State of San Francisco Bay 2011
Appendix B

WATER - Freshwater Inflow Indicators and Index
Technical Appendix

Prepared by Christina Swanson
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I. Background

San Francisco Bay, at the interface between California's largest rivers and the Pacific Ocean, is important spawning, nursery and rearing habitat for a host of fishes and invertebrates, a migration corridor for anadromous fishes like salmon, steelhead and sturgeon, and breeding and nesting habitat for waterfowl and shorebirds. The amounts, timing and patterns of freshwater inflow to the Bay define the quality and quantity of this estuarine habitat and drive key ecological processes (Jassby et al. 1995; Kimmerer 2002, 2004; Feyrer et al. 2008, 2010; Moyle and Bennett, 2008; Moyle et al., 2010; and see Estuarine Open Water Habitat indicator and Flood Events indicator). The mixing of inflowing fresh water and saltwater from the ocean creates low salinity, or "brackish" water habitat for estuary-dependent species. Changes in inflows trigger reproduction and migration, and high flows transport nutrients, sediments and organisms to and through the Bay, promote mixing and circulation within the estuary and flushing contaminants.

Most of the fresh water that flows into the San Francisco Bay comes from the Sacramento and San Joaquin Rivers, which provide >90% of total inflow in most years and have large impacts on salinity regimes in the estuary. Smaller streams around the estuary, like the Napa and Guadalupe rivers, Alameda, San Francisquito, Coyote, Sonoma creeks, and many smaller tributaries, contribute the balance and can have large environmental effects on a local level. All of these rivers have large seasonal and year-to-year variations in flow, reflecting California's seasonal rainfall and snowmelt patterns, and unpredictable times of floods and droughts that are often driven by ocean conditions like El Nino and La Nina.

In the Bay's Sacramento-San Joaquin watershed, several factors have had and are having substantial impacts on the amounts, timing and patterns of freshwater inflows to the estuary (Figure 1). First, flows in most of the Bay's largest tributary rivers have been greatly altered by dams. Many of these dams were built for the purpose of reducing flood events and to store the mountain runoff for later use and export to other regions in the state. Second, large amounts of water are extracted from the rivers and the Delta upstream of the Bay. Collectively, these diversions can remove large percentages of the total flow, even during of relatively high flow. This reduces the amounts of fresh water that flow into the estuary and can decrease inflows to levels below important threshold for habitat creation and sediment transport. Finally, the effects of climate change on flows in the watershed are already detectable and are predicted to increase. With warmer temperatures, increasing proportions of the precipitation in the watershed come as rain, which runs off immediately, rather than snow, which melts and flows into the rivers later in the season. In the rivers and the Bay, the result is more frequent but shorter duration high flow events earlier in the year driven by rain runoff rather than the long duration spring snowmelt flood flows of the past.

The Freshwater Inflow Index uses six indicators to evaluate the amounts, timing, and patterns of freshwater inflow to the estuary from the Sacramento-San Joaquin watershed. In order to account for the system's natural seasonal and year-to-year variability, each of the indicator measurements is made in comparison to what the freshwater inflow conditions would have been if there were no dams or water diversions, referred to as "unimpaired" conditions. The first two of the indicators measure how much water flows into the estuary each year and during the ecologically important spring period. Two other indicators measure the variability of freshwater inflows, both between years and the seasonal variability within each year. The fifth indicator measures how frequently the estuary receives high inflows, which are usually driven by flood conditions in the estuary's watershed. The final indicator measures how frequently the estuary experiences inflow conditions similar to what would have occurred in "critically dry" years, the driest 20% of years, under unimpaired conditions. For each year, the Freshwater Inflow Index is calculated by combining the results of the six indicators into a single number.

II. Data Sources and Definitions

A. Data Sources

Most of the fresh water that flows into the San Francisco Estuary comes from the Sacramento and San Joaquin River basins, which provide >90% of total inflow in most years.[1] Smaller streams around the estuary, principally the Napa and Guadalupe Rivers, Alameda, San Francisquito, Coyote, Sonoma Creeks, and many smaller tributaries, contribute the balance but flow data for these streams is very limited. Therefore, all of the Freshwater Inflow indicators were calculated using flow data from the Sacramento-San Joaquin Delta and watershed only.

The indicators and Index were calculated for each year[2] using data from the California Department of Water Resources (CDWR) DAYFLOW model (for "actual flows," termed "Delta outflow" in the dataset) and CDWR's Central Valley Streams Unimpaired Flows and Full Natural Flows datasets (for "unimpaired flows," and see below).[3] DAYFLOW is a computer model developed in 1978 as an accounting tool for calculating historical Delta outflow and other internal Delta flows.[4] DAYFLOW output is used extensively in studies by State and federal agencies, universities, and consultants. DAYFLOW output is available for the period 1930-2010. Annual and monthly unimpaired flow data for total Delta outflow were from the CDWR California Central Valley Unimpaired Flow dataset (1921-2003; using the "Delta Unimpaired Total Outflow" dataset).[5] For 2004-2010, annual and monthly unimpaired flows were calculated by a regressions developed from the Central Valley unimpaired flow data (using the 1930-1994 period) and the corresponding unimpaired runoff estimates from the "Full Natural Flows" (FNF) dataset[6] for the ten largest rivers in the watershed.[7]

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[1] The Sacramento River provides 69-95% (median=85%) and the San Joaquin River provides 4-25% (median=11%) of total freshwater inflow to the San Francisco Bay (Kimmerer, 2002).

[2] Flow indicators were calculated for each water year. The water year is from October 1-September 30.

[3] For both the DAYFLOW and Central Valley Streams Unimpaired Flows datasets, total freshwater inflow to the San Francisco Estuary from the Sacramento-San Joaquin watershed is referred to as "net Delta outflow".

[4] More information about DAYFLOW is available at http://www.water.ca.gov/dayflow/.

[5] California Central Valley Unimpaired Flow dataset and report is available at: http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/bay_delta_plan/water_quality_control_planning/docs/sjrf_spprtinfo/dwr_2007a.pdf

[6] Full Natural Flows datasets are available at: http://cdec.water.ca.gov/cgi-progs/previous/FNF

[7] The ten rivers are the Sacramento, Feather, Yuba, American, Cosumnes, Mokelumne, Stanislaus, Merced and San Joaquin Rivers. The regression for annual flow is: Unimpaired Delta outflow = -3692.54 + 1.31(10-river unimpaired runoff); n=65, r^2=0.998, p<0.001.

B. Definitions

Water Year Type: Runoff from the Sacramento-San Joaquin watershed can vary dramatically from year to year, a function of California's temperate climate and unpredictable occurrences of droughts and floods. To categorize these large year-to-year variations in flow, we used annual unimpaired inflows to classify each year as one of five water year types: wet, above normal, below normal, dry, and critical.[8] Year types were established based on frequency of occurrence during the period of 1930-2009, with each year type comprising 20% of all years.[9] Figure 2 shows annual unimpaired inflows with year type classification shown by the different colors of the bars.

Unimpaired Inflow: Unimpaired inflow is the freshwater inflow that, under the same hydrological conditions but without the effects of dams and diversions in the Sacramento-San Joaquin watershed, would have flowed into the estuary (see Figure 1).

Pre-dam Inflow: The period prior to the completion of major dams in the watershed, from 1930-1943, is referred to as the "pre-dam" period. During this period, actual flows were somewhat similar to unimpaired flows.

III. Indicator Evaluation

The San Francisco Estuary Partnership's Comprehensive Conservation and Management Plan (CCMP) calls for "increase[ing] freshwater availability to the estuary", "restor[ing] healthy estuarine habitat" and "promot[ing] restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary" are non-quantitative. However, California's State Water Resources Control Board (SWRCB) recently determined that, in order to protect public trust resources in the Sacramento-San Joaquin Delta and San Francisco Estuary, 75% of unimpaired runoff from the Sacramento-San Joaquin watershed should flow out of the Delta and into the estuary (SWRCB 2010).[10] Therefore, the "primary" reference conditions for most of the Freshwater Inflow indicators were developed based this recommendation.

A primary reference condition was established for each indicator. For most of the indicators, this reference condition was developed based on the SWRCB's recommendation for 75% of unimpaired flow to the estuary. Pre-dam flows were also used as the basis for some indicators. Measured indicator values that were higher than the primary reference condition were interpreted to mean the indicator results met the CCMP goals and corresponded to "good" ecological conditions.

[8] Despite use of the term "below normal", this year type includes the median, with half of all years receiving more runoff and the other half of years receiving less runoff.
[9] Terminology for the five year types follows that used by state and federal water management agencies although, for water management purposes in the Sacramento and San Joaquin basins, water year types are determined using other factors, such as the previous year's precipitation, as well as than frequency of occurrence.
[10] The SWRCB recommendation was for the winter-spring period (January-June) and it was expressed as the 14-day running average of estimated unimpaired runoff, rather than as an annual or seasonal total.

In addition to the primary reference condition, information on the range and trends of indicator results, results from other watersheds, and known relationships between freshwater inflow conditions and physical and ecological conditions in estuaries was used to develop several intermediate reference conditions, creating a five-point scale for a range of evaluation results from “excellent,” “good, “fair,” “poor” to “very poor”. The size of the increments between the different evaluation levels was, where possible, based on observed levels of variation in the measured indicator values (e.g., standard deviations) in order to ensure that the different levels represented meaningful differences in the measured indicator values. Each of the evaluation levels was assigned a quantitative value, or score, from “4” points for “excellent” to “0” points for “very poor.” For each year, the Freshwater Inflow Index was calculated as the average of these six scores. Specific information on the primary and intermediate reference conditions is provided in the following sections describing each of the indicators.

