. since 1944) a new, modified spring water supply was observed, namely, the appearance of persistent consecutive critical dry periods (critical dry periods of wetness = when RRI_5 and RDO_5 are 50% or more below their normals).

These altered values of spring RRI_5 and RDO_5 resulted in an increase from no dry periods (in the case of natural runoff) up to 8-13 (April), to 23-27 (May), and 23-33 (June) periods of very low discharge for regulated runoff.

Moreover, since the early 1970's, wet periods have diminished considerably (for May and June).

It must be emphasized that upstream, downstream and total water regulations superimposed on natural fluctuations in wetness have led not only to significant increase in the numbers of periods of subnormal and critical low wetness but also resulted in a gradual reduction in annual and seasonal water supply to alarming levels which would have not been observed for unimpaired runoff fluctuations for 5-year periods since 1912.

Analysis of the average water withdrawals (per 5 years) underscore two distinctive periods (for more details see Figs. 3-2 through 3-14 and Rozengurt et al., 1987):

1. Pre-project period, 1915-1943
2. Post-project period, 1944-1984.

There are significant differences in water development between these periods:

1. During the pre-project period there were no large water storage and conveyance systems.

2. During the post-project period, CUP & SWP multipurpose reservors (with a capacity of one order of magniture greater capacity than the small, local storage facilities) and 6 pumps (with a capacity for moving 7 MAF per year) were added to the system.

3. The relatively small total water withdrawals of the pre-project period (upstream and Delta) took place mainly during April - June while post-project water withdrawals occured from November to June.

As a result, water withdrawals of the second period exert a much stronger influence on the seasonal redistribution and residual volumes of runoff discharges to the Delta-Bay ecosystem than impoundment of the rivers of the first period.

The effects of this water management are: The average natural water supply to the Delta for 5-year periods was reduced 30% for the winter and 60% for the spring. The extreme high values of spring NRI_5 and NDO_5 were reduced 1.5 to 3 times.

Therefore, residual spring discharges in many instances correspond to lower than subnormal period of wetness.

The result of this runoff transformation is that the water supply during April - June became, in many instances, equal to the low discharges of August-October (artificially increased by polluted runoff from agricultural drainage network in conjunction with small upstream releases).

The extensive seasonal diversion may be blamed for another phenomenon, namely, the annual RRI_5 and RDO_5, (predominant range of 10-15 MAF) has become a permanent new feature of low water supply to the system. In other words, first, these volumes are 1.8-2.8 times less than the unimpaired water supply and second, they correspond to dry or critical dry periods of wetness, the recurrences of which are much higher than it is possible to observe for unimpaired water supply.

4. Since the project operations began, (especially from the late 60's on) the spring regulated water supply to the system was reduced 1.6-2.0 times in comparison with unimpaired spring water supply to the Delta-Bay system for 5-year periods (prevailing water supply pre-project range was equal to 3 - 4 MAF). Therefore, for the period of 1976-1984, residual spring Delta outflow in the majority of cases corresponded to a subnormal and below subnormal wetness when compared with the statistics for unimpaired runoff.

It should be emphasized that under natural conditions such low spring outflow would be considered a very rare event, i.e., probability of exceedence or recurrence interval would be at least once per 15 - 25 years; instead these values of runoff in many cases are currently observed during consecutive 5-year periods.

5. This recent development in spring and annual regulated water discharges (RRI_5 and RDO_5) is abnormal relative to the more stable physical, chemical and biological characteristics of the Delta-Bay ecosystem of relatively low fluctuations of NRI_5 and NDO_5 (from their normals) that existed prior to the influence of human development.

Figures 3-2 through 3-14 illustrate the gradual increase of upstream, downstream and total diversions for the pre- and post-project periods for 5-year intervals.

6. As can be seen, for each month of the 5-year periods, there are significant differences in the volumes of water withdrawn before (1915 - 1943) and after project implementation (1944-84):

a. During the pre-project period withdrawals were not only relatively small but also much lower than for the post-project period, especially for the late winter and spring. (Figs. 3-5 through 3-11)

b. During the pre-project period the total average volumes of diversions of their monthly normal Delta outflow were October(27%) and November(2%), December(20%), January(10%), February(10%), and March(10%). In other words, the diversions were in the range of 0.1 - 0.6 MAF and in some instances small upstream releases were observed.

c. For the same months, during the post-project period, total diversions increased slightly, especially for November, while for October due to returning water discharges from agricultural fields and some storage releases, total water diversions were relatively small.

d. The inner Delta diversions nearly doubled, especially since the late 60's.

In winter (January and March), average upstream and total diversions increased several times for the period 1944-1984, in comparison with the pre-project period.

Average upstream diversions (e.g., monthly mean of 5-year periods) were 0.8 - 1.0 MAF for January, and 0.9 - 2.3 MAF for March. The average total diversions ranged between 0.2 & 1.8 MAF and 0.9 - 2.1 MAF respectively.

For January the upstream average was 24% - 30% of the normal river inflow while the total average was 25 - 51% of normal Delta outflow.

For March, the upstream average was 23 - 64% of the normal NRI, and the total average was 23 - 54% of its normal NDO. Table 3-1,2,3)

It should be emphasized that these strong deviations of extreme average diversions from the monthly normals (e.g., normal means the mean monthly NRI and NDO computed for each month of the base period of 1921-1978) were observed for winter during the second part of post-project period, when the major water facilities of CVP and SWP were completed.

Spring

As expected, the most significant changes took place during spring, especially for April and May. (Figs. 3-9, 10, 11)

7. The post-project upstream and total average diversions increased for April, May and June almost 3 - 4 times; 2.7 and 2.3 times; 2 and 2.5 times, respectively, and the average inner Delta diversions were almost doubled in comparison to their pre-project levels.

These relative values when converted to absolute values account for an average of 6 and 8 MAF diverted during the spring. Meanwhile, the maximum values of diversions per year are 1.2 - 2.5 times higher. (Tables 3-1, 2, 3)

The extreme combined winter and spring water withdrawals from the Sacramento-San Joaquin River system constitute more than 60% of the 5-year average water supply and, compounded by an overall decline in water supply, therefore exert great pressure on migration, spawning and feeding activities of fish as well as on many other regime characteristics (e.g. nutrient flux and sediment load to the system; phyto-, zoo-, and ichtyoplankton; temperature; velocity; oxygen content; salt intrusion to the Delta and intensity of its repulsion; flushing of the ecosystem; etc.).

During the last 20 years, Spring RRI_5 and RDO_5 have been predominantly in the range of 1.5 - 2.5 MAF, which is less than half of the range for unimpaired runoff.

These residual volumes, which became a new feature for the 1968 - 1984 period on an almost continuous basis, correspond to subnormal and even lower than subnormal spring discharges, which under unimpaired conditions, would have occurred only several times per 15 - 35 years.

(It should be pointed out that the same type of development in other parts of the world, namely, the western part of the Black Sea, the Sea of Azov, and the Caspian Sea have resulted in the formidable transformation of the estuarine ecology, irreparable losses in fishery, disruption of freshwater intakes for agricultural and other water uses in the deltas. (Baydin, 1980; Rozengurt and Haydock, 1981; Rozengurt and Herz, 1981; Bronfman and Khlebnikov, 1985; Tolmazin, 1986; Volovic, 1986: Rozengurt and Hedgpeth, 1987).

Fall

In the light of the significant reduction of critical winter and, especially, spring runoff, the relatively small changes (3-3,4, 14) which took place in the late summer-fallwater supply to the Delta-Bay ecosystem may be considered negligible. (In contrast to the pre-project period, there has been no deficit in water supply to the system for the late summer - early fall (September) for the last 20 years as a result of increases in returning water discharges.) The average water increments from drainage networks are one order of magnitude less than water withdrawals during the preceding spring.

In general, the residual volume of RRI_5 is hardly enough to balance the water losses produced by evapotranspiration and local consumption use in the Delta. Moreover, the average 5-year period fall water supply which is of questionable quality comprises only one sixth of the volume of the Delta. Therefore, it is hard to believe that this flow can improve the Delta water quality and freshwater balance or be a positive value for the fall salmon run.

Annual

As previously reported (Rozengurt et al., 1987a) and discussed earlier in this chapter, water diversion in the winter, and especially spring, constitute the major volume of annual diversions. Therefore, the annual role of the gradual increasing trend in seasonal water withdrawals since 1944 may be better described through the dynamics of 5-year average annual volumes of diverted water (Fig. 3-2).

The upstream, downstream (inner Delta withdrawals and export) and total diversions during the post-project period have increased sharply to levels never observed in the Sacramento - San Joaquin system since irrigation became the main feature of economic development of the Central Valley at the beginning of this century. This trend, which started in the late 1950's, has not abated even during periods of natural runoff deficits such as 1976-77.

Therefore, it is not surprising that this trend in water withdrawals, especially since 1965, has resulted in a chronic water deficit in the Delta and the Bay. In addition, upstream diversions are currently 1.5-3 times higher than downstream withdrawals - illustrating that water facilities are not capable of holding and releasing excess water to benefit the Delta and Bay in dry and critical years.

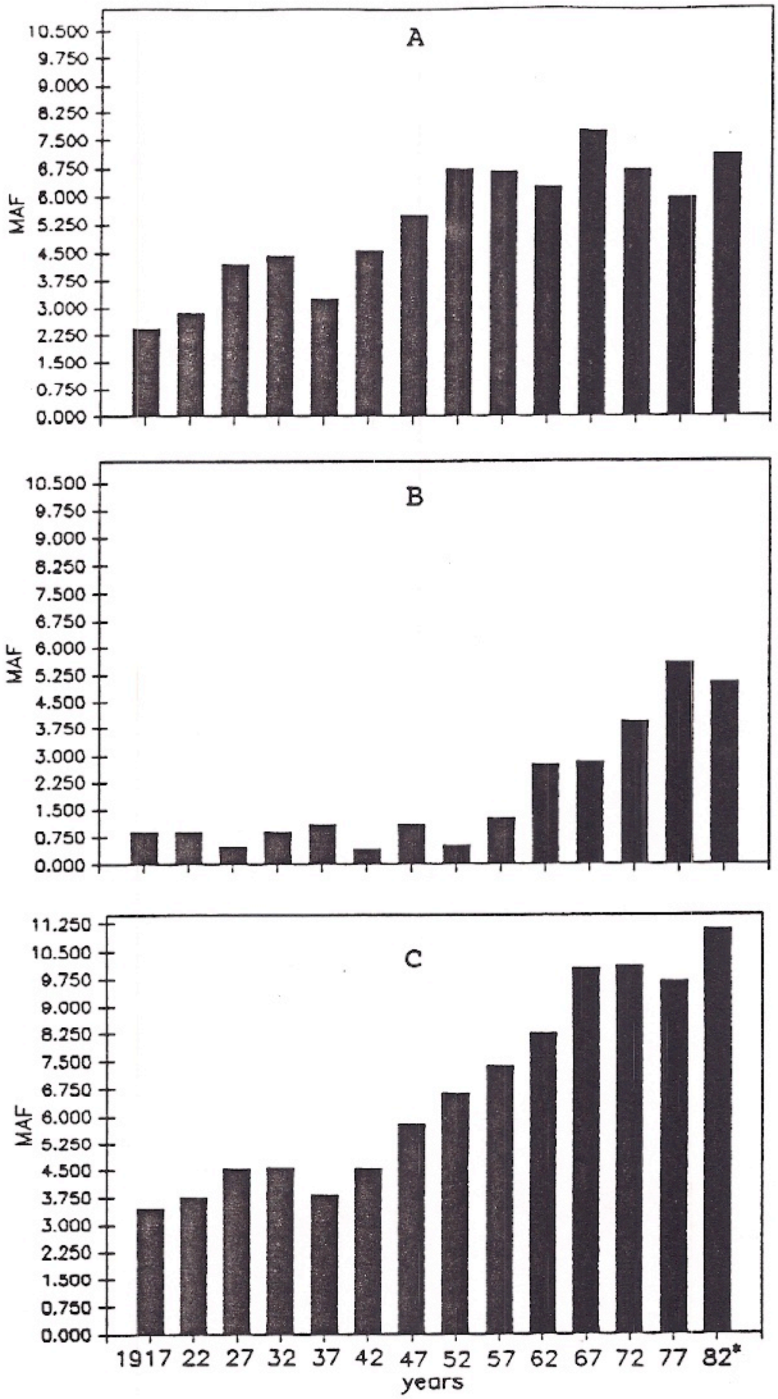


Fig. 3-2 The mean annual volume of water diverted for 5-year periods from the Sacramento-San Joaquin River basin during pre-project (1915-1943) and post-project (1943-1983) periods: A) Upstream, B) Inner Delta, C) Total Diversions. The years marked are the pivotal years of the period, e.g., 1917 = 1915-1919. (* = 4-year period)

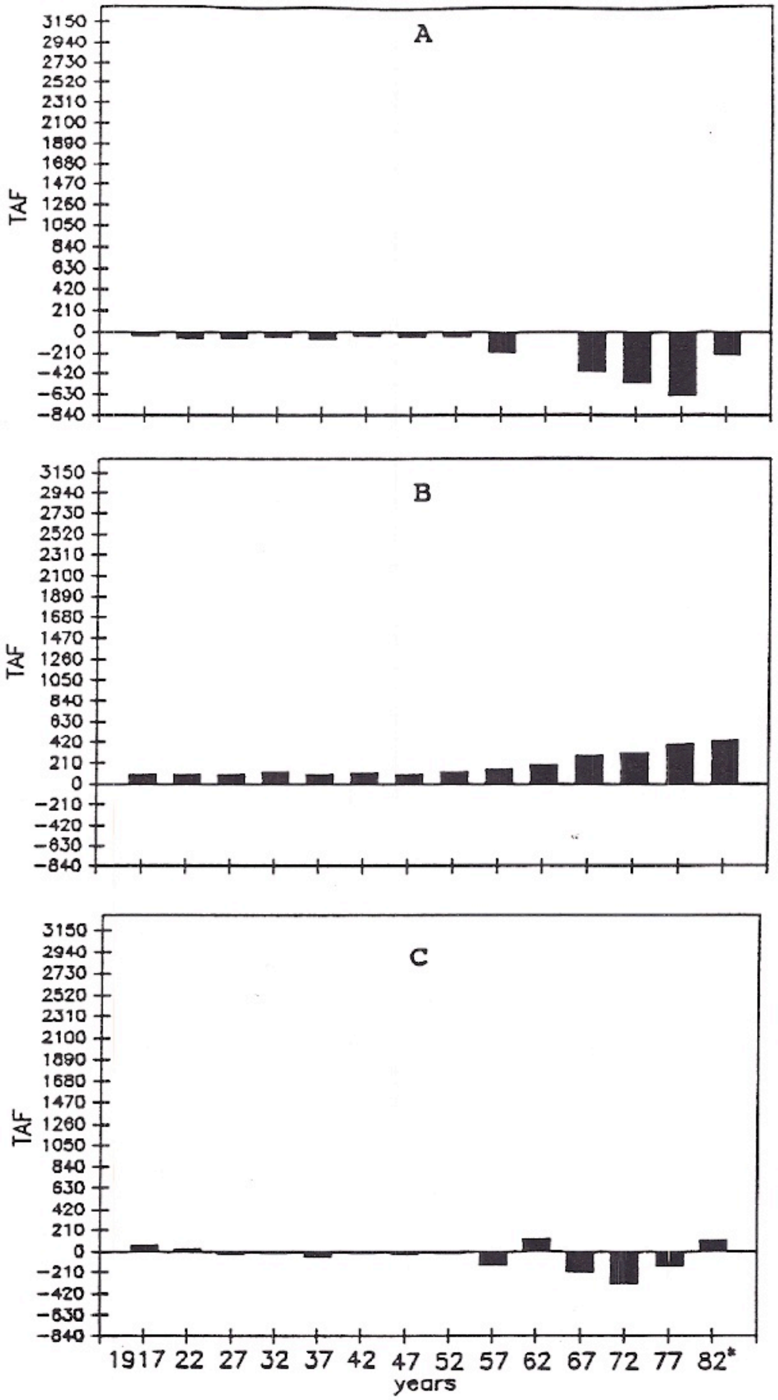


Fig. 3-3 The mean volume of water diverted for 5-year periods from the Sacramento-San Joaquin River basin during pre-project (1915-1943) and post-project (1943-1983) periods: A) Upstream, B) Inner Delta, C) Total Diversions, for the month of October. Negative diversions represent returning water from storage facilities and agricultural drainage network. The years marked are the pivotal years of the period, e.g., 1917 = 1915-1919. (* = 4-year period)

