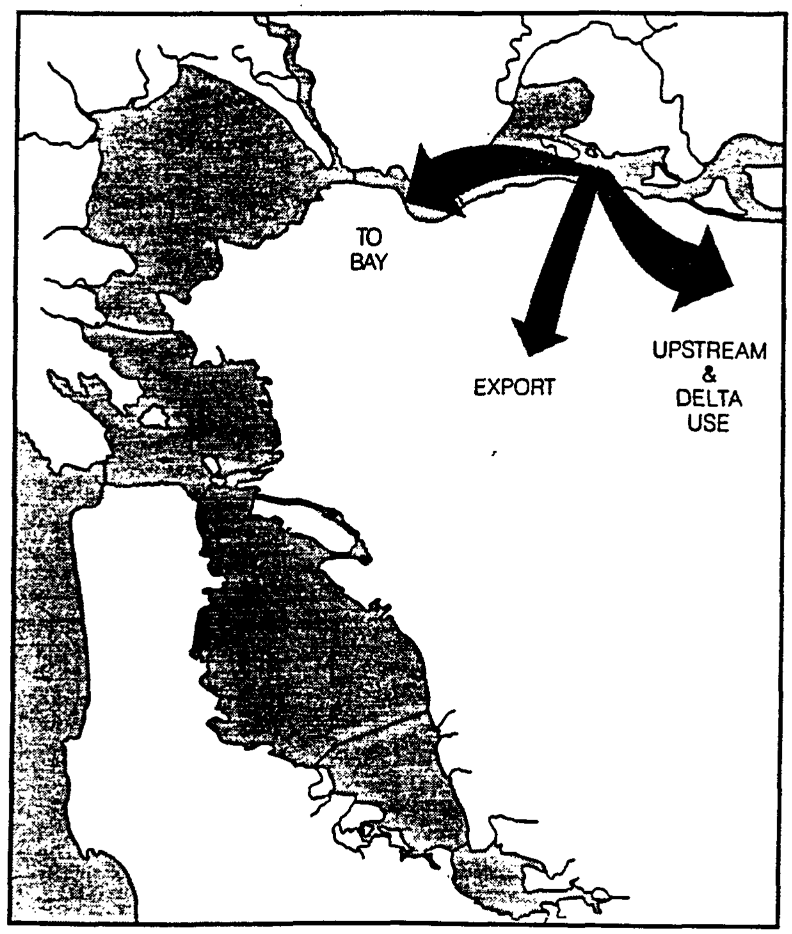
Appendix 6

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



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

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

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

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

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

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

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

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

$$R = P - E$$

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

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

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

where $$W_1 S_1 = W_2 S_2$$

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

$$N = P+Q-E$$

or $$W_1 = N + W_2$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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