Indicator and Index results were analyzed using analysis of variance and simple linear regression to identify differences among different time periods and trends with time.

IV. Indicators

A. Annual Inflow

1. Rationale

The amount of freshwater inflow to an estuary is a physical and ecological driver that defines the quality and quantity of estuarine habitat (Jassby et al. 1995; Kimmerer 2002; 2004 Feyrer et al. 2008, 2010; Moyle and Bennett, 2008; Moyle et al., 2010). In the Sacramento-San Joaquin watershed, annual runoff varies substantially for year-to-year, but during the past century, freshwater inflows into the estuary have been greatly altered by upstream dams and water diversions. Nine of the ten largest rivers that flow in the estuary’s Sacramento-San Joaquin watershed have large storage dams, where runoff is captured, stored and diverted. Additional water diversions are located along the rivers downstream of the dams and, in the Delta where the river flow into the estuary, local, state and federal water diversions extract more water for local and distant urban and agricultural. The resultant changes in the amount of freshwater flow that actually reaches the estuary have affected the estuarine ecosystem and the plants and animals that depend on it.

2. Methods and Calculations

The Annual Inflow indicator measures the amount of fresh water from the Sacramento-San Joaquin watershed that flows into San Francisco Estuary each year compared to the amount that would have flowed into the estuary under unimpaired conditions. The indicator was calculated for each year (1930-2010) using data for total annual actual freshwater inflow and estimated total annual unimpaired inflow.

The indicator is calculated as:

Annual Inflow (% of unimpaired) = [(actual inflow/unimpaired inflow)*100].

By incorporating unimpaired inflow as a component of the indicator calculation, the Annual Inflow indicator has been normalized to account for natural year-to-year variations in precipitation.

3. Reference Conditions

The primary reference condition for the Annual Inflow indicator was established as 75%, a level based on the SWRCB's recommendation for freshwater inflows needed to support public trust resources in the estuary. Annual inflows that were greater than 75% of unimpaired inflows were considered to reflect "good" conditions. Additional information from trends and variability in annual inflows and from other estuaries was used to develop several other intermediate reference conditions. Table 1 below shows the quantitative reference conditions that were used to evaluate the results of the Annual Inflow indicator.

4. Results

Results of the Annual Inflow indicator are show in Figure 3.

The amount of fresh water flowing into the San Francisco Estuary each year has been reduced.

On an annual basis, the percentage of the freshwater runoff from estuary's largest watershed that flows into the estuary has been significantly reduced. For the most recent 10-year period (2001-2010), on average only 52% of unimpaired inflow actually flowed into the estuary. In 2010, only 39% of unimpaired inflow reached the estuary. In 2009, annual inflow only 32% of unimpaired, the third lowest percentage of freshwater inflow in the 81-year data record. In ten of the past 20 years (50% of years), the percentage of unimpaired flow that flowed into the estuary was less than 50%.

The proportional alteration in annual freshwater inflow to the estuary differs by water year type.

The greatest alterations to freshwater inflows (expressed as a percentage of estimated unimpaired inflow) occur in dry years. Since the 1950s, the percentages of unimpaired flow that reached the estuary averaged 43% in critically dry years, 53% in dry years, 62% in below normal years, 68% in above normal years and 73% in wet years.

Freshwater flow into the San Francisco Estuary, as a percentage of unimpaired flow, has declined over time.

The percentage of unimpaired flow that actually flowed into the estuary has declined significantly over the past several decades (regression, $p<0.001$). Significant declines in the percentage of unimpaired inflow reaching the estuary have occurred in all water years types (regression, all test, $p<0.05$). Before construction of most of the major dams on the estuary's tributary rivers (1930-1943, the "pre-dam" period), an average of 82% of estimated unimpaired flow actually reached the estuary. By the 1980s, the percentage had decreased significantly to just 60% (1980-1989 average; Mann-Whitney, $p<0.01$). The average for the most recent 10-year period, 49%, is somewhat lower but, due to the large inter-annual variability associated with hydrology, not significantly different than flows during the 1980s.

Based on annual inflows, CCMP goals to increase fresh water availability to the estuary have not been met.
Current freshwater inflows to the estuary are well below the 75% level identified by the SWRCB as necessary to protect public trust resources and estuarine health. Current inflows are also somewhat lower than those measured in the 1980s, the period during which the CCMP was developed and established.

B. Spring Inflow

1. Rationale

Freshwater inflows during the spring provide important spawning and rearing habitat for many estuarine fishes and invertebrates (Jassby et al., 1995; Kimmerer, 2002; 2004; see also Estuarine Open Water habitat indicator). For a number of species, population abundance and/or survival are strongly correlated with the amounts of inflow the estuary receives during the spring and the location of low salinity, brackish water habitat, where fresh water from the rivers meets saltwater from the Pacific Ocean. Abundance and/or survival are higher when spring inflows are high and low salinity habitat is located downstream in the estuary, closer to the Golden Gate compared to years in which it is located further upstream (Jassby et al, 1995; Kimmerer 2002; 2004; Kimmerer et al., 2008).

2. Methods and Calculations

The Spring Inflow indicator measures the amount of fresh water from the Sacramento-San Joaquin watershed that flows into San Francisco Estuary during the spring, February-June, compared to the amount that would have flowed into the estuary during that season under unimpaired conditions. The indicator was calculated for each year (1930-2010) using data for February-June actual freshwater inflow and estimated total annual unimpaired inflow.

The indicator is calculated as:

Spring Inflow (% of unimpaired)
= [(actual inflow, Feb-June/unimpaired inflow, Feb-June)*100].

By incorporating unimpaired inflow as a component of the indicator calculation, the Spring Inflow indicator has been normalized to account for natural variations in precipitation.

3. Reference Conditions

The primary reference condition for the Spring Inflow indicator was established as 75%, a level based on the SWRCB’s recommendation for freshwater inflows needed to support public trust resources in the estuary. Spring inflows that were greater than 75% of unimpaired inflows were considered to reflect "good" conditions. Additional information from trends and variability in spring inflows and from other estuaries was used to develop several other intermediate reference conditions. Table 2 below shows the quantitative reference conditions that were used to evaluate the results of the Spring Inflow indicator.

4. Results

Results of the Spring Inflow indicator are show in Figure 4.

The amount of fresh water flowing in the San Francisco Estuary during the spring has been reduced.
The percentage of the springtime runoff from estuary's largest watershed that flows into the estuary has been significantly reduced. For the most recent 10-year period (2001-2010), on average only 42% of unimpaired inflow actually flowed into the estuary. In 2010, only 32% of unimpaired inflow reached the estuary. In 2009, annual inflow only 27% of unimpaired, the seventh lowest percentage of freshwater inflow in the 81-year data record. In 12 of the past 20 years (60% of years), the percentage of unimpaired flow that flowed into the estuary was less than 50%.

The proportional alteration in spring inflow to the estuary differs by water year type.
The greatest alterations to freshwater inflows (expressed as a percentage of estimated unimpaired inflow) occur in dry years. Since the 1950s, the percentages of unimpaired flow that reached the estuary averaged 32% in critically dry years, 41% in dry years, 52% in below normal years, 60% in above normal years and 76% in wet years.

Spring flow into the San Francisco Estuary, as a percentage of unimpaired flow, has declined over time.
The percentage of unimpaired flow that actually flowed into the estuary during the spring has declined significantly over the past several decades (regression, $p<0.001$). Significant declines in the percentage of unimpaired inflow reaching the estuary have occurred in all water years types except wet years (regression, all tests, $p<0.05$). Before construction of most of the major dams on the estuary's tributary rivers (1930-1943, the "pre-dam" period), an average of 79% of estimated unimpaired flow actually reached the estuary. By the 1980s, the percentage had decreased significantly to just 49% (1980-1989 average; t-test, $p<0.001$). The average for the most recent 10-year period, 42%, is somewhat lower but, due to the large inter-annual variability associated with hydrology, not significantly different than flows during the 1980s.

Based on spring inflows, CCMP goals to increase fresh water availability to the estuary have not been met.
Current spring inflows to the estuary are well below the 75% level identified by the SWRCB as necessary to protect public trust resources and estuarine health. Current inflows are also somewhat lower than those measured in the 1980s, the period during which the CCMP was developed and established.

C. Inter-annual Variation in Inflow

1. Rationale

Runoff from the Sacramento-San Joaquin watershed, which provides >90% of the total freshwater inflow to the San Francisco Estuary, varies dramatically from year to year, a function of California's temperate climate and unpredictable occurrence of droughts and floods. Just as the amount of freshwater inflow into an estuary is a physical and ecological driver that defines the quality and quantity of estuarine habitat (Jassby et al. 1995; Kimmerer 2002, 2004; Feyrer et al. 2008, 2010; Moyle and Bennett, 2008; Moyle et al., 2010), the inter-annual variability of freshwater inflows, a key feature of estuaries, drives spatial and temporal variability in the ecosystem and creates the dynamic habitat conditions upon which native fish and invertebrate species depend.

2. Methods and Calculations

The Inter-annual Variation in Inflow indicator measures the difference between the inter-annual variation in actual annual inflow to San Francisco Estuary and that of unimpaired annual inflow for the same period. For the two annual inflow measures, variation was measured as the standard deviation (expressed in units of thousands of acre-feet, TAF) for prior ten-year period that ended in the measured year. The indicator was calculated for each year (1939-2010) as the difference between the standard deviations (SD).