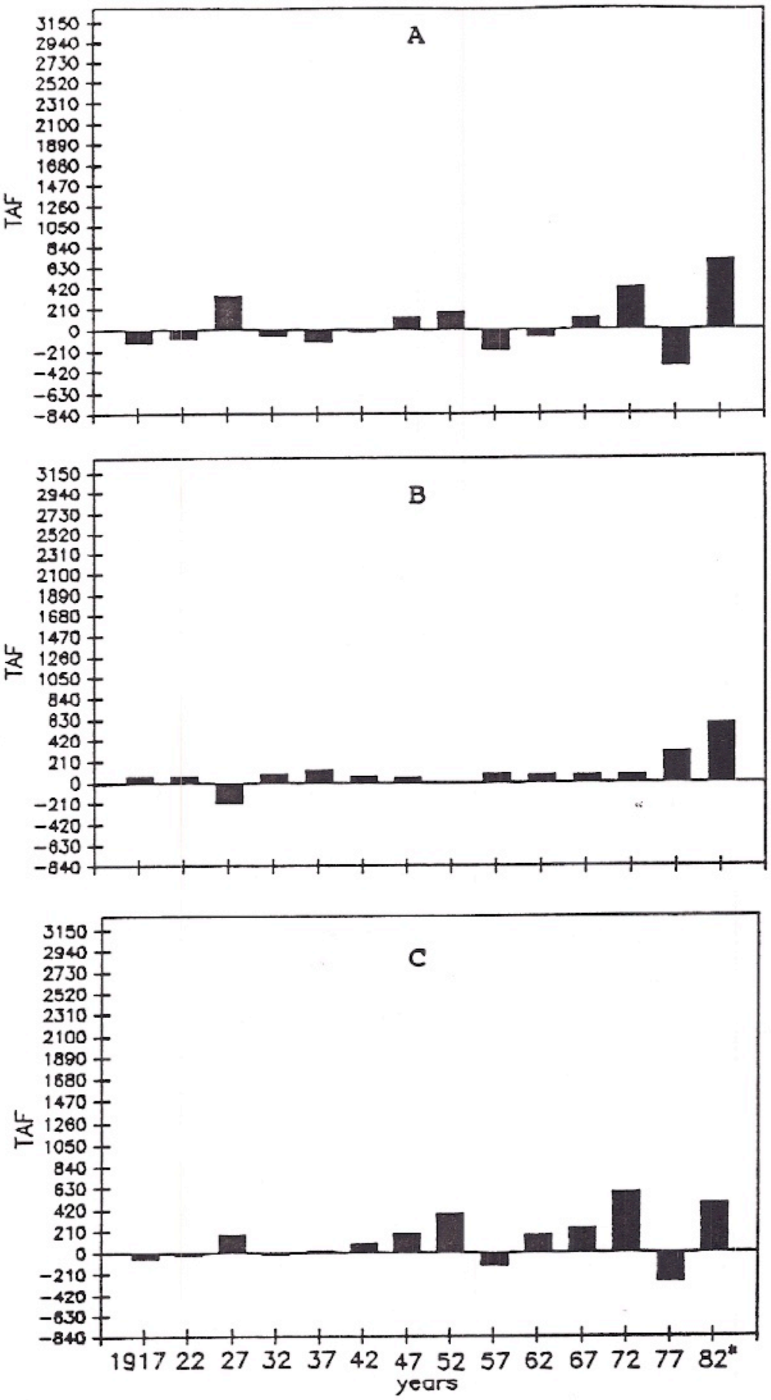


Fig. 3-4 The mean volume of water diverted for 5-year periods from the Sacramento-San Joaquin River basin during pre-project (1915-1943) and post-project (1943-1983) periods: A) Upstream, B) Inner Delta, C) Total Diversions, for the month of November. Negative diversions represent returning water from storage facilities and agricultural drainage network. The years marked are the pivotal years of the period, e.g., 1917 = 1915-1919. (* = 4-year period)

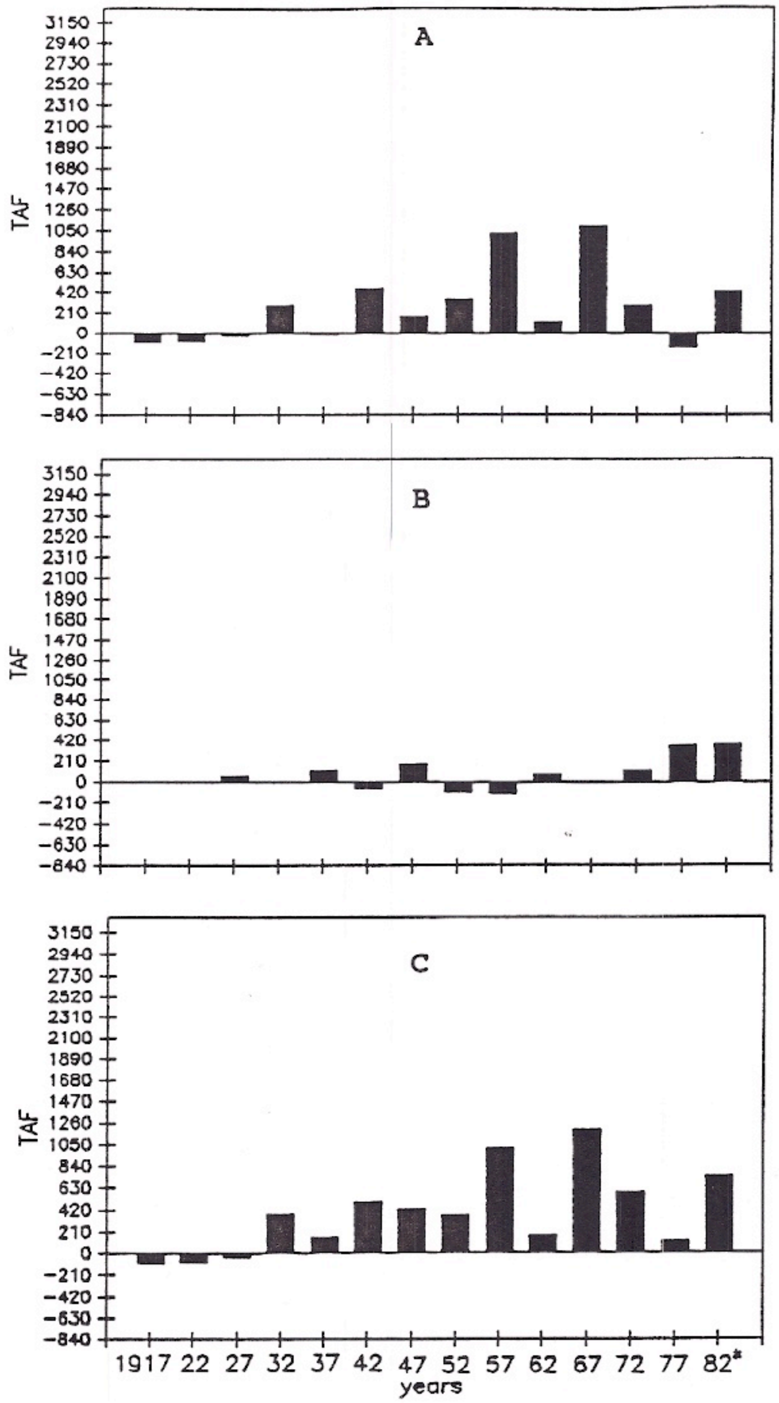


Fig. 3-5 The mean volume of water diverted for 5-year periods from the Sacramento-San Joaquin River basin during pre-project (1915-1943) and post-project (1943-1983) periods: A) Upstream, B) Inner Delta, C) Total Diversions, for the month of December. Negative diversions represent returning water from storage facilities and agricultural drainage network. The years marked are the pivotal years of the period, e.g., 1917 = 1915-1919. (* = 4-year period)

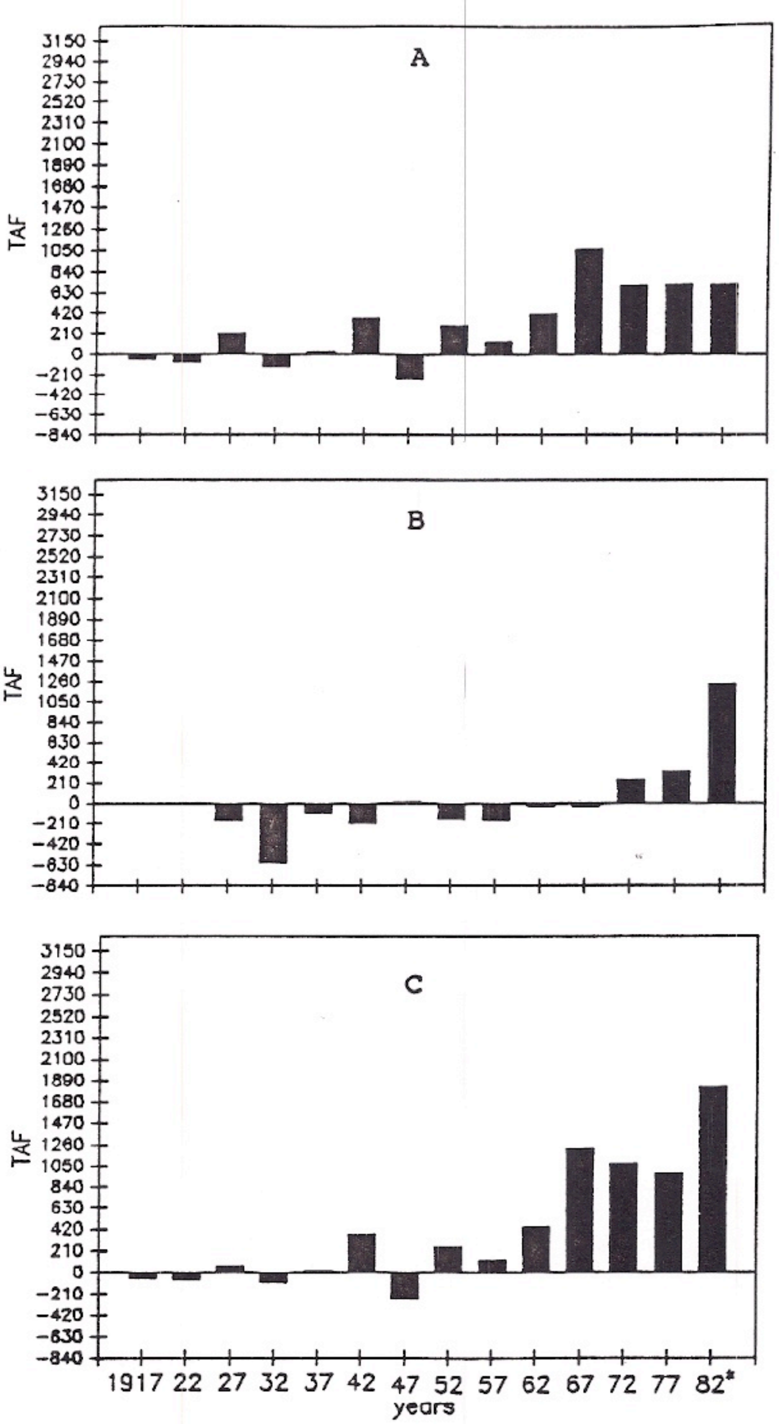


Fig. 3-6 The mean volume of water diverted for 5-year periods from the Sacramento-San Joaquin River basin during pre-project (1915-1943) and post-project (1943-1983) periods: A) Upstream, B) Inner Delta, C) Total Diversions, for the month of January. Negative diversions represent returning water from storage facilities and agricultural drainage network. The years marked are the pivotal years of the period, e.g., 1917 = 1915-1919. (* = 4-year period)

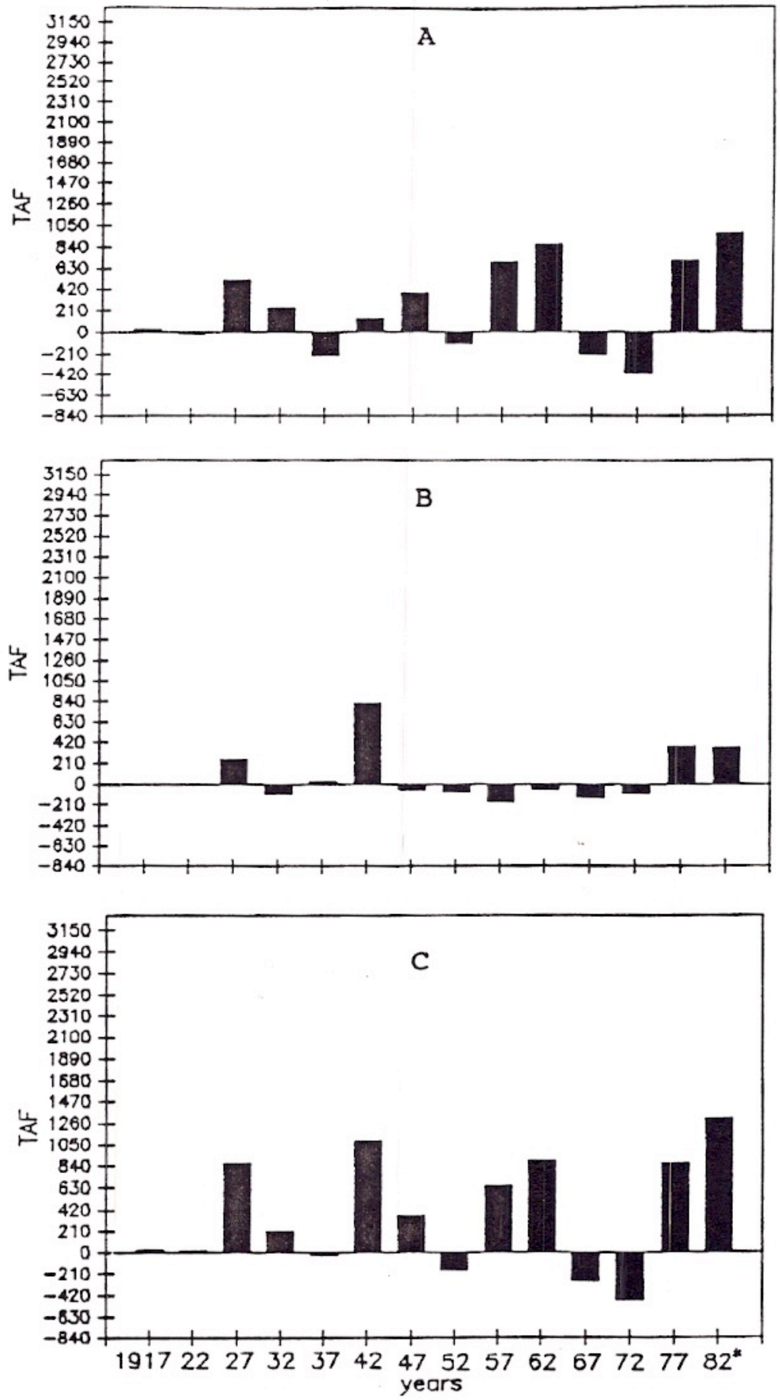


Fig. 3-7 The mean volume of water diverted for 5-year periods from the Sacramento-San Joaquin River basin during pre-project (1915-1943) and post-project (1943-1983) periods: A) Upstream, B) Inner Delta, C) Total Diversions, for the month of February. Negative diversions represent returning water from storage facilities and agricultural drainage network. The years marked are the pivotal years of the period, e.g., 1917 = 1915-1919. (* = 4-year period)

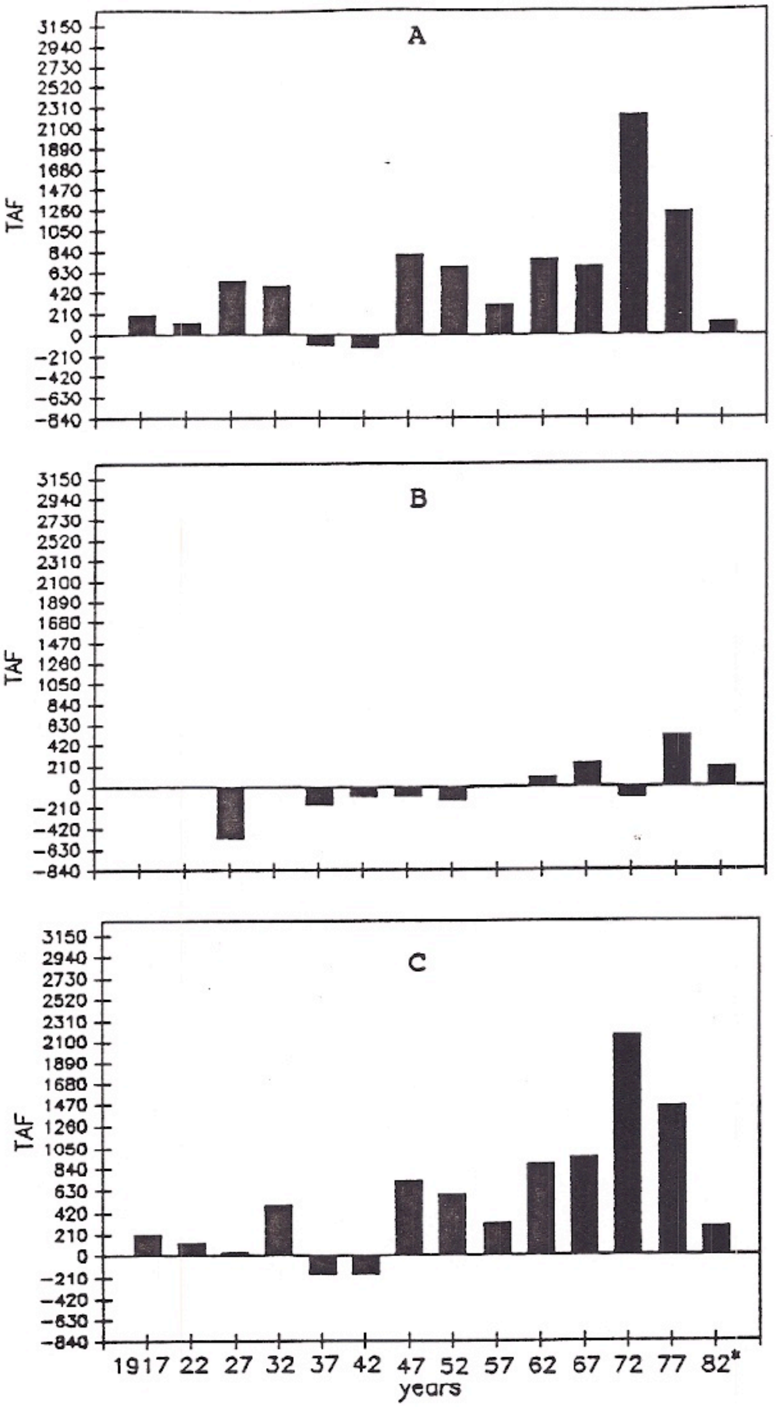


Fig. 3-8 The mean volume of water diverted for 5-year periods from the Sacramento-San Joaquin River basin during pre-project (1915-1943) and post-project (1943-1983) periods: A) Upstream, B) Inner Delta, C) Total Diversions, for the month of March. Negative diversions represent returning water from storage facilities and agricultural drainage network. The years marked are the pivotal years of the period, e.g., 1917 = 1915-1919. (* = 4-year period)

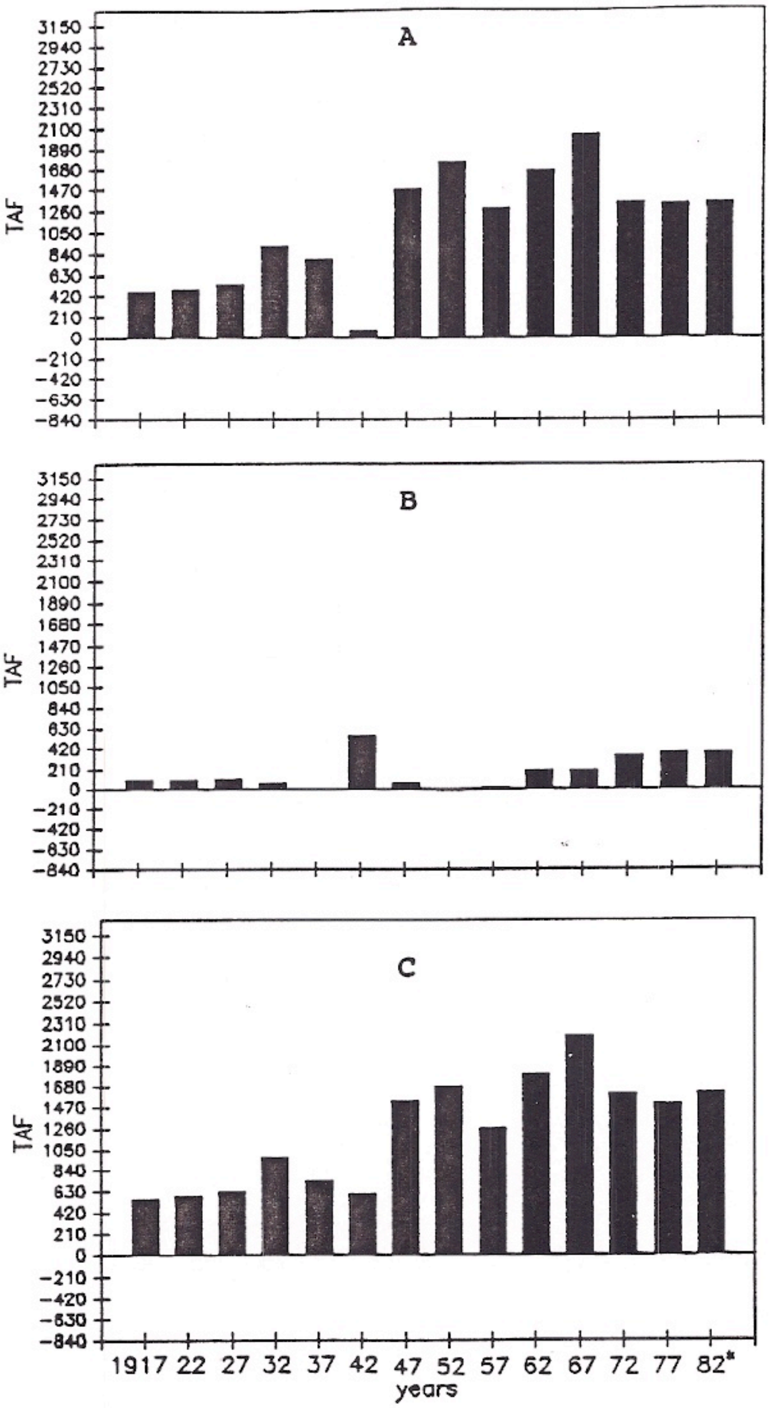


Fig. 3-9 The mean volume of water diverted for 5-year periods from the Sacramento-San Joaquin River basin during pre-project (1915-1943) and post-project (1943-1983) periods: A) Upstream, B) Inner Delta, C) Total Diversions, for the month of April. Negative diversions represent returning water from storage facilities and agricultural drainage network. The years marked are the pivotal years of the period, e.g., 1917 = 1915-1919. (* = 4-year period)

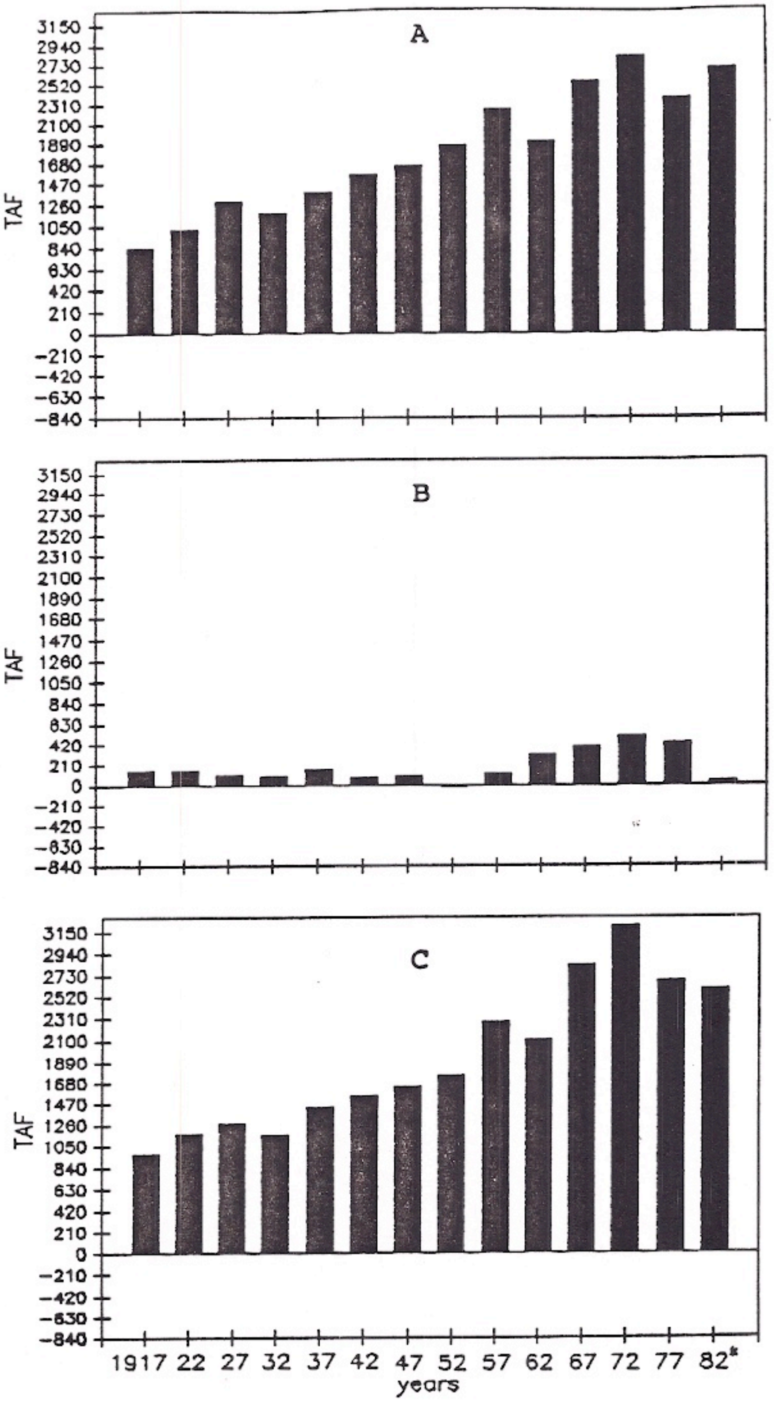


Fig. 3-10 The mean volume of water diverted for 5-year periods from the Sacramento-San Joaquin River basin during pre-project (1915-1943) and post-project (1943-1983) periods: A) Upstream, B) Inner Delta, C) Total Diversions, for the month of May. Negative diversions represent returning water from storage facilities and agricultural drainage network. The years marked are the pivotal years of the period, e.g., 1917 = 1915-1919. (* = 4-year period)