The indicator is calculated as:

Inter-annual Variation in Inflow (TAF)
= (SD in actual inflow for year$_{(0\text{ to }-9)}$) – (SD in unimpaired inflow for year$_{(0\text{ to }-9)}$).

By incorporating unimpaired inflow as a component of the indicator calculation, the Inter-annual Variation in Inflow indicator has been normalized to account for natural year-to-year variations in precipitation.

3. Reference Conditions

The primary reference condition for the Inter-annual Variation in Inflow indicator was established by calculating the difference in inter-annual variation of unimpaired annual inflows and unimpaired inflows that had been reduced by 15-25% (depending on water year type)[11] for the same period. Based on this calculation, the reference condition was set at -1700 TAF. Differences between inter-annual variation of actual and unimpaired inflows that were less than this (i.e., less negative) were considered to reflect "good" conditions. Additional information from trends and variability in inter-annual variability was used to develop several other intermediate reference conditions. Table 3 below shows the quantitative reference conditions that were used to evaluate the results of the Inter-annual Variation in Inflow indicator.

4. Results

[11] For calculation of the reference condition, unimpaired inflows<29,500 TAF (60% of years) were reduced by 25%, unimpaired inflows between 29,500 and 42,000 TAF were reduced 20%, and unimpaired inflows >42,000 TAF were reduced by 15%.

Results of the Inter-annual Variation in Inflow indicator are show in Figures 5 and 6.

Inter-annual variability in inflows to the San Francisco Estuary has varied substantially over time.
The magnitude of inter-annual variability of unimpaired and actual freshwater inflows to the San Francisco Estuary is itself highly variable, reflecting unpredictable periodic differences in total annual flows that can vary by an order of magnitude (i.e., high inter-annual variation and large standard deviation) as well as periodic sequences of years with relatively comparable annual flows (i.e., low inter-annual variation and low small standard deviation) (Figure 5). Over the 81-year data record, unimpaired annual flows since the early 1980s have been substantially more variable (1980-2010 average variability: 17,042 TAF) than annual unimpaired flows during the earlier 40 years (1939-1979 average variability: 12,908 TAF). Inter-annual variation in actual annual flows showed a similar pattern (1939-1980 average: 12,082 TAF compared to the 1981-2009 average: 14,900 TAF).

Inter-annual variability in inflows to the San Francisco Estuary has been reduced.
Since the late 1960s, when large storage dams on most the estuary's large tributary rivers were completed (i.e., the "post-dam" period), there has been a significant decrease in the inter-annual variability of actual inflows to the estuary compared to the inter-annual variability of unimpaired flows measured for the same 10-year periods (t-test, $p<0.001$) (Figure 6). For the 1939-1967 period, the average difference in variability between actual and unimpaired flows was -256 TAF compared to the average difference in variability for the 1968-2010 period of -2158 TAF. Since the 1980s, inter-annual variation in annual freshwater inflows has varied but not changed significantly: the difference between actual and unimpaired variation in the 1980s (1980-1989), -2315 TAF, is not significantly different than that measured in the 2000s (2000-2010), -1573 TAF (t-test, $p>0.05$).

Based on recent inter-annual variation of inflows to the estuary, CCMP goals to increase freshwater availability to the estuary and restore healthy estuarine habitat and function have been met in some years.
Since 2005, inter-annual variation in annual freshwater inflow to the estuary conditions have been above the reference condition developed based on the SWRCB flow criteria. However, inter-annual variation conditions were well below this reference condition for the decade prior to this and for 19 of the past 30 years. This most recent five-year period also coincides with a period of relatively low inter-annual variation in annual flows (see Figure 5).

D. Seasonal Variation in Inflow

1. Rationale

Freshwater inflow to the San Francisco Estuary varies dramatically within the year, reflecting both California's Mediterranean climate with its wet and dry seasons as well as the high elevations in estuary's Sacramento-San Joaquin watershed in which large proportions of precipitation fall as snow that melts and runs off to the rivers later in the spring and early summer (see Figure 1). These seasonal variations in inflow create different kinds of habitat, for example, large areas of low salinity open water habitat in the estuary (Kimmerer 2002, 2004; Moyle et al. 2010). They drive important ecological processes such as flooding, which transports sediment, nutrients and organisms downstream and promotes mixing and circulation of estuary waters. And they trigger and facilitate key life history stages of both plants and animals, including reproduction, dispersal and migration.

2. Methods and Calculations

The Seasonal Variation in Inflow indicator measures the difference between the seasonal (or intra-annual) variation in actual monthly average inflow to San Francisco Estuary and that of unimpaired monthly inflow for the same year. For the two monthly inflow measures, variation was measured as the standard deviation (expressed in units of cubic feet per second, cfs). The indicator was calculated for each year (1930-2010) as the difference between the standard deviations.

The indicator is calculated as:

Seasonal Variation in Inflow (cfs)
= (SD in actual monthly average inflow) – (SD in unimpaired monthly average inflow).

By incorporating unimpaired inflow as a component of the indicator calculation, the Seasonal Variation in Inflow indicator has been normalized to account for natural year-to-year variations in precipitation.

3. Reference Conditions

The primary reference condition for the Seasonal Variation in Inflow indicator was established by calculating the difference in seasonal variation of unimpaired monthly inflows and unimpaired inflows that had been reduced by 15-25% (depending on water year type)[12] for the same period. Based on this calculation, the reference condition was set at -6700 cfs. Differences between inter-annual variation of actual and unimpaired inflows that were less than this (i.e., less negative) were considered to reflect “good” conditions. Additional information from trends and variability in seasonal variability was used to develop several other intermediate reference conditions. Table 4 below shows the quantitative reference conditions that were used to evaluate the results of the Seasonal Variation in Inflow indicator.

4. Results

Results of the Seasonal Variation in Inflow indicator are show in Figures 7 and 8.

Seasonal variability in inflows to the San Francisco Estuary is directly related to hydrology.

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[12] For calculation of the reference condition, unimpaired inflows<29,500 TAF (60% of years) were reduced by 25%, unimpaired inflows between 29,500 and 42,000 TAF were reduced 20%, and unimpaired inflows >42,000 TAF were reduced by 15%.

The magnitude of seasonal variation in unimpaired and actual freshwater inflows to the San Francisco Estuary varies directly with hydrology, as measured by unimpaired inflows: variability is high in wet years and low in dry years (regression, both tests, $p<0.001$) (Figure 7).

Seasonal variability in inflows to the San Francisco Estuary has been reduced.
Seasonal variability of freshwater inflows to the estuary has declined significantly (regression, $p<0.001$) (Figure 8). The decline began in the mid-1940s, when the first of large storage dams in the estuary's watershed were completed. In the "pre-dam" period (1930-1943), the difference between actual and unimpaired seasonal variability was -2200 cfs; by the 1980s the difference between actual and unimpaired seasonal variation was significantly larger, -9069 cfs (t-test, $p<0.05$). Since the 1980s, seasonal variation has continued to decline: in the 1990s, the average difference between actual and unimpaired variation fell to -9723 cfs and in the 2000s it averaged -11,644 cfs. In 2010, it was -19,587 cfs, the sixth greatest difference between actual and unimpaired seasonal variability in the 81-year record.

Based on recent seasonal variations of inflows to the estuary, CCMP goals to increase freshwater availability to the estuary and restore healthy estuarine habitat and function have not been met in most years.
Since the 1980s, the seasonal variability of freshwater inflows to the estuary have been below the reference conditions and not met the CCMP goals in 70% of years. In the most recent decade, the CCMP goal was met only once, in 2006.

E. Peak Flow

1. Rationale

High, or "peak", freshwater inflows to the San Francisco Estuary occur following winter rainstorms and during the spring snowmelt. High inflows transport sediment and nutrients to the estuary, increase mixing of estuarine waters, and create low salinity habitat in Suisun and San Pablo Bays (the upstream reaches of the estuary), conditions favorable for many estuary-dependent fish and invertebrate species. In rivers and estuaries, peak flows and the flood events they typically produce are also a form of "natural disturbance" (Kimmerer 2002, 2004; Moyle et al., 2010).

2. Methods and Calculations

The Peak Flow indicator measures the frequency, as number of days per year, of peak flows into the San Francisco Estuary, compared to the number of days that would be expected based on unimpaired runoff from the estuary's watershed. Peak flow was defined as the 5-day running average of actual freshwater inflow>50,000 cfs. Selection of this threshold value was based on two rationales: 1) flows of this magnitude shift the location of low salinity habitat[13] downstream to 50-60 km (depending on antecedent conditions), providing favorable conditions for many estuarine invertebrate and fish species; and 2) examination of DAYFLOW data suggested that flows above this threshold corresponded to winter rainfall events as well as some periods during

[13] The location of low salinity habitat in the San Francisco Estuary is often expressed in terms of X2, the distance in km from the Golden Gate to the 2 ppt isohaline.

the more prolonged spring snowmelt, therefore this indicator evaluated the estuary's responses to a key aspect of seasonal flow variation in its watershed.

The indicator is calculated as the difference between the actual number of days of peak flow per year and the expected number of days of peak flow per year:

Peak flow (days) = # days peak flow (actual) – # days peak flow (predicted).

Daily unimpaired flow data are available for only a few recent years therefore, to predict the number of days of peak flow per year under unimpaired conditions, a polynomial regression was developed based on actual flows from the 1930-1943 "pre-dam" period, before major storage dams were constructed on the watershed's large rivers (Figure 7). Water Year 1983, the year with the highest annual unimpaired inflow on record and during which flows were minimally affected by water management operations, was also included in this regression analysis to provide a high inflow value and anchor the regression. The regression equation is shown in Figure 9. For years in which the polynomial regression predicted a number of days of peak that was less than zero and in which the actual number of days of peak flows was zero, the indicator value (the difference between actual and predicted) was set to zero.[14] By incorporating peak flow frequency predictions based on pre-dam conditions as an estimate of unimpaired inflow as a component of the indicator calculation, the Peak Flow indicator has been normalized to account for natural year-to-year variations in precipitation.