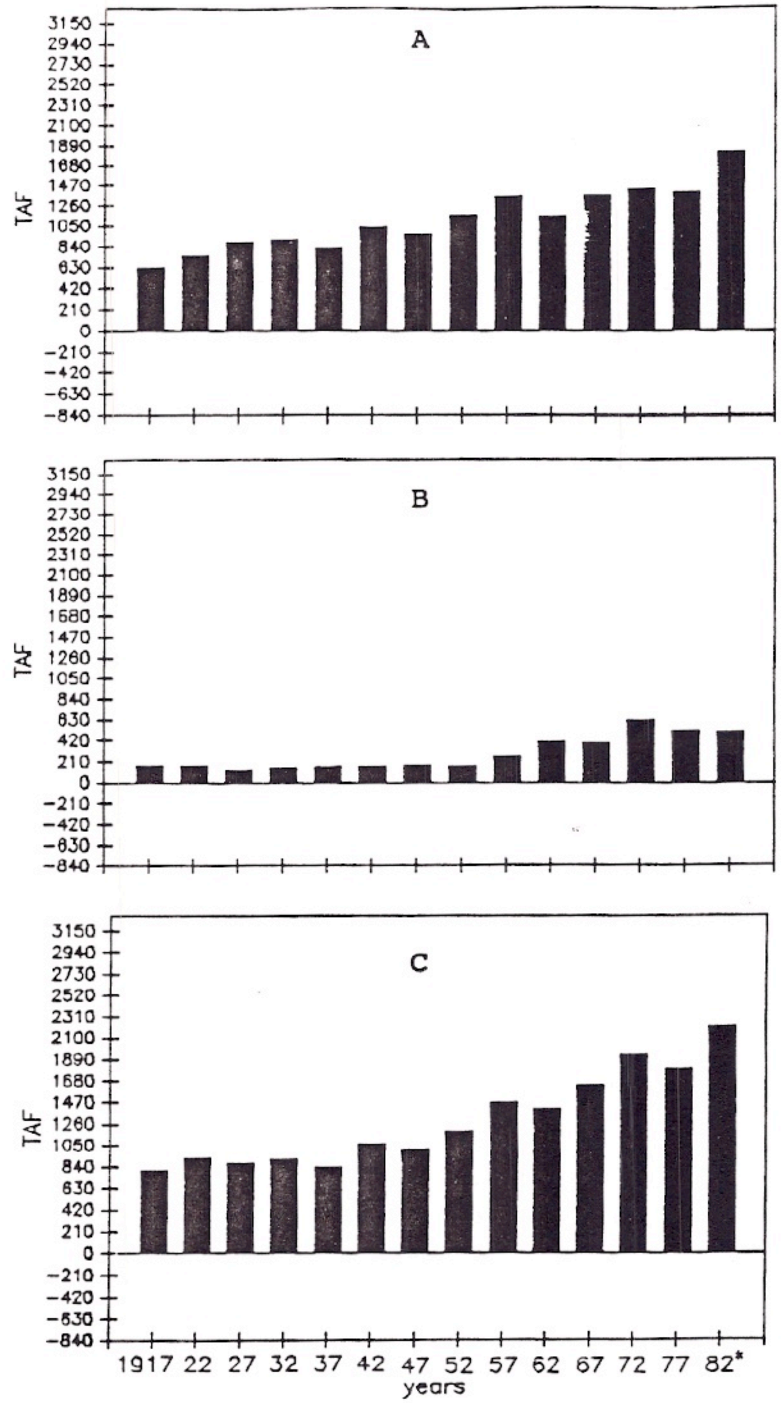


Fig. 3-11 The mean volume of water diverted for 5-year periods from the Sacramento-San Joaquin River basin during pre-project (1915-1943) and post-project (1943-1983) periods: A) Upstream, B) Inner Delta, C) Total Diversions, for the month of June. Negative diversions represent returning water from storage facilities and agricultural drainage network. The years marked are the pivotal years of the period, e.g., 1917 = 1915-1919. (* = 4-year period)

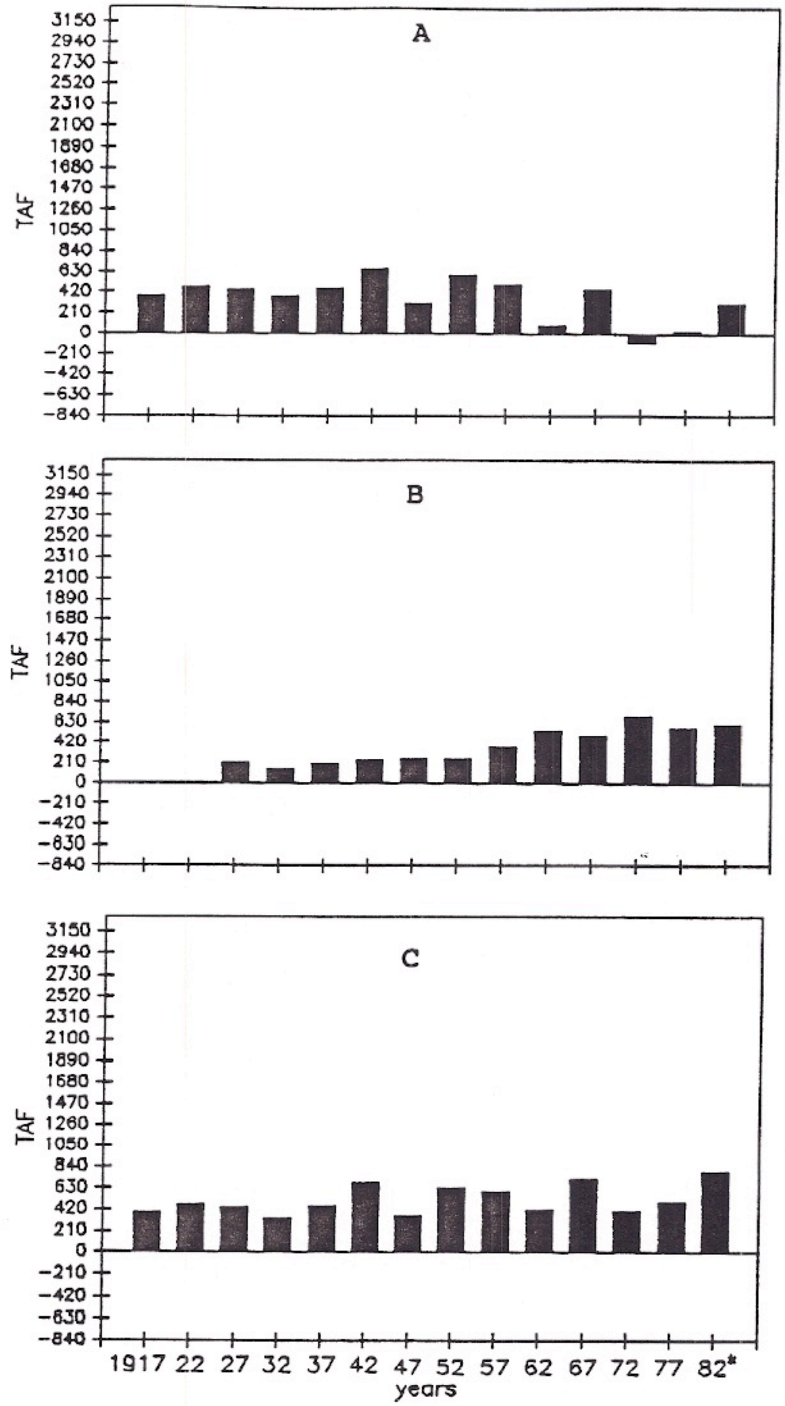


Fig. 3-12 The mean volume of water diverted for 5-year periods from the Sacramento-San Joaquin River basin during pre-project (1915-1943) and post-project (1943-1983) periods: A) Upstream, B) Inner Delta, C) Total Diversions, for the month of July. Negative diversions represent returning water from storage facilities and agricultural drainage network. The years marked are the pivotal years of the period, e.g., 1917 = 1915-1919. (* = 4-year period)

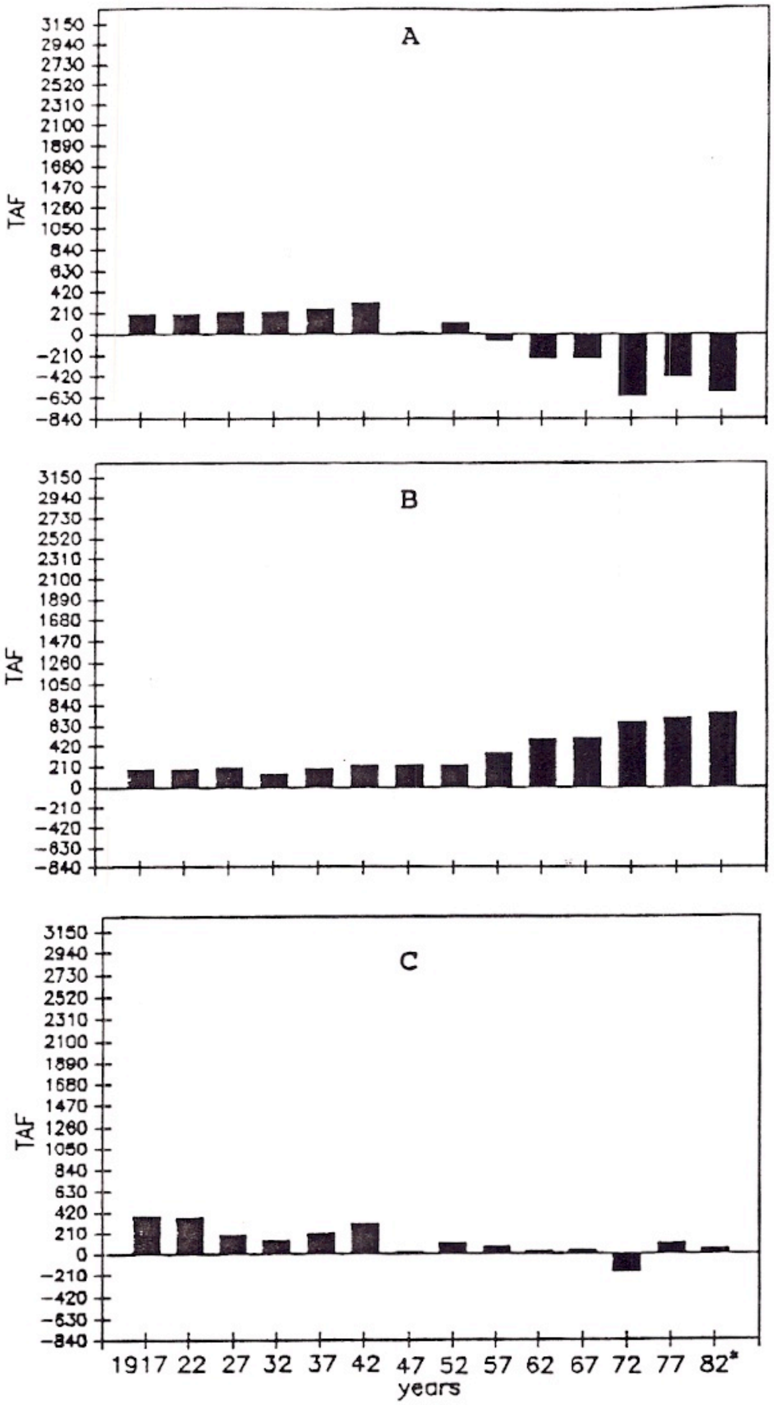


Fig. 3-13 The mean volume of water diverted for 5-year periods from the Sacramento-San Joaquin River basin during pre-project (1915-1943) and post-project (1943-1983) periods: A) Upstream, B) Inner Delta, C) Total Diversions, for the month of August. Negative diversions represent returning water from storage facilities and agricultural drainage network. The years marked are the pivotal years of the period, e.g., 1917 = 1915-1919. (* = 4-year period)

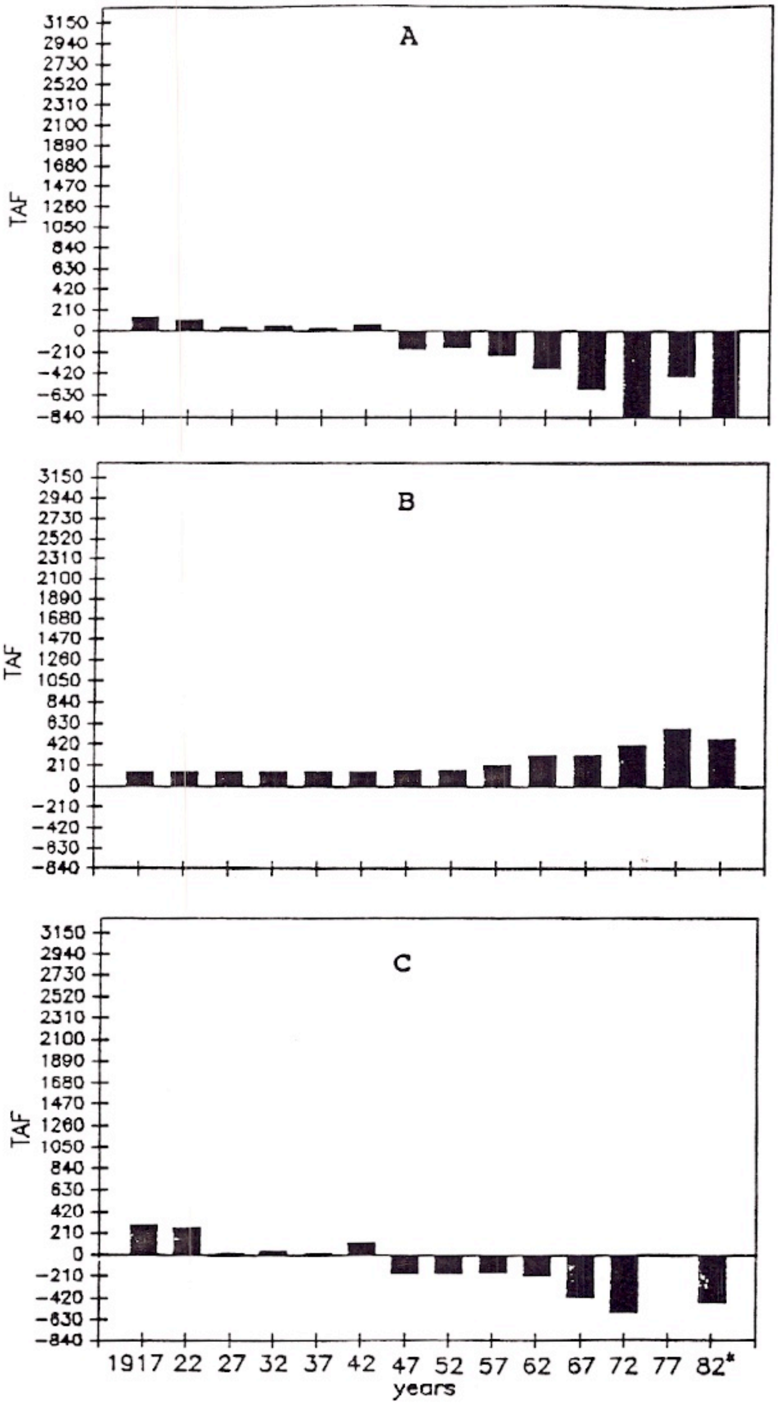


Fig. 3-14 The mean volume of water diverted for 5-year periods from the Sacramento-San Joaquin River basin during pre-project (1915-1943) and post-project (1943-1983) periods: A) Upstream, B) Inner Delta, C) Total Diversions, for the month of September. Negative diversions represent returning water from storage facilities and agricultural drainage network. The years marked are the pivotal years of the period, e.g., 1917 = 1915-1919. (* = 4-year period)

Table 3-1 The maximum and minimum monthly total diversions from the Sacramento-San Joaquin River/Delta system for 5-year periods between 1915 and 1983 (in thousand acre feet).

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1915–19												
max.	14	0	4	28	71	103	25	164	110	0	0	0
(year)	(1917)	all yrs	(1919)	(1916)	(1919)	(1918)	(1919)	(1917)	(1917)	all yrs	all yrs	all yrs
min	0	0	0	0	14	57	123	97	29	0	0	0
(year)	(15,16, 18,19)	all yrs	(15,19)	(15,17,18)	(1916)	(1916)	(1916)	(1915)	(1918)	all yrs	all yrs	all yrs
1920–24												
max.	0	52	31	75	51	128	270	458	126	0	0	0
(year)	all yrs	(1920)	(1920)	(1921)	(1924)	(1921)	(1923)	(1923)	(1923)	all yrs	all yrs	all yrs
min.	0	0	2	0	0	16	104	103	42	0	0	0
(year)	all yrs	(21,23)	(1921)	(20,24)	(1921)	(1922)	(1921)	(1921)	(1920)	all yrs	all yrs	all yrs
1925–29												
max.	115	284	228	186	3879	2992	884	1618	1440	853	515	234
(year)	(1925)	(1927)	(1927)	(1927)	(1927)	(1928)	(1926)	(1927)	(1927)	(1927)	(1925)	(1925)
min.	-62	-120	-79	-139	-91	-3964	493	1070	787	516	325	150
(year)	(1928)	(1929)	(1929)	(1929)	(1926)	(1927)	(1925)	(1925)	(1926)	(1926)	(1929)	(1929)
1930–34												
max.	198	58	688	-96	457	853	1188	1808	1616	719	467	231
(year)	(1932)	(1932)	(1932)	(1931)	(1930)	(1932)	(1932)	(1932)	(1933)	(1932)	(1932)	(1932)
min.	-61	-18	-96	-274	-202	32	813	814	579	323	278	100
(year)	(1931)	(1931)	(1933)	(1932)	(1933)	(1930)	(1934)	(1934)	(1931)	(1931)	(1931)	(1930)

Note: Negative values denote water releases.