3. Reference Conditions

The reference condition was established based on the 95% confidence interval for the polynomial regression developed from pre-dam and 1983 data (see Figure 9 above). Over most of the range of unimpaired inflows, the maximum value for the 95% confidence interval was 15 days. Therefore the reference condition was set at twice this value, or -30 days (i.e., 30 fewer days of peak flow compared to the number predicted based on unimpaired inflow). Differences between actual and predicted number of days of peak flow that were less than this (i.e., less negative) were considered to reflect "good" conditions. Additional information from the polynomial regression and trends and variability in peak flows was used to develop several other intermediate reference conditions. Table 5 below shows the quantitative reference conditions that were used to evaluate the results of the Peak Flow indicator

4. Results

Results of the Peak Flow indicator are show in Figure 10.

The frequency of peak flows into the San Francisco Estuary varies with water year type. Actual peak flow frequency (as number of days per year) is highest in wet years, when there are of 144 days of peak flow per year on average for the 80 year data record, lowest in critically dry years (<2 days/year). Dry years have an average of 13 days/years, below normal years an average of 48 days/year and above normal years an average of 85 days. Since 1944, after dams on most the estuary's large tributary rivers were completed, actual peak flow frequency is

[14] This occurred in only three years: 1931, 1976 and 1977.

significantly lower that would be predicted based on estimated unimpaired flow conditions (Mann-Whitney, $p<0.001$). There are an average of 12 fewer days of peak flows in critically dry years, 31 fewer days in dry years, 42 fewer days in below normal years, 54 fewer days in above normal years and 41 fewer days in wet year.

Peak flow frequency has declined over time.
Peak flow frequency, expressed as the difference between actual peak flow frequency and predicted peak flow frequency under estimated unimpaired flow conditions, is highly variable but has declined significantly over the 81-year period of record (regression, $p<0.001$). Most of the decline occurred after 1943, immediately following completion of most of the large dams on the estuary's large tributaries. However, since 1944, peak flow frequency has continued to decline over time in dry, above normal and wet years (regression, $p<0.05$; regression for critically dry years, $p=0.052$; regression for below normal years, $p=0.08$). On average, there are 36 fewer days of peak flows per year since the mid-1940s than during the 1930-1943 period. In the 1980s, peak flows were reduced by an average of 39 days. In the 2000s, there was an average of 48 fewer days of peak flows.

Based on recent peak flow frequency, CCMP goals to increase freshwater availability to the estuary and restore healthy estuarine habitat and function have been met in less than 50% of years.
In the most recent decade (as well as for the most recent 5-year period), the reduction in peak flow frequency has been greater (i.e., more negative) than the reference condition (-30 days) in 60% of years. Since 1980, the reference condition for peak flow frequency has not been met in 58% of years.

F. Dry Year Frequency

1. Rationale

California's Mediterranean climate is typified by unpredictable cycles of droughts and floods. Runoff from the Sacramento-San Joaquin watershed, which provides >90% of the total freshwater inflow to the San Francisco Estuary, can vary dramatically from year to year, and freshwater inflow to the San Francisco Estuary is a key physical and ecological driver that defines the quality and quantity of estuarine habitat (Jassby et al. 1995; Kimmerer 2002, 2004; Feyrer et al. 2008, 2010; Moyle and Bennett, 2008; Moyle et al., 2010). Water storage and diversions in the estuary's watershed reduce the amounts of fresh water that reach the estuary and can result in inflow conditions comparable to dry hydrological conditions in years when actual hydrological conditions in the watershed are not dry. In dry years, total annual freshwater inflow, seasonal variations in inflow and the quantity and quality of low-salinity estuarine habitat are all reduced, resulting in stressful conditions for native resident and migratory species that rely on the estuary. Multi-year sequences of dry years, or droughts, exacerbate these stressful conditions and often correspond to population declines and shifts and/or decreases in species' distributions.

2. Methods and Calculations

The Dry Year Frequency indicator measures the difference between the frequency of critically dry years based on estimated unimpaired freshwater inflows to the estuary (and actual hydrological conditions in the Sacramento-San Joaquin watershed) and the frequency of critically dry years experienced by the estuary based on actual freshwater inflows. Critically dry (CD) years were defined as the driest 20% of years in the 80-year estimated unimpaired Delta outflows dataset, with total annual inflows to the estuary of less than 15,000 thousand acre-feet (see Table 6).

For the indicator, actual total annual freshwater inflows to the estuary for each year were categorized using this water year type classification scale. For each year (1939-2010), the number of CD years that occurred for the prior ten-year period that ended in the measured year was calculated for both unimpaired flows and actual flows. The indicator measured the difference between the number of CD years that occurred under unimpaired conditions and the number that occurred in actual conditions.

The indicator is calculated as:

Dry Year Frequency
= (# CD years, unimpaired inflow conditions for $\text{year}_{(0 \text{ to } -9)}$) – (# CD years, actual inflow conditions for $\text{year}_{(0 \text{ to } -9)}$).

By incorporating unimpaired inflow as a component of the indicator calculation, the Dry Year Frequency indicator has been normalized to account for natural year-to-year variations in precipitation.

3. Reference Conditions

The reference condition for the Dry Year Frequency indicator was established by calculating the average difference between CD frequency in unimpaired inflows and for unimpaired inflows that had been reduced by 15-25% (depending on water year type).[15] Based on this calculation, the reference condition was set at 1.5 years. Differences in the numbers of CD years between 10-year sequences of actual and unimpaired flows that were less than this were considered to reflect "good" conditions. Additional information from trends and variability in CD year frequency was used to develop several other intermediate reference conditions. Table 7 below shows the quantitative reference conditions that were used to evaluate the results of the Dry Year Frequency indicator.

4. Results

Results of the Dry Year Frequency indicator are show in Figures 11 and 12.

The frequency of critically dry inflows to the San Francisco Estuary has varied over time.

[15] For calculation of the reference condition, unimpaired inflows<29,500 TAF (60% of years) were reduced by 25%, unimpaired inflows between 29,500 and 42,000 TAF were reduced 20%, and unimpaired inflows >42,000 TAF were reduced by 15%.

While the classification of critically dry (CD) year inflows is based on the bottom quintile from the 80-year unimpaired dataset, the frequency of critically dry hydrological conditions (i.e., hydrological conditions that result in CD freshwater inflow to the estuary) has been more variable over that period (Figure 11, upper panel). The number of CD years per 10 year period for unimpaired conditions ranged from zero, during the 1950s and 1960s, to as high as six out of ten years, during the late 1980s and early 1990s. For actual conditions, which were affected by the amounts of water stored and diverted from the estuary's watershed, the frequency of freshwater inflows in amounts comparable to what the estuary would experience in CD years under unimpaired conditions, was higher (Figure 11, bottom panel, and Figure12). The largest increases in CD year frequency occurred in the 1960s, a period during which there were no CD years based on hydrological conditions in the estuary's watershed, but during which the estuary received freshwater inflows comparable to CD conditions in an average of six out of 10 years. In the 1980s, an average of 1.8 years were critically dry in the watershed but in the estuary an average of 4.4 years were critically dry (i.e., there were an average of 2.6 more CD years out of 10 years than there were based on hydrological conditions in the estuary's watershed). Conditions during the most recent decade (2001-2010) were similar, with an average of 4.8 CD out of 10 years for the estuary compared to just 2.7 CD years based on unimpaired conditions in the estuary's watershed.

The frequency of freshwater inflow conditions in the San Francisco Estuary that are comparable to critically dry years has increased.
Since 1944, when major dams on the estuary's tributary rivers were completed, the frequency of freshwater inflow conditions that correspond to CD years has increased significantly (Wilcoxon Signed Rank test, $p<0.001$) (Figure 12). On average, the estuary experienced 2.8 more CD years per 10-year period than it would have based on estimated unimpaired inflows and actual hydrological conditions in its largest watershed. On the basis of actual freshwater inflows, the estuary is experiencing chronic drought conditions, particularly during the 1960s and 2000s when conditions in the estuary's watershed were not chronically dry.

Based on recent critically dry year frequencies in the estuary, CCMP goals to increase freshwater availability to the estuary and restore healthy estuarine habitat and function have not been met in most years.
Since 2003, the estuary has experienced two to five more years per 10-year period of CD freshwater inflow conditions that it would have under unimpaired conditions. As of 2010, eight of the past 10 years, or 80% of years, were, for the estuary, critically dry (compared to just three critically dry years, 30% of years, in estuary's watershed based on actual hydrological conditions). During the past 60 years, the frequency of critically dry conditions in the estuary has been 50% (30 of 60 years had actual total annual freshwater inflows <15,000 TAF) and the running 10-year frequency of CD conditions was greater than the reference condition in 50 years (83% of years).

V. Freshwater Inflow Index

The Freshwater Inflow Index aggregates the results of the six indicators (Annual Inflow, Spring Inflow, Inter-annual Variation in Inflow, Seasonal Variation in Inflow, Peak Flow and Dry Year Frequency) into a single number.

A. Index Calculation

For each year, the Freshwater Inflow Index is calculated by averaging the quantitative scores of the six indicators. Each indicator is weighted equally. An index score greater than 3 was interpreted to represent "good" conditions and an index score less than 1 was interpreted to represent "very poor" conditions.

B. Results

Results of the Freshwater Inflow Index are shown in Figure 13.

Freshwater inflow conditions in the estuary have declined.
Based on the Freshwater Inflow Index, freshwater inflow conditions to the estuary have declined significantly (regression, $p<0.001$). The decline in the Index is driven by declines in all six indicators of freshwater inflow conditions. Most of the decline occurred during the 1950s and 1960s, the period after and during which major dams on the majority of the estuary's largest tributary rives were completed. The Index fell from an average of 3.2 in the 1940s (1939-1949 average), to 2.7 in the 1950s and 1.8 in the 1960s. The Index was relatively stable during the 1970s and 1980s (1970-1979 average: 1.7; 1980-1989: 1.85), improved slightly in the 1990s, concurrent with an unusually wet sequence of years (1990-1999: 2.0) and then declined somewhat in the 2000s, falling to 1.65 (2000-2009 average). The 2010 Freshwater Inflow Index (0.67, or "very poor") was the lowest for the 72-year record, and the 2009 Index (0.83) was the second lowest.[16]

Based on the Freshwater Inflow Index, CCMP goals to increase freshwater availability to the estuary and restore healthy estuarine habitat and function have not been met.
Based on the Freshwater Inflow Index, freshwater inflow conditions in the San Francisco Estuary are "fair" in some years, "poor" in most years and "very poor" in the two most recent years (2009 and 2010). Degraded inflow conditions reflect severe reductions in the amounts of freshwater inflow in most years, substantial reductions in both year-to-year and seasonal variability of inflows, severe reductions in the frequency of peak flows and high frequencies of inflows comparable to critically dry conditions, in effect, chronic drought conditions. y of "very poor" conditions for Annual Inflow, Spring Inflow, Peak Flow and Dry Year Frequency, and "poor" conditions for Seasonal Variation.

C. Summary and Conclusions

Collectively the six indicators of the Freshwater Inflow Index provide a comprehensive assessment of the status and trends for freshwater inflow conditions to the San Francisco Estuary from it largest watershed. Each of the indicators shows significant alterations to inflows to the

[16] The 1993 Freshwater Inflow Index was also 0.83.

estuary, including reductions in the amounts of inflows, reductions in inter-annual and seasonal variability, reduced frequency of peak flows and increased frequency of annual inflows to the estuary that are comparable to the relatively rare critically dry hydrological conditions in the watershed. Table 8 summarizes the indicator results relative to the CCMP goals (as they are expressed by the reference conditions).

VI. Peer Review

The Freshwater Inflow indicators and index build upon the methods and indicators developed by The Bay Institute for the 2003 and 2005 Ecological Scorecard San Francisco Bay Index and for the San Francisco Estuary Partnership Indicators Consortium. The Bay Institute's Ecological Scorecard was developed with input and review by an expert panel that included Bruce Herbold (US EPA), James Karr (University of Washington, Seattle), Matt Kondolf (University of California, Berkeley), Pater Moyle (University of California, Davis), Fred Nichols (US Geological Survey, ret.), and Phillip Williams (Phillip B. Williams and Assoc.). The versions of the indicators and index presented in this report were also reviewed and revised according to the comments of Bruce Herbold and Luisa Valiela (US EPA).

VII. References

Feyrer, F., M. L. Nobriga and T. R. Sommer. 2008. Multidecadal trends for three declining fish species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Can J. Fish. Aquat. Sci. 64:723-734.

Feyrer, F., K. Newman, M. Nobriga and T. Sommer. 2010. Modeling the Effects of Future Outflow on the Abiotic Habitat of an Imperiled Estuarine Fish. Estuaries and Coasts DOI 10.1007/s12237-010-9343-9.

Jassby, A.D., W. J. Kimmerer, S. G. Monismith, C. Armour J. E. Cloern, T. M. Powell, J. R. Schubel and T. J. Vendlinski. 1995. Isohaline Position as a Habitat Indicator for Estuarine Populations. Ecological Applications 5:272-289.

Kimmerer, W. J. 2002. Physical, biological, and management responses to variable freshwater flow into the San Francisco Estuary. Estuaries 25:1275-1290.

Kimmerer, W. J. 2004. Open-Water Processes of the San Francisco Estuary: from physical forcing to biological responses. San Francisco Estuary and Watershed Science [online serial]. Vol. 2, Issue 1 (February 2004), Article 1.

Kimmerer, W. J., E. S. Gross and M. L. MacWilliams. 2008. Is the Response of Estuarine Nekton to Freshwater Flow in the San Francisco Estuary Explained by Variation in Habitat Volume? Estuaries and Coasts 32:375-389. Available at: http://bestscience.org/docs/seminar/KimmererEtAl2009EstuariesCoasts%5B1%5D.pdf

Moyle, P. B. and W.A. Bennett. 2008. The future of the Delta ecosystem and its fish. Technical Appendix D. Comparing Futures for the Sacramento-San Joaquin Delta.

Public Policy Institute of California. San Francisco, CA. 1-38.

Moyle, P.B., W.A. Bennett, W.E. Fleenor, and J.R. Lund. 2010. Habitat variability and complexity in the Upper San Francisco Estuary. Working Paper, Delta Solutions, Center for Watershed Sciences, University of California, Davis.

SWRCB (2010) Development of Flow Criteria for the Sacramento-San Joaquin Delta Ecosystem. State Water Resources Control Board report prepared pursuant to the Sacramento-San Joaquin Delta Reform Act of 2009, August 3, 2010. Available at: http://www.waterboards.ca.gov/waterrights/water_issues/programs/bay_delta/deltaflow/final_rpt.shtml.

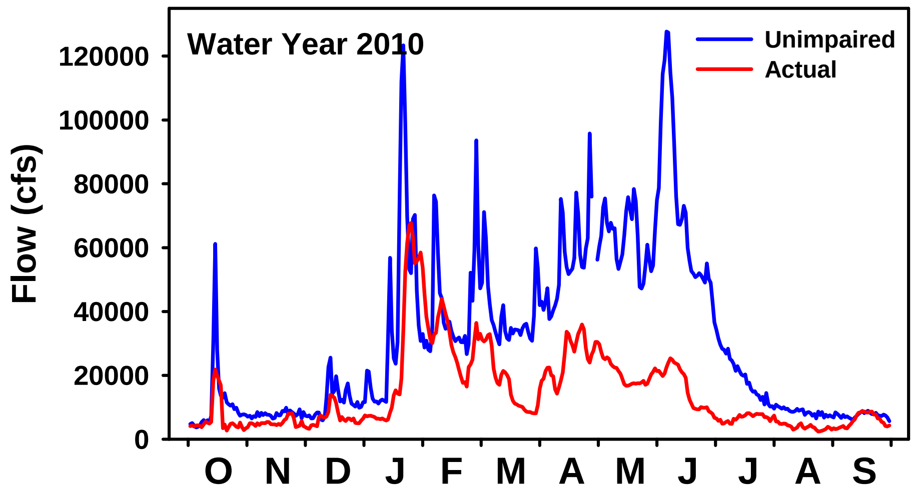


Figure 1. The amounts and timing of freshwater inflows to the San Francisco Estuary have been altered by dams and water diversions in the estuary's watershed. For Water Year 2010, this graph compares freshwater inflow conditions that would have occurred if there were no dams and water diversions, referred to as "unimpaired" conditions (blue line), with actual freshwater inflows (red line). Data sources: California Department of Water Resources and California Data Exchange Center.

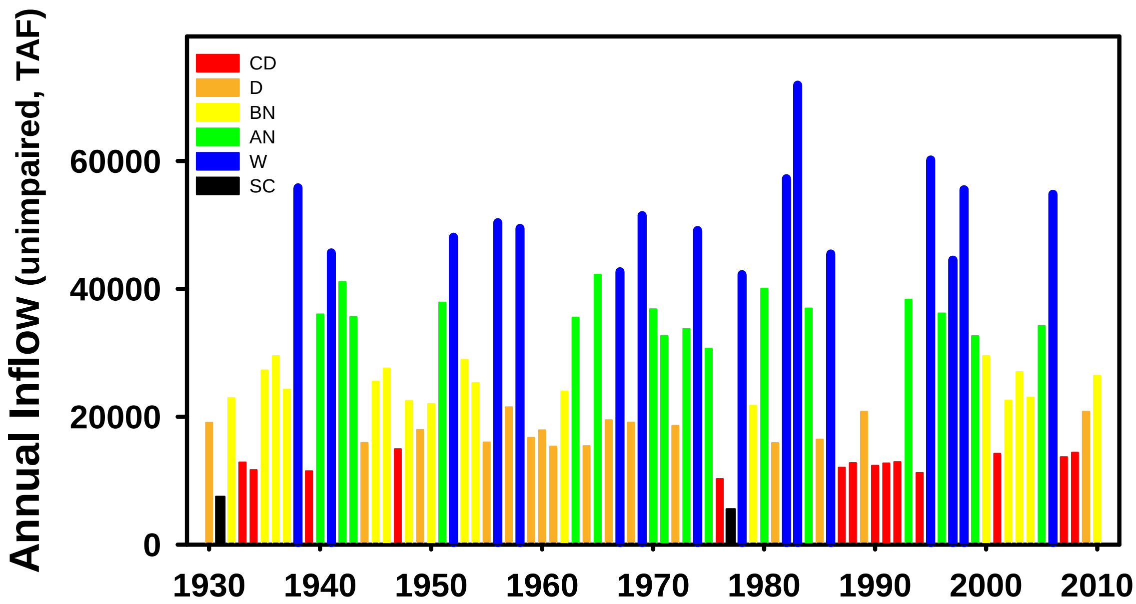


Figure 2. Freshwater inflow to the San Francisco Estuary varies from year-to-year. This graph shows the variations in unimpaired inflow for the 1930-2010, with the different water year types (critically dry, dry, below normal, above normal and wet) shown by the colors of the bars. In this graph, the driest 2.5% of years, or "super-critically dry" years, are also shown with the black bars.