Table 3-1 continued.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1935–39												
max.	141	152	719	304	388	627	1428	2035	1163	792	521	199
(year)	(1935)	(1935)	(1938)	(1936)	(1935)	(1939)	(1939)	(1937)	(1935)	(1938)	(1938)	(1938)
min.	−24	−67	−148	−238	−1047	−835	276	1127	729	446	344	131
(year)	(1936)	(1939)	(1939)	(1935)	(1938)	(1938)	(1938)	(1939)	(1939)	(1939)	(1939)	(1936)
1940–44												
max.	154	294	902	1004	3504	410	2604	2164	1535	1002	608	303
(year)	(1940)	(1943)	(1942)	(1943)	(1942)	(1944)	(1942)	(1944)	(1942)	(1942)	(1942)	(1941)
min.	6	−31	−107	−1261	−595	−1145	−1712	1324	895	652	439	145
(year)	(1943)	(1944)	(1944)	(1941)	(1943)	(1941)	(1940)	(1942)	(1940)	(1940)	(1940)	('40,'45)
1945–49												
max.	184	455	1590	689	1078	934	1844	2149	1492	749	268	44
(year)	(1948)	(1946)	(1946)	(1948)	(1945)	(1947)	(1948)	(1949)	(1945)	(1945)	(1945)	(1947)
min.	−146	−107	−164	−1499	−84	307	1098	1493	912	416	192	−69
(year)	(1949)	(1949)	(1949)	(1946)	(1946)	(1945)	(1947)	(1948)	(1947)	(1949)	(1949)	(1948)
1950–54												
max.	480	1716	1539	969	503	1001	2114	2208	1849	1260	467	48
(year)	(1951)	(1951)	(1952)	(1954)	(1950)	(1953)	(1954)	(1952)	(1953)	(1952)	(1953)	(1954)
min.	−63	−783	−266	−909	−546	−159	1359	1521	1089	498	183	−32
(year)	(1954)	(1954)	(1951)	(1952)	(1951)	(1952)	(1952)	(1951)	(1950)	(1951)	(1951)	(1950)

Note: Negative values denote water releases.

Table 3-1 continued.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1955–59												
max.	75	101	4617	766	2012	674	1952	2920	1831	1187	355	92
(year)	(1956)	(1956)	(1956)	(1959)	(1957)	(1955)	(1959)	(1958)	(1956)	(1956)	(1953)	(1959)
min.	-174	-256	-243	-1287	-501	-97	-434	1586	1073	432	129	-177
(year)	(1959)	(1959)	(1959)	(1956)	(1956)	(1956)	(1958)	(1959)	(1959)	(1959)	(1959)	(1958)
1960–64												
max.	591	478	478	848	1482	1823	2870	2614	2140	983	372	93
(year)	(1963)	(1964)	(1961)	(1963)	(1962)	(1960)	(1962)	(1963)	(1962)	(1963)	(1963)	(1961)
min.	-159	-106	-416	148	34	237	1281	1926	1130	434	151	-180
(year)	(1964)	(1963)	(1964)	(1961)	(1964)	(1962)	(1963)	(1961)	(1961)	(1960)	(1964)	(1963)
1965–69												
max.	246	424	4951	3595	1821	1954	2849	4817	2645	1494	445	90
(year)	(1969)	(1969)	(1965)	(1969)	(1968)	(1967)	(1969)	(1969)	(1967)	(1967)	(1965)	(1968)
min.	-406	-363	-509	-362	-1805	-392	974	2041	-800	361	87	-722
(year)	(1968)	(1968)	(1966)	(1965)	(1969)	(1969)	(1967)	(1968)	(1968)	(1966)	(1969)	(1969)
1970–74												
max.	-13	2122	1548	3158	847	3928	2524	4718	2590	977	198	-121
(year)	(1973)	(1974)	(1970)	(1970)	(1972)	(1974)	(1973)	(1973)	(1974)	(1974)	(1973)	(1972)
min.	-429	-437	-346	-22	-2460	119	91	2375	1471	244	-105	-688
(year)	(1970)	(1970)	(1971)	(1973)	(1970)	(1973)	(1974)	(1972)	(1972)	(1972)	(1971)	(1974)

Note: Negative values denote water releases.

Table 3-1 continued.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1975–79												
max.	258	318	1811	4296	1876	3471	2322	4657	3667	1614	334	289
(year)	(1978)	(1978)	(1978)	(1978)	(1978)	(1975)	(1979)	(1975)	(1978)	(1978)	(1978)	(1976)
min.	–558	–699	–641	142	258	447	590	761	385	174	164	–123
(year)	(1978)	(1975)	(1975)	(1975)	(1977)	(1977)	(1977)	(1977)	(1976)	(1976)	(1979)	(1975)
1980–83												
max.	286	3164	2134	2190	2483	1743	2857	3121	3905	1280	250	–11
(year)	(1982)	(1982)	(1982)	(1980)	(1982)	(1982)	(1982)	(1982)	(1983)	(1983)	(1980)	(1981)
min.	–46	–11	75	–798	123	–850	–257	1676	687	34	–112	–1008
(year)	(1981)	(1981)	(1983)	(1982)	(1983)	(1983)	(1983)	(1981)	(1981)	(1981)	(1982)	(1983)

Note: Negative values denote water releases.

Table 3-2 The maximum and minimum monthly upstream diversions for 5-year periods between 1925 and 1983 (in thousand acre feet).

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1925–29												
max.	41	1267	133	485	1610	2122	1092	1537	1303	621	299	85
(year)	(1925)	(1927)	(1925)	(1927)	(1927)	(1928)	(1927)	(1927)	(1927)	(1927)	(1925)	(1925)
min.	-118	-68	-334	-68	331	-246	-580	926	630	347	138	8
(year)	(1928)	(1929)	(1927)	(1929)	(1926)	(1927)	(1928)	(1925)	(1926)	(1928)	(1929)	(1929)
1930–34												
max.	75	26	868	-4	531	814	1127	1720	1457	491	265	85
(year)	(1932)	(1932)	(1932)	(1931)	(1930)	(1932)	(1932)	(1932)	(1933)	(1932)	(1932)	(1932)
min.	-157	-122	-176	-273	-209	81	755	722	446	289	172	-38
(year)	(1931)	(1934)	(1931)	(1932)	(1933)	(1930)	(1934)	(1934)	(1931)	(1934)	(1930)	(1930)
1935–39												
max.	23	160	217	349	423	678	1358	1932	1009	563	309	59
(year)	(1935)	(1935)	(1938)	(1936)	(1937)	(1939)	(1939)	(1937)	(1935)	(1938)	(1938)	(1938)
min.	-131	-378	-201	-127	-2149	-525	298	1026	562	347	214	-5
(year)	(1938)	(1938)	(1939)	(1937)	(1938)	(1936)	(1938)	(1939)	(1939)	(1939)	(1936)	(1936)
1940–44												
max.	48	318	998	1225	2342	425	1001	2097	1374	767	390	151
(year)	(1940)	(1943)	(1942)	(1943)	(1940)	(1944)	(1944)	(1944)	(1942)	(1942)	(1942)	(1941)
min.	-111	-111	-142	-1042	-1335	-975	-1731	1275	733	426	223	-7
(year)	(1943)	(1944)	(1944)	(1941)	(1942)	(1941)	(1940)	(1942)	(1940)	(1940)	(1940)	(1940)

Note: Negative values denote water releases.

Table 3-2 continued.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1945–49												
max.	127	428	1804	650	1302	1021	1858	2017	1332	519	53	-115
(year)	(1948)	(1945)	(1946)	(1948)	(1945)	(1949)	(1948)	(1949)	(1945)	(1945)	(1945)	(1947)
min.	-282	-239	-1104	-1497	-72	437	1021	1466	750	133	-60	-229
(year)	(1949)	(1949)	(1948)	(1946)	(1946)	(1945)	(1947)	(1948)	(1947)	(1949)	(1949)	(1948)
1950–54												
max.	408	1878	1774	968	631	1143	2184	2355	1758	1023	275	-78
(year)	(1951)	(1951)	(1952)	(1954)	(1950)	(1954)	(1954)	(1954)	(1953)	(1952)	(1953)	(1954)
min.	-212	-839	-113	-525	-520	158	1270	1417	887	216	-89	-225
(year)	(1954)	(1954)	(1950)	(1952)	(1951)	(1951)	(1952)	(1951)	(1950)	(1951)	(1951)	(1951)
1955–59												
max.	-33	53	5304	843	2065	676	1883	2894	1727	977	155	-83
(year)	(1956)	(1956)	(1956)	(1956)	(1957)	(1955)	(1956)	(1958)	(1956)	(1956)	(1956)	(1959)
min.	-395	-392	-316	-889	-257	-60	-163	1280	665	-89	-334	-465
(year)	(1959)	(1959)	(1959)	(1956)	(1956)	(1956)	(1958)	(1959)	(1959)	(1959)	(1959)	(1958)
1960–64												
max.	558	470	412	930	1804	1690	2607	2346	1719	456	-120	-202
(year)	(1963)	(1964)	(1962)	(1963)	(1962)	(1960)	(1962)	(1963)	(1962)	(1963)	(1963)	(1961)
min.	-380	-245	-509	192	-94	213	1322	1622	691	-123	-358	-528
(year)	(1964)	(1963)	(1964)	(1961)	(1964)	(1962)	(1961)	(1961)	(1961)	(1961)	(1964)	(1963)

Note: Negative values denote water releases.

Table 3-2 continued.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1965–69												
max. (year)	-234 (1969)	440 (1967)	5118 (1965)	3495 (1969)	1879 (1968)	1816 (1967)	2639 (1969)	4377 (1969)	2337 (1967)	1254 (1967)	-33 (1965)	-291 (1966)
min. (year)	-644 (1968)	-473 (1968)	-466 (1966)	-232 (1965)	-1437 (1967)	-822 (1969)	916 (1967)	1543 (1968)	405 (1966)	-200 (1968)	-479 (1969)	-904 (1969)
1970–74												
max. ear)	425 (1973)	1952 (1974)	1448 (1970)	2818 (1970)	671 (1972)	5790 (1974)	2216 (1973)	4162 (1973)	1917 (1971)	77 (1974)	-430 (1970)	-573 (1972)
min. (year)	-629 (1970)	-547 (1970)	-494 (1971)	-94 (1973)	-2186 (1970)	-41 (1973)	-209 (1974)	1839 (1972)	787 (1972)	-332 (1972)	-818 (1974)	-1132 (1974)
1974–79												
max. (year)	96 (1978)	126 (1978)	1563 (1978)	4005 (1978)	1455 (1978)	2137 (1975)	2050 (1978)	4008 (1975)	2988 (1978)	848 (1978)	-129 (1977)	-4 (1977)
min. (year)	-912 (1975)	-895 (1975)	-916 (1976)	-396 (1976)	40 (1977)	195 (1977)	402 (1977)	519 (1977)	-63 (1976)	-352 (1976)	-622 (1975)	-806 (1975)
1980–83												
max. (year)	-2 (1982)	3030 (1982)	1883 (1982)	2086 (1980)	2130 (1982)	1372 (1981)	2527 (1982)	2731 (1982)	3509 (1983)	826 (1983)	-382 (1981)	-458 (1981)
min. (year)	-467 (1981)	-9 (1980)	-254 (1983)	-775 (1982)	-276 (1983)	-881 (1983)	-387 (1983)	1375 (1981)	363 (1981)	-530 (1980)	-716 (1982)	-1254 (1983)

Note: Negative values denote water releases.

Table 3-3 The maximum and minimum monthly inner Delta diversions for 5-year periods between 1925 and 1983 (in thousand arce feet).

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1925-29												
max. (year)	139 (1929)	27 (1926)	562 (1927)	-27 (1925)	2269 (1927)	237 (1925)	1176 (1928)	144 (1925)	161 (1928)	233 (1928)	216 (1925)	150 ('25,'28)
min. (year)	56 (1928)	-983 (1927)	-91 (1929)	-345 (1926)	-1240 (1925)	-3718 (1927)	-514 (1927)	46 (1926)	69 (1925)	144 (1926)	141 (1926)	142 (1929)
1930-34												
max. (year)	136 (1933)	106 (1930)	125 (1930)	57 (1934)	7 (1933)	45 (1934)	76 (1933)	92 (1934)	161 (1932)	228 (1932)	38 (1931)	148 (1931)
min. (year)	96 ('31,'34)	32 (1932)	-180 (1932)	-142 (1930)	-218 (1932)	-49 (1930)	39 (1930)	60 (1931)	133 (1931)	0 (1931)	202 (1932)	136 (1934)
1935-39												
max. (year)	118 (1935)	420 (1938)	502 (1938)	-18 (1939)	1102 (1938)	67 (1936)	70 (1939)	423 (1938)	167 (1939)	229 (1938)	212 ('36,'38)	152 (1937)
min. (year)	89 (1936)	-8 (1935)	-38 (1937)	-220 (1935)	-526 (1936)	-376 (1937)	-55 (1935)	53 (1936)	139 (1936)	99 (1939)	110 (1939)	136 (1934)
1940-44												
max. (year)	127 (1944)	102 (1940)	63 (1940)	-32 (1944)	4839 (1942)	-15 (1944)	1870 (1942)	94 (1943)	165 (1941)	235 ('42,'44)	218 ('41,'42)	152 ('40,'43)
min. (year)	98 (1942)	-24 (1943)	-342 (1941)	-301 (1940)	-296 (1940)	-248 (1943)	-23 (1944)	49 (1942)	158 (1944)	226 (1940)	214 (1944)	150 (1944)

Note: Negative values denote water releases.

Table 3-3 continued.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1945–49												
max. (year)	136 (1949)	132 (1949)	1077 (1948)	39 (1948)	7 (1948)	-32 (1946)	94 (1949)	132 (1949)	176 (1949)	283 (1949)	252 (1949)	169 (1949)
min. (year)	46 (1946)	-50 (1945)	-214 (1946)	-32 (1947)	-224 (1945)	-189 (1949)	-14 (1948)	27 (1948)	160 (1945)	230 (1945)	214 (1946)	150 (1945)
1950–54												
max. (year)	150 (1950)	68 (1950)	72 (1954)	1 (1954)	7 (1953)	-64 (1953)	89 (1952)	130 (1952)	216 (1951)	282 (1951)	272 (1951)	200 (1951)
min. (year)	72 (1951)	-162 (1951)	-320 (1951)	-384 (1952)	-171 (1954)	-324 (1952)	-122 (1953)	-444 (1954)	91 (1953)	223 (1954)	192 (1953)	126 (1954)
1955–59												
max. (year)	221 (1959)	136 (1959)	90 (1957)	-23 (1957)	-53 (1957)	80 (1957)	285 (1959)	306 (1959)	408 (1959)	521 (1959)	463 (1959)	288 (1958)
min. (year)	108 (1956)	-14 (1955)	-687 (1956)	-398 (1956)	-401 (1958)	-224 (1958)	-271 (1958)	26 (1958)	104 (1956)	210 (1956)	189 (1956)	140 (1955)
1960–64												
max. (year)	241 (1961)	145 (1960)	93 (1964)	42 (1962)	128 (1964)	150 (1964)	289 (1964)	341 (1964)	439 (1961)	564 (1961)	509 (1964)	348 (1963)
min. (year)	33 (1963)	2 (1961)	35 (1963)	-82 (1963)	-322 (1962)	10 (1963)	-50 (1963)	268 (1963)	392 (1964)	527 (1963)	477 (1960)	295 ('60,'61)

Note: Negative values denote water releases.