Table 1. Quantitative reference conditions and associated interpretations for results of the Annual Inflow indicator. The primary reference condition, which corresponds to “good” conditions, is in bold.

Annual Inflow		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>87.5% of unimpaired	“Excellent”	4
>75% of unimpaired	**“Good”**	**3**
>62.5% of unimpaired	“Fair”	2
>50% of unimpaired	“Poor”	1
≤50% of unimpaired	“Very Poor”	0

Figure 3. Changes in the Annual Inflow indicator for the San Francisco Estuary, expressed as the percentage of estimated unimpaired flow that reaches the estuary, from 1930-2010. The top panel shows the results as the decadal averages and the bottom panel shows results for each year. Horizontal dashed line shows the reference condition (75%).

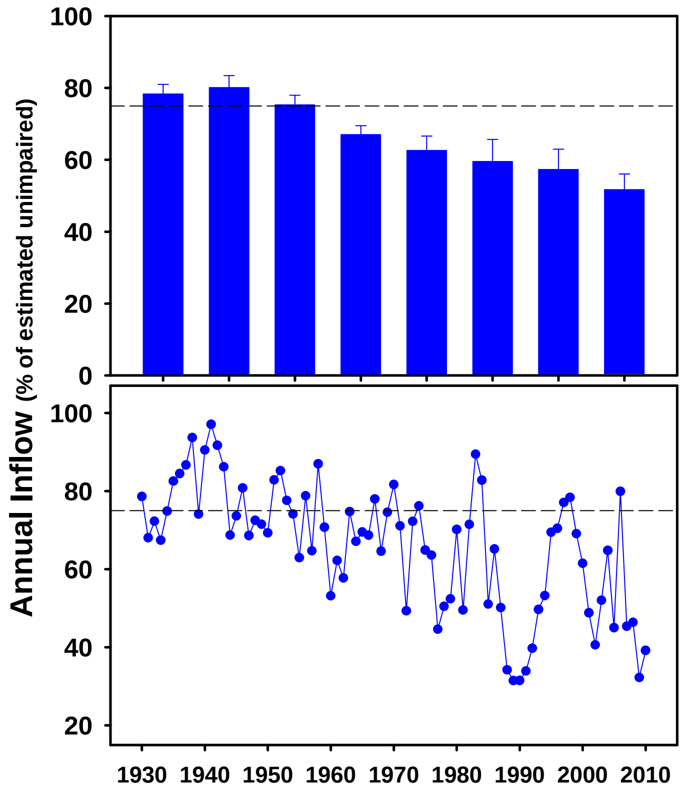


Table 2. Quantitative reference conditions and associated interpretations for results of the Spring Inflow indicator. The primary reference condition, which corresponds to “good” conditions, is in bold.

Spring Inflow		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>87.5% of unimpaired	“Excellent”	4
>75% of unimpaired	**“Good”**	**3**
>62.5% of unimpaired	“Fair”	2
>50% of unimpaired	“Poor”	1
≤50% of unimpaired	“Very Poor”	0

Figure 4. Changes in the Spring Inflow indicator for the San Francisco Estuary, expressed as the percentage of estimated unimpaired flow that reaches the estuary, from 1930-2010. The top panel shows the results as the decadal averages and the bottom panel shows results for each year. Horizontal dashed line shows the reference condition (75%).

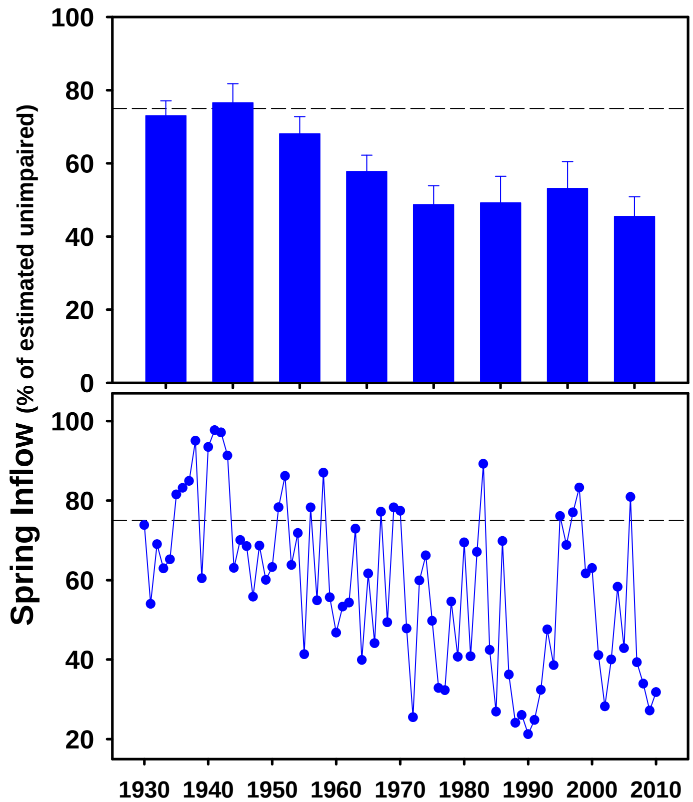
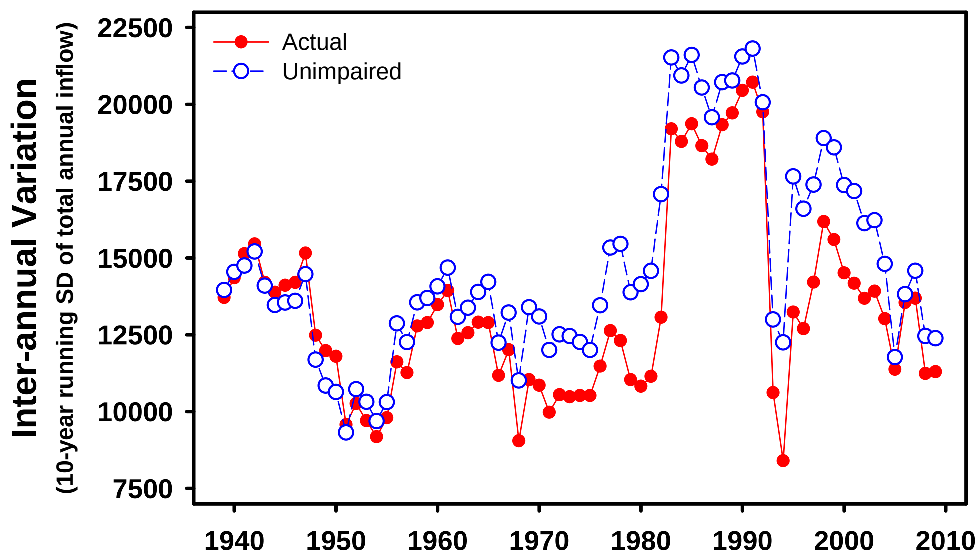


Table 3. Quantitative reference conditions and associated interpretations for results of the Inter-annual Variation in Inflow indicator. The primary reference condition, which corresponds to “good” conditions, is in bold.

Inter-annual Variation in Inflow		
Quantitative Reference Condition	Evaluation and Interpretation	Score
>-850 TAF	“Excellent”	4
>-1700 TAF	**“Good”**	**3**
>-2550 TAF	“Fair”	2
>-3400 TAF	“Poor”	1
≤-3400 TAF	“Very Poor”	0

Figure 5. Inter-annual variation in actual and unimpaired annual freshwater inflows to the San Francisco Estuary from 1939-2010 (each point is the standard deviation for running 10-year periods ending in that year).



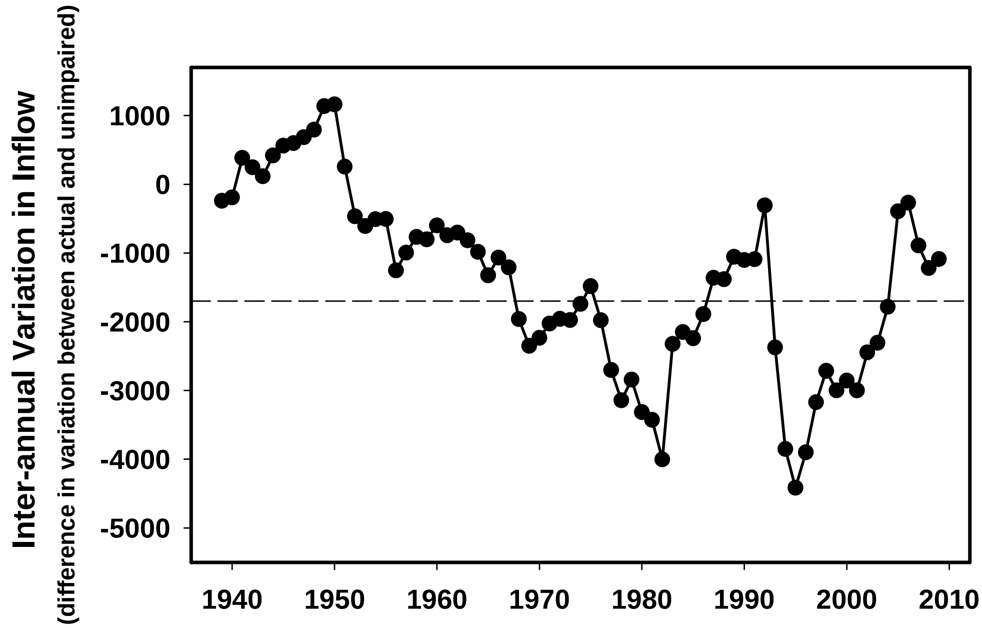


Figure 6. Changes in the Inter-annual Variation in Inflow indicator, expressed as the difference between actual and unimpaired inter-annual variations in inflow to the San Francisco Estuary, from 1939-2010. Horizontal dashed line shows the reference condition (-1700 TAF).

Table 4. Quantitative reference conditions and associated interpretations for results of the Seasonal Variation in Inflow indicator. The primary reference condition, which corresponds to “good” conditions, is in bold.

Seasonal Variation in Inflow		
Quantitative Reference Condition	Evaluation and Interpretation	Score
>0 cfs	“Excellent”	4
>-6700 cfs	**“Good”**	**3**
>-13,400 cfs	“Fair”	2
>-20,100 cfs	“Poor”	1
≤-20,100 cfs	“Very Poor”	0

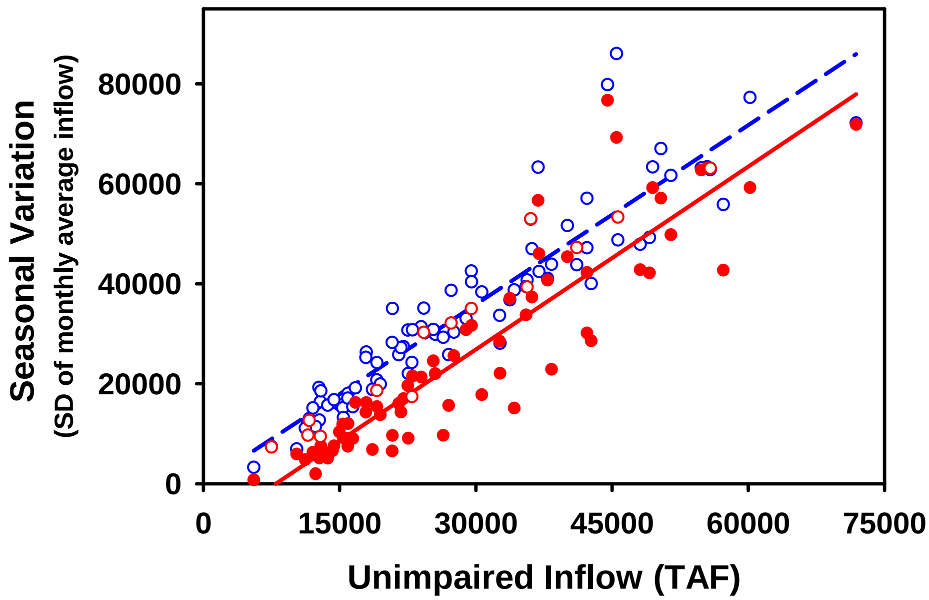


Fig 7. Seasonal variability in freshwater inflows (SD of average monthly flows, cfs; Y axis) is directly related to hydrology, as expressed by unimpaired inflow to the estuary (TAF; X axis). Seasonal variability of unimpaired inflows is shown in the blue open symbols, actual), seasonal variability of actual flows is shown in the open red symbols (1930-1943, the pre-dam period) and solid red circles (1944-2010).

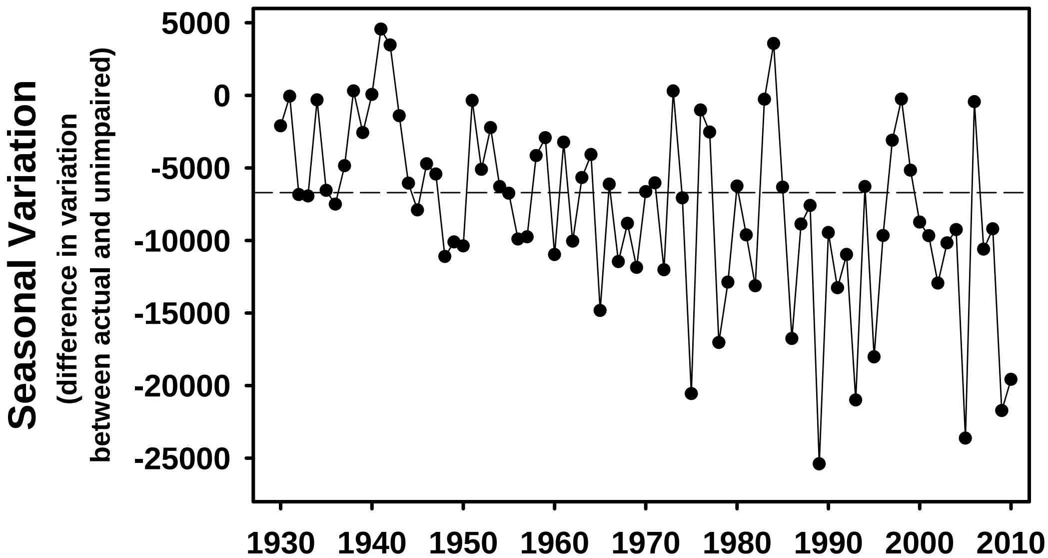


Figure 8. Changes in the Seasonal Variability in Inflows indicator, expressed as the difference between actual and unimpaired seasonal variations in inflow to the San Francisco Estuary, from 1939-2010. Horizontal dashed line shows the reference condition (-6700 cfs).

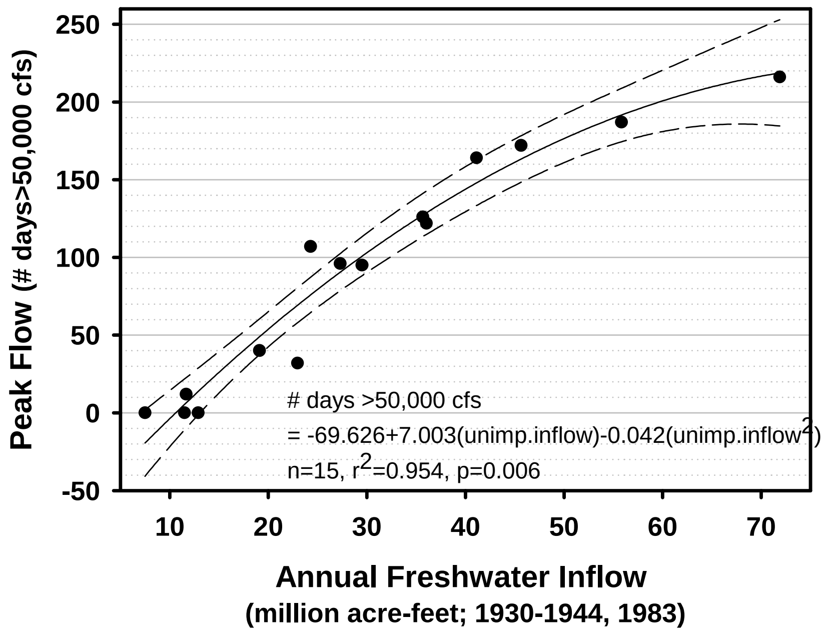


Figure 9. Actual (symbols) and predicted (regression with confidence limits) number of days of peak flow per year in relation to total annual inflow for 1930-1943 and 1983. This relationship was used to establish the reference condition for evaluation of the Peak Flow indicator.

Table 5. Quantitative reference conditions and associated interpretations for results of the Peak Flow indicator. The primary reference condition, which corresponds to "good" conditions, is in bold.

Peak Flow		
Quantitative Reference Condition	Evaluation and Interpretation	Score
>-15 days	"Excellent"	4
>-30 days	**"Good"**	**3**
>-45 days	"Fair"	2
>-60 days	"Poor"	1
≤-60 days	"Very Poor"	0

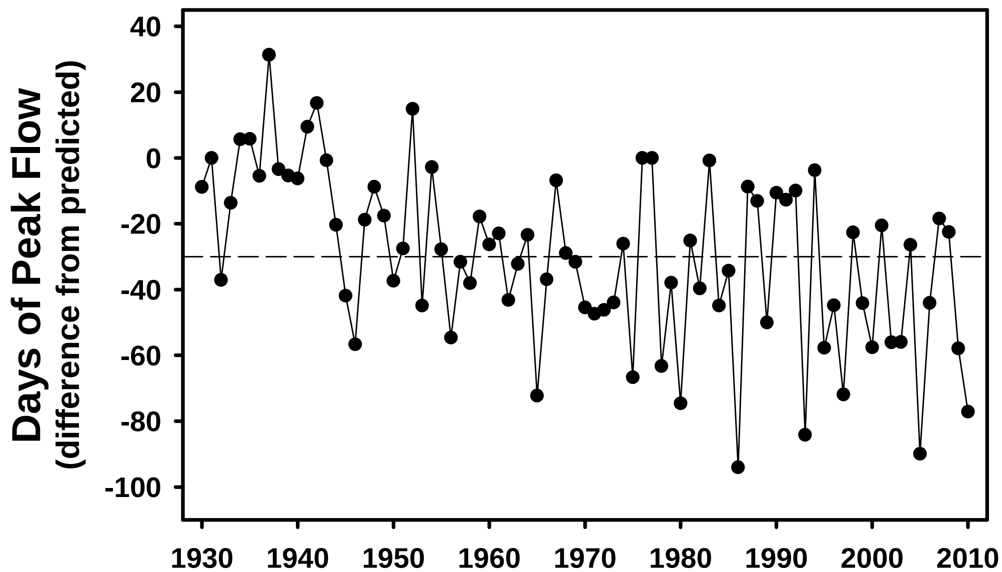


Figure 10. Changes in the Peak Flow indicator, expressed as the number of days different from predicted, for the San Francisco Estuary, from 1930-2010. Horizontal dashed line shows the reference condition (-30 days).