Table 3-3 continued.

	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept
1965–69												
max. (year)	480 (1969)	290 (1969)	128 (1969)	100 (1969)	83 (1965)	430 (1969)	418 (1968)	498 (1968)	440 (1966)	588 (1968)	566 (1969)	490 (1968)
min. (year)	215 (1965)	−98 (1967)	−167 (1965)	−130 (1965)	−490 (1969)	138 (1967)	55 (1965)	321 (1965)	−1296 (1968)	240 (1967)	378 (1967)	182 (1969)
1970–74												
max. (year)	412 (1973)	226 (1972)	274 (1973)	340 (1970)	176 (1972)	508 (1972)	434 (1972)	624 (1974)	734 (1974)	900 (1974)	826 (1974)	472 (1973)
min. (year)	200 (1970)	−152 (1971)	100 (1970)	72 (1973)	−526 (1973)	−1862 (1974)	300 (1974)	404 (1971)	508 (1970)	576 (1972)	526 (1970)	334 (1970)
1975–79												
max. (year)	704 (1976)	638 (1976)	614 (1976)	540 (1976)	795 (1975)	1334 (1975)	710 (1975)	649 (1975)	679 (1978)	790 (1979)	870 (1979)	708 (1979)
min. (year)	162 (1978)	144 (1977)	204 (1975)	16 (1979)	−37 (1979)	190 (1978)	144 (1978)	242 (1977)	271 (1977)	325 (1977)	331 (1977)	248 (1977)
1980–83												
max. (year)	523 (1981)	479 (1981)	457 (1981)	437 (1983)	432 (1982)	385 (1982)	511 (1981)	518 (1982)	577 (1980)	701 (1981)	806 (1981)	614 (1980)
min. (1983)	359 (1983)	201 (1982)	325 ('80,'82)	24 (1982)	237 (1980)	−4 (1983)	219 (1983)	265 (1983)	448 (1982)	502 (1982)	674 (1983)	347 (1982)

Note: Negative values denote water releases.

Since that time annual upstream, downstream and total diversions in average for 5-year periods have been about 7, 4 and 11 MAF respectively, or as much as 2.3, 4 and 2.9 times higher than those documented for the pre-project periods.

Annual maximum water diversions were 1.2 to 2.2 times higher (especially if the preceding year or several years were classified as of subnormal wetness) than the CUP & SWP water, 'entitlement' of 9.2 MAF (1990-2000 projections = 7 MAF for CVP and 2.2 MAF for SWP).

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 (Fig. 3-15). (It should be noted that for the same period the total losses of freshwater supply to the Sea of Azov accounted for 300 MAF.)

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.

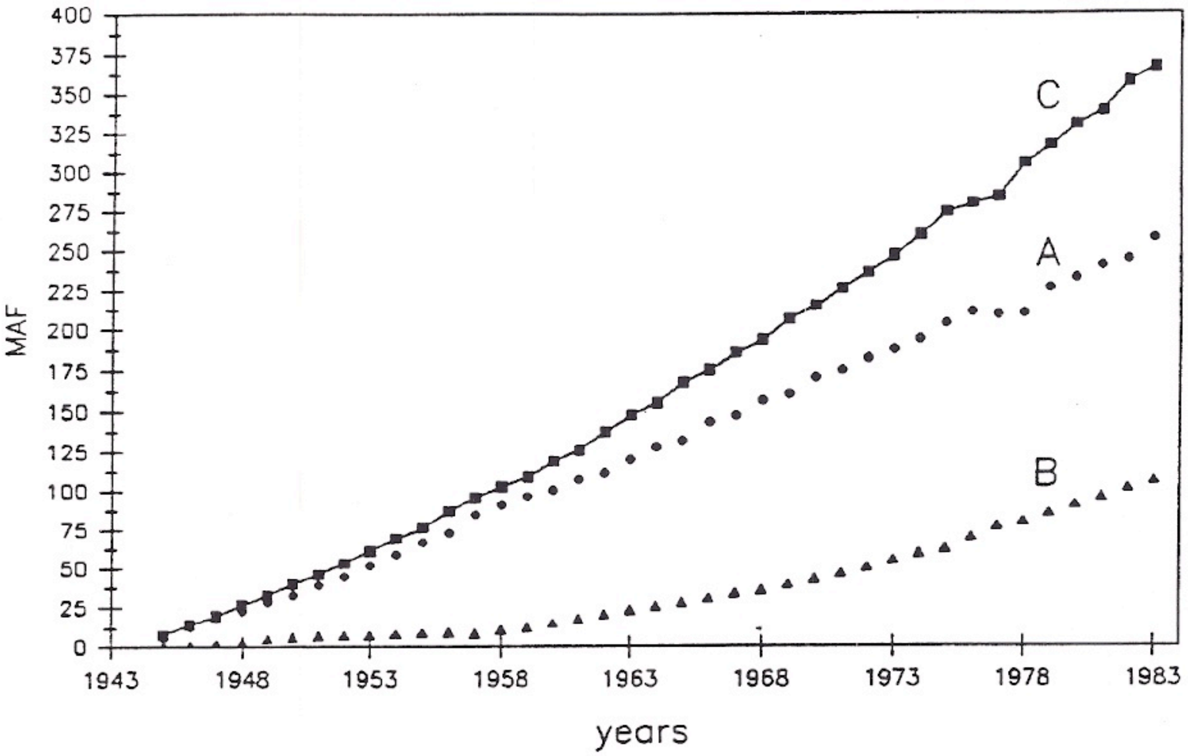


Fig.3-15 The cumulative volumes of water which have not reached the Delta/Bay ecosystem since 1944 due to water diversions from the Sacramento-San Joaquin river basin: (A) upstream, (B) downstream (Delta comsumptive use and export) and (C) total.

Conclusions

From the comparisons of changes in chronological annual and seasonal runoff fluctuations, as well for 5-year running mean, the following conclusions can be drawn:

1. There are two periods of water development in the Sacramento - San Joaquin River basin characterized by several distinctive features:

A. Pre-project period (1915 - 1943), was characterized as follows:

(a) There were no large water storage or conveyance facilities in the river watershed although there were numerous small dams;

(b) Most of the water diversions took place in spring (April, May, June);

(c) Inner Delta diversions were negligible;

(d) The predominant total annual diversions were within 3 - 4 MAF or on average 15% of the normal Delta outflow of 27.8 MAF.

B. Post-project period (1944 - 1983) is characterized by:

(a) Gradual increase in the amount of large storage facilities;

(b) Construction of powerful water conveyance facilities into and out of the Delta;

(c) Water diversions performed during October through June.

As result of construction of the sophisticated CVP and SWP water storage facilities (accumulation capacity equal to 71% of normal unimpaired runoff) and conveyance systems in and out of the Delta (15 - 20% of the normal Delta outflow), the post-project period natural water supply to the estuarine system has been reduced to unprecedented levels. Runoff limitations are determined by the size of watershed, amount of precipitation over its geophysical boundary, and many other climatological and physical parameters. They are responsible for the stochastically and physically limited ability of the watershed to renew the water resources of a river network on an annual basis.

Given the paramount importance of water development in the Sacramento-San Joaquin River basin for the welfare of California, it is important to remember the existence of these limitations (extreme conditions may occur only as very rare events) particularly when the current and future of the Delta-Bay ecosystem is in question.

Due to water diversions and river impoundments the following negative changes in flow conditions have taken place (it should be noted that such modifications are not unique. They have been observed in other systems as well, where they have also been accompanied by deterioration of fisheries and other resource values).

1. Current annual diversions result in 35-55% reductions in the total 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 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 = 80-95% - subnormal wetness or below). Instead low values of annual RRI and RDO occur every 2-5 years.

3. Gradual substantial increases of annual 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 such a low level (never before observed) that categories of favorable wetness have been substituted by years of wetness unfavorable for the Delta-Bay regime characteristics and fishery.

4. The number of sub-normal, 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 natural river inflow and natural Delta outflow (NDO) decreased by half.

5. As a result, the San Francisco Bay ecosystem experiences chronic deficits in annual water supply up to 65%, particularly for years of normal, subnormal and critical wetness.

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. Absolute values of upstream diversions of a predominant range of 10-12 MAF per year, are 6-8 times higher than before the CVP and SWP were completed.

8. The absolute downstream diversions (Delta consumptive use and export) were in some years, e.g., 1975, of the same magnitude as the upstream diversions, a phenomenon never observed in the pre-project period. The predominant range of annual Delta diversions since 1967 was 4-5 MAF. These values are almost 5 times higher than the Delta withdrawals before the projects.

9. The major cause of these persistent decreases in annual runoff is that diversions in <u>winter</u> (primarily upstream) range <u>between 15 and 45% and</u> for <u>spring</u> (upstream and downstream) <u>between 30 and 80% or more.</u>

10. As a result of upstream and Delta diversions the highest values of natural runoff have been truncated for all but autumn months.

Regulated river inflow and Delta outflow <u>during all post-project winter and spring months were 2-5 times lower than they were for the pre-project period</u>. The resulting regulated discharge to the Bay would have occurred once every 5-10 years under natural flow conditions (p = 75-97%; recurrence interval of at least once per 5-20 years).

11. For the <u>post-project period</u>, the trend of upstream diversion, 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). <u>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</u>. 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.

12. 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.

13. 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.

14. As a result of the significant transformation of seasonal and annual runoff, the amount of subnormal, lower than subnormal and even critical dry years were increased several times for annual and especially for spring runoff.

In other words, values of annual or seasonal regulated inflow/Delta outflow that would be considered very rare under unimpaired conditions, (i.e., having a recurrence interval of once per 30 - 40 years,) are witnessed now at least once per 4 years and even more often.

It should be emphasized that the frequency of subnormal or dryer months (for the late winter and spring) are 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 or lower than subnormal wetness (with the exception of some historic wet years such as 1983).

Due to extensive spring upstream, downstream and total diversions a new phenomenon appeared in the seasonal runoff distribution; namely, in more than 50% of the cases for the last 20 years, the monthly controlled runoff of late summer and fall was almost equal to the regulated spring river inflow/Delta outflow.

This type of seasonal redistribution cannot, under any circumstances, be considered a positive event for the river-Delta-Bay ecosystem because only high spring runoff is capable of repelling salt intrusion (to prevent salt build-up in the estuary for months to come, as well as to provide a maximum nutrient output to the estuary and optimal conditions for the survival of the living resources [including but not limited to migration, spawning and feeding]).

Therefore, when the level of annual water withdrawals gradually increase beyond the limits of the dominant runoff and deviations of the normal then the persistent chronic water deficit within the system is pronounced.

5-year Periods

This deficit may be seen more clearly in the mean annual and seasonal runoff fluctuation for 5-year periods. (5-year periods reflect phases of precipitation and are responsible for the cumulative water supply to the estuary).

1. The number of subnormal and dry 5-year periods of wetness of the RRI_5 and RDO_5, especially since 1944 have increased more than 5 times in comparison with those for NRI_5 and NDO_5 for the same period of observations,

2. For the entire period of record (1921-1983), more than 70% of the periods of the 5-year running mean regulated river discharges have been subnormal and lower than subnormal wetness while only 7% of the 54 periods (5-year) of unimpaired annual river discharges have been subnormal or lower than subnormal wetness.

Therefore, had unimpaired runoff fluctuations been preserved the atypical high frequency of low wetness would not have occurred.

3. While the predominant deviations of unimpaired annual and spring runoff for 5-year periods from normal for the Sacramento and San Joaquin Rivers (as well as for the Susquehanna, Potomac, James, Delaware, Apalachicola, Volga, Danube, Don, Kuban and many others) are in the range of 25-30%, <u>the annual and spring regulated water supply negative deviations have the ranges of 35 up to 60% and 40 up to 85% respectively</u>.

These differences in deviations for two different sets of runoff variables illustrate the level of anthropogenic changes in natural regime characteristics of river flow and should not be disregarded by those involved in water development and preservation of the estuarine environment. This is especially true in light of the fact that <u>ecological conditions in the river-Delta-estuary-coastal zone ecosystem cannot be considered as formed on an annual basis</u>. (There are numerous publications, some of them cited in this report which show that the average salinity concentration of the estuarine water body and commercial and recreational fishery are strongly related to monthly and annual runoff fluctuations lagged by some period of time (months or years). Therefore, it is not surprising that the chronic water deficit in the San Francisco Bay system has had a strong impact on fishery and other resources of the Bay. During the last 40 years diversions have been at least 6.6 MAF per year for upstream diversions, 2.8 MAF per year for the Delta and 9.4 MAF per year of total water diversions.

It is important to note that these average values of depletion obscure the fact that for some years, especially following subnormal or dry years of natural wetness, seasonal and annual diversions have been 1.5-2 times higher than these averages, e.g., in 1978 more than 20 MAF or 78% of the normal were diverted to replenish the losses sustained by storage during the two preceding dry years.

Between 1944 and 1983, the upstream, downstream and total cumulative losses reached 262, 104 and 366 MAF respectively (Fig. 3-15). Cumulative upstream and downstream water losses amount to 202 and 80 times the volume of the Delta (1.3 MAF) while the total diversions account for 61 times the volume of the San Francisco Bay (6MAF).

CHAPTER 8

SUMMARY, CONCLUSIONS & RECOMMENDATIONS

Estuaries, the meeting places of fresh and salt water, are among the world's most important natural habitats. Throughout history such areas have been critically significant because they provide fishing, transportation and recreation, as well as fresh water for drinking, power, irrigation, and waste disposal dilution.

Today, over half the people in the world live within 125 miles of a coast. Eighty percent of the global and 70-80% of the U.S. fish and shellfish catch come from areas influenced by fresh water and nutrient inflow from streams, rivers and estuaries. Many thousands of tons of salmon and other anadromous fishes caught each year migrated long distances from the ocean to their home rivers to spawn.

Published results regarding water development in rivers entering the <u>Black Sea, the Sea of Azov, Caspian</u> and <u>Mediterranean Seas</u> in Europe and Asia all point to the conclusion that when successive spring and annual water withdrawals exceeded 30% and more than 40-50% of the normal unimpaired flow respectively, (computed as the average for 50-60 years of observations), water quality and fishery resources in the river-delta-estuary-coastal zone (ocean) ecosystem deteriorated to levels which overrode the ability of the system to restore itself.

Commercial and recreational catches of Russian sturgeon, pike-perch, brim, mackerel, sprat, etc. have been extinguished in the Dniester and Dnieper Estuaries and the most productive Western part of the Black Sea since the late 1960's.

In the Sea of Azov (once the most productive sea in the World), the commercial catch of Russian sturgeon, as well as numerous other valuable semi-anadromous and anadromous fish, dropped from hundreds of thousands to several thousand tons over the last two decades of runoff regulation. (Their requirements for sufficient quantity and quality of water during migration and spawning are almost the same as for the Chinook salmon, striped bass and shad in the San Francisco Bay Area.) The same phenomena were observed in the Caspian Sea as well as with the commercial catch of Salmon in Northern Europe.

In the Nile Delta-Mediterranean Sea coastal zone, the coastal commercial catch of Sardinnela and other species that are dependent on runoff have dropped from more than one hundred thousand tons in the 1950's to several thousand tons since the Aswan Dam operation (1964).

The commercial catch of striped bass in the Chesapeake Bay region has declined up to 70% due to water regulation and pollution. The same percentage decline of fish and shellfish has been observed in the Delaware Bay and the Texas lagoons.

The impoundment of the Murray-Darling River system in Australia and construction of the salt barrier in its Delta has eliminated the fisheries in this area since the 1940's.

Comparable studies and many publications have reached similar conclusions; namely, despite reproductive cycles and behavioral and physiological differences among the estuarine fish species, historic catch levels for each appear to reflect underlying relationships which require specific volumes of runoff discharges, particularly in late winter and spring.

Under natural conditions approximately 60%-70% of the flow takes place during this period, and this flow is responsible for:

1) Repelling the intrusion of sea water into the Delta;

2) Providing necessary levels of nutrients (organic and inorganic materials, phosphate, silicates, nitrogen, etc.);

3) Producing flow conditions necessary for anadromous fish migration, spawning and rearing;

4) Creating a large entrapment zone which optimizes survival of fry and the food on which they feed;

5) Providing flushing and mixing flows to maintain water quality conditions (dissolved oxygen and temperature throughout the water column); and

6) Entraining large amounts of salty water as it flows through the estuary to the ocean, creating a dynamic salinity equilibrium within the system.

Although all of these conditions play important roles in the hatching and development of fish of a given year class, it is extremely important to note that the state of the estuary during this period is heavily influenced by past runoff conditions as well.

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

The research program of the Romberg Tiburon Center over the past three years was designed to (1) provide in-depth evaluation of freshwater inflow to the Delta and Bay, (2) assess 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)), and (3) assess the impacts of flow modification on the fishery resources of the system.

Purpose

The purpose of this report is to utilize the results of the previous investigation on the modification of freshwater flow to the Delta and Bay (Rozengurt et al., 1987a) to analyze the relationship between flow and commercial and recreational fish catches.

Methods

Our analysis was performed in two stages:

1) Annual commercial landings of salmon, striped bass and shad (mainly data for the pre-project period) were compared with spring and annual flows several years earlier. (The use of this procedure is based on the premise that flow has the greatest impact during the first seasons of an organism's life. This technique has been successfully used to show high correlations between flow during egg and larval stages and lobster catches as

long as 8-9 years later, as well as with shorter lag times for fish species generally landed 2-4 years after spawning.) Correlations between fish catch and the annual and seasonal flow conditions for a number of years preceding a given year's catch were calculated in order to examine cumulative effects of flow on fish from year of hatch to year of catch (3-5 years later).

2) The relationships between salmon fall run, Striped Bass Index of abundance and recreational catches (for the post-project period) vs. runoff were also examined with the same technique.

Findings

Modification of Freshwater Flow Conditions

As result of construction of the sophisticated CVP and SWP water storage facilities (with an accumulation capacity equal to 71% of normal unimpaired runoff) and conveyance systems into and out of the Delta (15-20% of the normal Delta outflow), the post-project period natural water supply to the Delta-San Francisco Bay estuarine system has been reduced to unprecedented levels:

1. Since 1967, absolute values of total diversions with predominant range of 10-12 MAF per year (with maximum values of 14-21 MAF) are 2.8 - 3.2 times (and up to 3-5 times) higher than before the CVP and SWP were completed (pre-project period 1915-1943).

2. The absolute values of predominant upstream diversion of 6-12 MAF for the post-project period, 1944-1984, are 3-5 times higher than for 1915-1943.

Absolute values of downstream diversions (Delta consumptive use and export) were in some years, e.g., 1975, of the same magnitude as the upstream diversion, a phenomenon never observed in the pre-project period. The predominant range of annual Delta diversions since 1967 was 4-5 MAF. These values are almost 5 times higher than Delta water withdrawals before the projects were completed.

3. The major cause of these persistent decreases in annual runoff is that diversions in winter (primarily upstream) range between 15 and 45% and in spring (upstream and downstream) between 30 and 80% or more of the natural water supply of the Sacramento-San Joaquin River-Delta subsystem.

4. Since the projects' (CVP and SWP) operations began (especially from the late 60's on), winter and spring regulated water supply to the system was reduced 1.2-1.4 and 1.6-2.4 times in comparison with unimpaired mean winter and spring water supply to the Delta-Bay system, respectively, for 5-year periods (prevailing range of unimpaired runoff is equal to 3-4 MAF). Therefore, for the period 1967-1984, residual winter and, especially spring Delta outflow in the majority of cases corresponded to subnormal and below subnormal wetness when compared with statistics for unimpaired runoff.

5. Between 1944 and 1983, the upstream, downstream and total cumulative losses due to diversions reached 262, 104 and 366 MAF respectively. Cumulative upstream and downstream water losses amounted to 202 and 80 times, respectively, the volume of the Delta (1.3 MAF) while the total diversions account for 61 times the volume of the San Francisco Bay (6 MAF).

6. 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 35-55% less than the natural mean Delta outflow (27.2 MAF).

It should by emphasized that the above-mentioned losses in water supply sustained by the river-Delta-San Francisco Bay ecosystem infer concomitant losses, in millions of tons, of the organic and inorganic matter required to provide adequate ecological conditions for living resources. Moreover, the chronic freshwater deficit may result, as it was documented for the San Francisco Bay and many other estuaries throughout the world, in unfavorable changes in circulation patterns, mixing processes, salinity and other regime characteristics.

7. Based on the experiences of 1924 and 1976-77, it should be emphasized that under natural conditions, annual and spring residual runoff to San Francisco Bay of 3-5 MAF and <1.5 MAF, respectively, would occur only very rarely (once per 100 or more years). If such extreme conditions occur on a regular basis, the Delta-Bay system will cease to function as an estuary and ultimately Delta agriculture, the fresh water quality (for drinking and irrigation), and the estuarine living resources will severely deteriorate.

8. Current decisions (including D-1485) regarding water distribution in California are based on a water year-type classification system (the Four-River Index) which excludes 25% of the Sacramento-San Joaquin river watershed. As a result, the normal (long-term mean) Four-River Index runoff ($\bar{Q}$ = 17.2 MAF;

1921-1978) accounts for only 61% of the normal Sacramento-San Joaquin River inflow to the Delta originating from 100% of the basin area ($\bar{Q}$ = 28.2 MAF; 1921-1978). Therefore, evaluation of wetness of the year, residual runoff and consequent planning for water diversions, based on the Four-River Index, overestimate the level of water availability in a manner incompatible with the relatively meager natural levels of runoff. It follows that in normal, and especially in sub-normal and dry years , the Four-River Index classification system influences decision-makers towards permitting higher (and potentially damaging) levels of diversions.

Recommendations: Runoff

We strongly recommend (as in our previous report, Rozengurt, Herz & Feld, 1987a) that the SWRCB discontinue the use of the Four River Index classification system and substitute it with a system which utilizes flow from the entire watershed for the determination of natural seasonal and annual wetness type, and subsequently, volumes of water available for diversion and correspondance of residual flows to natural flow statistics (i.e., water year-type). Only if total outflow is used as the basis for classification will it be possible to provide the flows needed to protect and maintain the fish and other resources of the Delta-San Francisco Bay system (Fig.3-1).

In our opinion, the recommendations contained in Decision 1485 (based on the Four River Index system) have resulted in spring flow levels that are unprecedented in the recorded history of the system (frequency of occurrence less than once per 100 years). The excessive spring water withdrawals, compounded by the late winter water diversions, have significantly reduced annual river and Delta discharges and contributed greatly to the deterioration of the resources of the system during the past decade.

Modification of landings

Chinook salmon (Oncorhynchus tshawytscha)

Between 1874 and 1914, commercial salmon catches in the Bay and Delta ranged from 2-11 million pounds per year (average = 6), and from 0.3 - 6 million pounds (average = 2) from 1915-1957 (when commercial fishing became restricted to the ocean). Since this span of time encompasses the pre-project and the beginning of post-project periods in water development, it affords an opportunity to assess the relationship between flow and salmon landings by examining catch/flow correlations.

1. For the 1916-1931 period, commercial salmon catch was highly correlated with annual mean regulated Delta outflow for the 5 years preceding (RDO_5) the year of catch ($r = 0.86$; $p < 0.01$), indicating that the volume of annual flow (19-23 MAF) during the years between spawn and maturity influenced catch success. Similar results, but with a slightly lower correlation, were obtained for the 1944-1957 period.

2. Correlations between spring flows and salmon catch, especially during the 1916-1930 period, indicated that even stronger relationships existed between mean regulated spring (April+May+June/3) flows and commercial landings lagged by 3-5

years of the spring runoff (r's = 0.80-0.97; $p < 0.05$). Successful catches resulted when spring flows averaged 2.5-4 MAF (or 42,014-67,222 cfs or 1,189-1,903 m^3/sec).

3. The number of fall-run salmon returning to spawn at Red Bluff (Sacramento River) also demonstrated reasonable correlation with annual and spring runoff for the years preceding the migration of a given year class and subsequent influence of high volumes of runoff on spawning success and survival.

Successful migration appears to require spring flows of 2.3-2.8 MAF (or 38,653-47,056 cfs or 1,094-1,332 m^3/sec).

In this case the total regulated spring Delta outflows of 6.9-8.4 MAF correspond to 40.6% and 44.2% of mean RDO of 17-19 MAF for several preceding years, respectively. (Here, as further in our discussion, the above-mentioned spring and annual volumes of RDO represent the statistics for years of subnormal wetness, e.g., 75-80% of probability of exceedence or recurrence interval of 4-5 years under conditions of unimpaired runoff.)

Striped bass (Loccus saxatilis)

1. Between 1889 and 1935 (when commercial fishing was banned), striped bass catches ranged from 0.5 and 1.4 million pounds. Populations have declined since that time and the recreational catch, which totaled approximately 60,000 fish per year in the early 1960s, dropped to 1,400 fish in 1980. The total Striped Bass Index of abundance has declined from a maximum of 117 in 1965 to a low of 6.5 in 1985.

2. Correlations between commercial striped bass catch and mean annual regulated flow for the 5 preceding years indicated a

good association for the periods 1918-1929 and 1916-1935 (r's= 0.70 and 0.79; p<0.01) while for spring, mean flow for 3 years (5 years before catch) showed slightly lower correlations (r's= 0.67 and 0.65; p <0.01) for the same periods.

3. These results indicate that optimal averaged commercial catches of striped bass (0.5 to 0.6 million pounds per year) were observed when average spring flows (April+May+June/3) for the preceding 3-5 years (lagged by 2-3 years) were in the range of 2.3-3.4 MAF, (38,653-57,139 cfs or 1,082-1,412 m^3/sec) and total spring RDO averaged between 6.9-10.2 MAF (or 38.3% and 46.4%, respectively, of mean annual regulated Delta outflow (RDO) of 18-22 MAF for 3-5 years prior to the year of catch) despite many regulations.

4. Correlations between recreational catch of striped bass and mean spring (April+May+June/3) and annual RDO for the preceding years (lagged by 3 years) illustrate that optimal recreational catch correspond to 2.0-3.0 MAF (i.e., total spring RDO of 6.0-9.0 MAF, or 35.3% and 42.9% of mean annual RDO of 17-21 MAF, respectively).

5. For the 1967-1981 period, correlations between the Striped Bass Index of abundance and 5-year running mean annual regulated Delta outflow yielded one of the highest correlations (r = 0.97; p<0.05), indicating that knowledge of the average flow conditions for 5 running years is a good predictor of Striped Bass Index level and therefore, abundance of fish suitable for recreational catch. These analyses indicate that five years of average annual regulated Delta outflow (RDO_5) of 15 MAF will be

followed by marginal bass abundance, while 18-21 MAF for 5 years will be followed by optimal bass populations.

6. Average spring (April+May+June/3) RDO_5 also were highly correlated with the Striped Bass Index for the 1959-1981 period ($r = 0.82$; $p<0.05$). As with annual flow, the results indicate that 3-5 years with average spring flows of 2-2.5 MAF (33,611-42,014 cfs or 951-1,189 m^3/sec) will result in optimal populations (total spring Delta outflows of 6.0-7.5 MAF correspond to 33.3-35.7% of mean annual Delta outflows for 3-5 years).

American Shad (*Alosa sapidissima*)

1. Between 1916 and 1957 (when commercial fishing was prohibited), landings ranged between 113,000 (1941) and 5.7 million pounds (1916). Correlations for the 1916-1931 period (when level of effort and techniques were relatively constant), indicate that average annual and spring regulated flows for the previous 3-4 years correlated quite well with the commercial shad catch ($r = 0.88$; $p<0.05$ for annual and $r = 0.89$, $p<0.05$ for spring flows).

2. During 1916-1931, landings of 1.5-2 million pounds followed 3- and 5-year periods with average spring Delta outflows of 2.5-3.5 MAF (42,014-58,819 cfs or 1,176-1,665 m^3/sec), i.e., for those periods total spring outflows of 7.5-10.5 MAF correspond to 41.7 and 42.0% of the mean annual flows of 8-25 MAF.

Conclusions

1. The similarities in the correlations between seasonal and annual regulated Delta outflow for the three species of anadromous fish suggest that a specific range of mean flows during consecutive springs, as well as consecutive years, have both a predictable effect on reproduction, recruitment in stock and catch success, and thereby supports the argument that there are cumulative effects of flow on fish (and perhaps on other species as well) in this and other estuaries.

2. In sum, for all three of the most valuable species of anadromous fish of the San Francisco Bay ecosystem (Chinook salmon, striped bass and American shad), the highest correlations between commercial catch and average spring and annual regulated outflows of the pre-project period of 1915-1943 (characterized by predominant upstream diversion) were obtained for catch of a given year against seasonal and annual regulated Delta outflow averaged for the preceding 3-5 years (RDO_3RDO_5).

3. As a rule, the mean spring RDO of <u>2.3-3.5</u> <u>MAF</u> (38,653-58,819 cfs or 1,082-1,665 m^3/sec), which correspond to 64-97% of the normal (unimpaired) spring Delta outflow of 3.6 MAF (for 1921-1978), provided the optimal commercial catch.

Under these conditions <u>the</u> <u>prevailing</u> <u>range</u> <u>of</u> <u>annual</u> <u>averaged</u> <u>regulated</u> <u>Delta</u> <u>outflow</u> was equal to <u>19-22</u> <u>MAF</u> (or 70-81% of the normal unimpaired Delta outflow = 27.2 MAF for the period of 1921-1978).