Table 6. Frequency-based classification of water years types based on estimated unimpaired annual inflow to the San Francisco Estuary.

Water year type	**Estimated unimpaired inflow to the San Francisco Estuary** (total annual, TAF)	**Years (1930-2009)**
Critically dry (driest 20% of years) NOTE: a "super-critical" category, corresponding to the driest 2.5% of years was also identified (see Figure 2)	<15,000 TAF (Super-critical: <8,000 TAF)	**1931**, 1933, 1934, 1939, 1947, 1976, **1977**, 1987, 1988, 1990, 1991, 1992, 1994, 2001, 2007, 2008 (n=16) Super-critical years are shown in **bold**.
Dry	15,000-21,500 TAF	1930, 1944, 1949, 1955, 1957, 1959, 1960, 1961, 1964, 1966, 1968, 1972, 1981, 1985, 1989, 2009 (n=16)
Below normal	21,500-29,500 TAF	1932, 1935, 1936, 1937, 1945, 1946, 1948, 1950, 1953, 1954, 1962, 1979, 2000, 2002, 2003, 2004 (n=16)
Above normal	29,500-42,000 TAF	1940, 1942, 1943, 1951, 1963, 1965, 1970, 1971, 1973, 1975, 1980, 1984, 1993, 1996, 1999, 2005 (n=16)
Wet (wettest 20% of years)	>42,000 TAF	1938, 1941, 1952, 1956, 1958, 1967, 1969, 1974, 1978, 1982, 1983, 1986, 1995, 1997, 1998, 2006 (n=16)

Table 7. Quantitative reference conditions and associated interpretations for results of the Dry Year Frequency indicator. The primary reference condition, which corresponds to "good" conditions, is in bold.

Dry Year Frequency		
Quantitative Reference Condition	Evaluation and Interpretation	Score
<1 year	"Excellent"	4
<2 years	**"Good"**	**3**
<3 years	"Fair"	2
<4 years	"Poor"	1
≥4 years	"Very Poor"	0

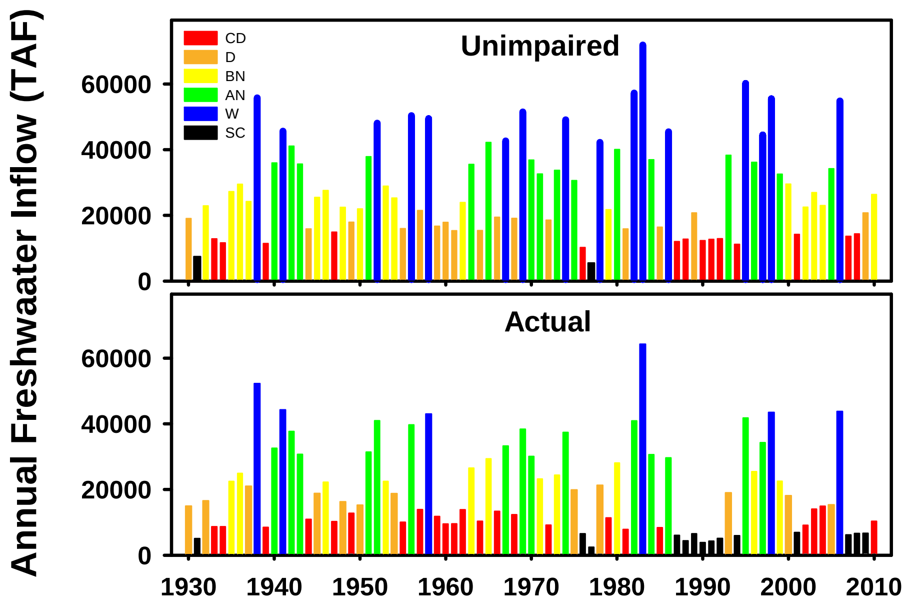


Figure 11. Freshwater inflows to the San Francisco Estuary under unimpaired conditions (top panel) and actual conditions (bottom panel). Each histogram bar has been colored to show the frequency-based water year type classification for unimpaired flows. The critically dry category was further partitioned to show "super-critical" years, comparable to the driest 2.5% of years of unimpaired flows.

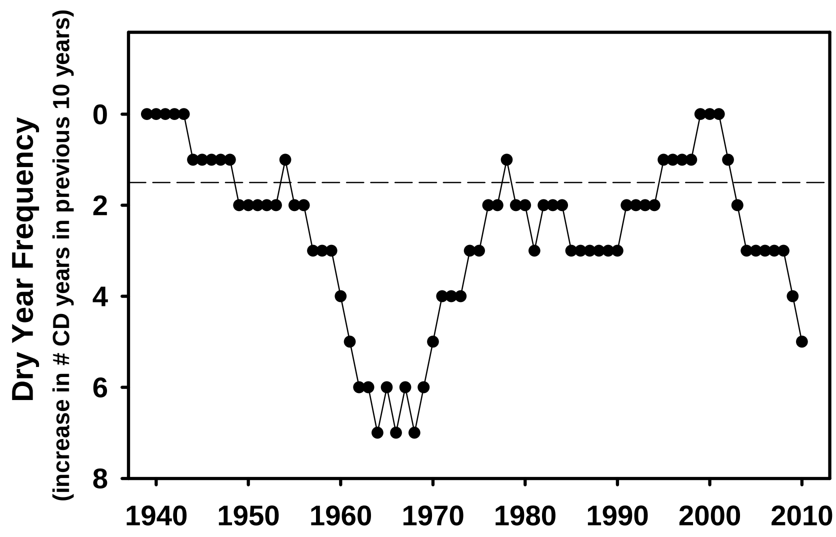


Figure 12. Changes in the Dry Year Frequency indicator, expressed as number of years more in a 10-year period)of critically dry freshwater inflow conditions to the San Francisco Estuary, from 1939-2010. Horizontal dashed line shows the reference condition (1.5 years).

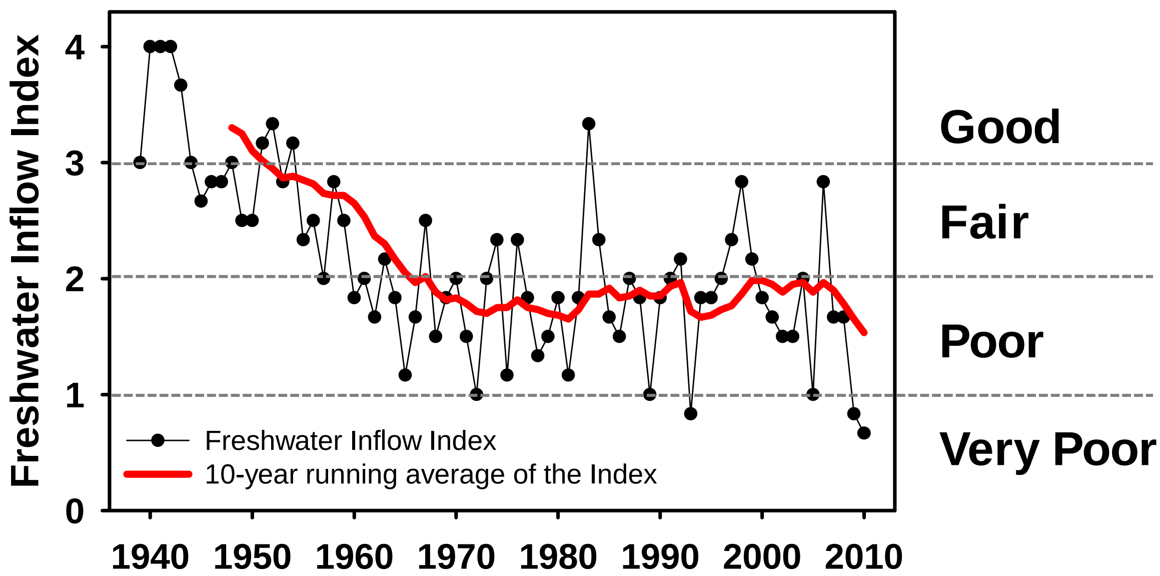


Figure 13. Changes in the Freshwater Inflow Index for the San Francisco Estuary from 1939-2010. Black lines and symbols show the annual Index values, solid red line shows the 10-year running average for the Index. Horizontal dashed lines shows the reference conditions and associated interpretations.

Table 8. Summary of results, relative to the CCMP goals to "increase freshwater availability to the estuary", "restore healthy estuarine habitat" and "promote restoration and enhancement of stream and wetland functions to enhance resiliency and reduce pollution in the Estuary," of the six freshwater inflow indicators for the San Francisco Estuary.

Indicator	CCMP Goal Met (yes, no or % met)	
	Past 10 years	Past 5 years
Annual Inflow	No (not met in 90% of years)	No (not met in 80% of years)
Spring Inflow	No (not met in 90% of years)	No (not met in 80% of years)
Inter-annual Variation in Inflow	Partially met (50% of years)	Yes
Seasonal Variation in Inflow	No (not met in 90% of years)	No (not met in 80% of years)
Peak Flow	Partially met (40% of years)	Partially met (40% of years)
Dry Year Frequency	Partially met (30% of years)	No