4. The highest correlations between production indices (<u>salmon</u> <u>fall</u> <u>run</u> and <u>SBI</u>), as well as <u>striped</u> <u>bass</u> <u>recreational</u> <u>catch</u>, and averaged spring and annual regulated Delta outflow for

several consecutive years of the post-project period of 1944-1985 may indicate that the range of 3- and 5-year running mean spring of 2.3-2.5 MAF (38,655-42,014 cfs) was able to maintain relatively tolerant ecological conditions for eggs, larvae and juvenile survival up to 1975. That is, total spring and annual RDO for the 3-5 years preceding the year of catch or index were 6.9-7.5 MAF and 17-19 MAF, respectively. (These ranges of spring and annual $RDO_{3,5}$ correspond to 64-70% and 62-70% of their normals, 3.6 and 27.2 MAF, respectively.)

When the gradual reduction of water supply exceeded these thresholds and reached mean spring and annual regulated volumes of 1.0-1.5 MAF and 11-15 MAF, respectively (or 27-40% and 40-45% of their normals), the signs of deterioration of environment of the riverine-estuarine system and its living resources became obvious.

It seems likely that the average spring water supply for several consecutive years contributes significantly to the adequate ecological conditions for eggs, larvae and juvenile survival. Therefore it is not surprising that these cumulative average regulated Delta outflows (with concomitant influence on nutrient level, salinity, temperature, dissolved oxygen, etc.) affect the overall estuarine environment and, as a result, the reproductive success of fish.

However, the predominant ranges of mean annual and spring water supply to the Bay for the 3- and 5-year periods were 1.5-2.5 times less (annual) and 2.5-3.5 times less (spring) than their normal levels for the last 10-15 years.

In our opinion, this, in combination with less visible man-induced factors, has resulted in a 19- and 60-fold reduction of SBI and salmon fall run between 1959-1985, respectively, as well as in the overall drastic decline of recreational catch of striped bass, recreational and commercial catch of salmon, shad, and steelhead trout in the Sacramento-San Joaquin river-Delta-Bay-coastal zone ecosystem.

The total economic losses due to declines in catch (between 1965-1986) of striped bass and salmon account for 1.6 billion dollars, or 2.6 billion dollars, if steelhead trout decline is taken into consideration (Meyer Resources, 1985; T. Beuttler, presentation at "Fish and Wildlife in the Bay-Delta Estuary" SWRCB Conference #4, 1986).

5. These and other similar historical examples of the relation between human needs for freshwater and protection of estuarine environments indicate that special consideration should be given to the consequences of timing and volume of spring and annual water withdrawals on recruitment and landings of anadromous fish because of their known sensitive response to cumulative fluctuations in freshwater supply. It may be possible to alleviate these problems and to protect water intakes in the Delta if limits to water diversion can be agreed upon, perhaps through the establishment of salinity and flow standards for San Francisco Bay (neither of which currently exist).

Recommendations

Based on this evaluation of modifications in regulated flows and their impacts on salmon, striped bass and shad populations and catches in the Delta and San Francisco Bay, we propose the following criteria for mean spring and annual regulated Delta outflows which must be maintained for periods of at least 2-3 consecutive years to ensure adequate water quality, seasonal displacement of the entrapment zone and optimal conditions for fish migration and spawning, as well as for juvenile survival and success in recreational and even commercial catch in the Delta-San Francisco Bay coastal zone ecosystem (Fig. 8-1, 8-2.; Table 8-1):

A. Total spring regulated Delta outflow = 6.9-7.5 MAF or mean spring (April+May+June/3) flows of at least 2.3-2.5 MAF (64.1-69.6% of the normal spring delta outflow, $\bar{Q}$ = 3.59 MAF) or 38,653-42,014 cfs.

B. Total annual regulated Delta outflows no less than 17-19 MAF (62.5-69.8% of the $\bar{Q}$ = 27.2 MAF).

Table 8-1 summarizes our recommendations for water standards and criteria to safeguard fisheries resources, based on our findings.

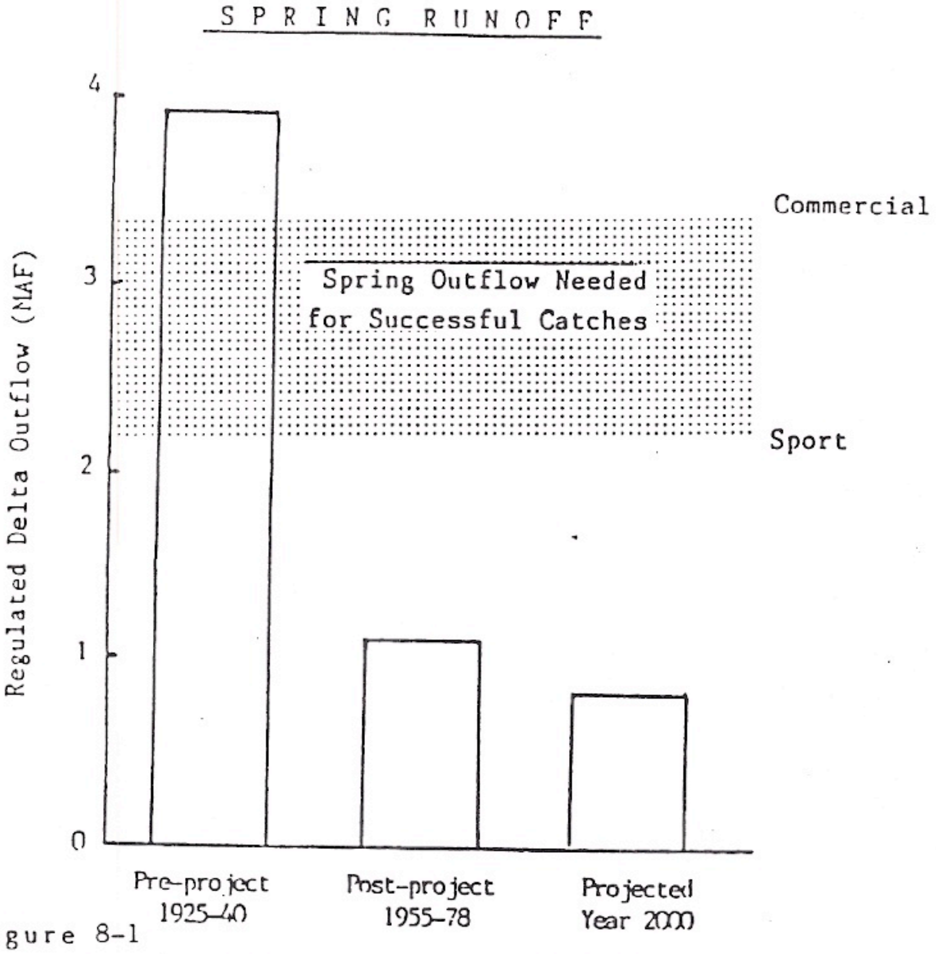


Figure 8-1

Pre-project (1925-40), post-project (1955-78) and projected (year 2000) spring regulated Delta outflow compared with outflow levels needed for successful commercial and sport fish catches (based on correlations between flow and catch for the 1915-40 period).

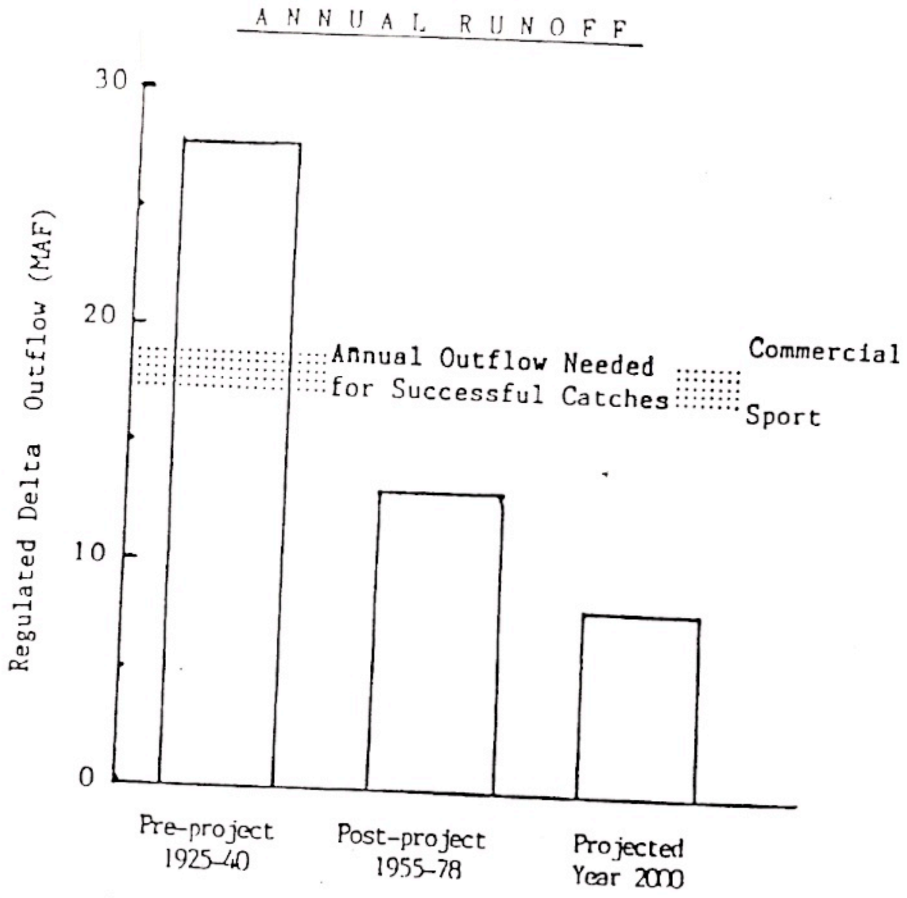


Figure 8-2
Pre-project (1925-40), post-project (1955-78) and projected (year 2000) annual regulated Delta outflow compared with outflow levels needed for successful commercial and sport fish catches (based on correlations between flow and catch for the 1915-40 period).

Table 8-1 Regulated Delta outflow and living resources of the river-Delta-San Francisco Bay ecosystem: pre- and post project observed values and recommendations*

<u>Pre-Project Period</u> - <u>Observed Values</u>:

Parameter\Fish	Commercial Catch		
	Salmon	Striped Bass	Shad
Total Spring Regulated Delta Outflow (RDO):			
MAF	7.5-12.0	6.9-10.2	7.5-10.5
(km^3)	(9.2-14.8)	(8.5-12.6)	(9.2-13.0)
Mean Spring RDO:			
MAF	2.5-4.0	2.3-3.4	2.5-3.5
cfs	42,014-67,222	38,653-57,139	42,014-58,819
(km^3)	(3.1-4.9)	(2.8-4.2)	(3.1-4.3)
(m^3/sec)	(1,189-1,904)	(1,094-1,618)	(1,189-1,666)
Annual RDO:			
MAF	19.0-23.0	18.0-22.0	18.0-25.0
(km^3)	(23.4-28.4)	(22.2-27.1)	(22.2-30.8)

	All 3 Species
Total Spring RDO:	
MAF	6.9-12.0
(km^3)	(8.5-14.8)
Mean Spring RDO:	
MAF	2.3-4.0
cfs	38,653-67,222
(km^3)	(2.8-4.9)
(m^3/sec)	(1,094-1,904)
Annual RDO:	
MAF	18.0-25.0
(km^3)	(22.2-30.8)

Table 8-1 continued

Post-Project Period - Observed Values:

Parameter\Fish	Salmon Fall Run	Striped Bass Index	Striped Bass Recreational Catch
Total Spring Regulated Delta Outflow (RDO):			
MAF	6.9-8.9	6.0-7.5	6.0-9.0
(km^3)	(8.5-11.0)	(7.4-9.2)	(7.4-11.1)
Mean Spring RDO:			
MAF	2.3-2.8	2.0-2.5	2.0-3.0
cfs	38,653-47,056	33,611-42,014	33,611-50,417
(km^3)	(2.8-3.4)	(2.5-3.1)	(2.5-3.7)
(m^3/sec)	(1,094-1,332)	(952-1,189)	(952-1,428)
Annual RDO:			
MAF	17.0-19.0	18.0-21.0	17.0-21.0
(km^3)	(21.0-23.4)	(22.2-25.9)	(21.0-25.9)

- -

Recommendations for all 3 species:	Recreational and Limited Commercial Catch
Total Spring RDO:	
MAF	6.9-7.5
(km^3)	(8.5-9.2)
Mean Spring RDO:	
MAF	2.3-2.5
cfs	38,653-42,014
(km^3)	(2.8-3.1)
(m^3/sec)	(1,094-1,189)
Annual RDO:	
MAF	17-21
(km^3)	(21.0-25.9)

- -

* Note:

The recommended total spring RDO for several years prior to migration and spawning of anadromous fish accounts for 63.9-69.4% of the normal spring Delta outflow of 10.8 MAF. The recommended total annual RDO accounts for 62.5-69.8% of the normal annual Delta outflow of 27.2 MAF. In this case, total

Table 8-1 continued

winter RDO of 8.5-9.5 MAF will account for 61.5-68.7% of the normal winter Delta outflow of 13.8 MAF; the total summer-autumn RDO of 1.6-2.0 MAF will account for 62.0-77.5% of the normal summer-autumn Delta outflow of 2.6 MAF.

The monthly redistribution of regulated outflows may differ from the seasonal averages (especially for winter and spring) provided that their volumes are able to maintain optimal balanced water quality conditions for the different water users.

Because, in our investigation, fish landings and indices are indicators of the health of the environment, the 3- and 5-year running mean RDO are assumed to be responsible for providing optimal conditions for:

- Landward migration, spawning and rearing,
- Seaward migration of juvenile fish,
- Physical, chemical and biological parameters of the entrapment zone (including nutrient supply) as well as its ultimate - spatio-temporal dynamics within the Suisun Bay - Carquinez Strait area,
- Adjustment of juvenile to salinity fluctuations in transition zones of the Delta-Suisun Bay subsystem,
- Water quality in the Delta suitable for different water users,
- Flushing intensity necessary to maintain adequate water quality in the esuarine system.

The recommended optimal range of Delta outflow discharges do not preclude the possibility of additional man-regulated releases, provided these releases will not result in the destabilization of the Delta levees (which have adjusted to impaired runoff and sediment load over the last forty years) or in the development of "shock" conditions for eggs, larvae and juvenile fish.

CONVERSIONS:

Cubic feet per second (cfs) x .028317 = cubic meters per second (m^3/sec)

Acre feet x 1.233 x 10^{-6} = cubic kilometers (km^3)

In our view, any statement published in the past claiming that it is possible to restore a historical level of fish population should be considered erroneous.

The restoration of historical fish levels would only be possible if historical levels of unimpaired runoff discharges, by season and year, as well as historical migration routes of spawning fish and their habitats were also restored.

Moreover, based on worldwide experience, as well as on the development of commercial and recreational fisheries on the Delta-San Francisco Bay ecosystem, future success in fish landings will depend upon the amount of water discharged into the estuarine system especially in the late winter-spring, rather than on the production of hatcheries. Hatcheries may create the illusion of preventing the extinction of a species but cannot restore the historical level of natural fish populations.

Therefore, only economically and ecologically balanced water management can adequately guard the interests of the estuarine environment and its water users. We cannot restore but we can preserve.