State of the Estuary Report 2015

Summary

WATER QUANTITY – Freshwater Inflow Indicators and Index
Summary

Prepared by Christina Swanson
Natural Resources Defense Council
September 2015

State of the San Francisco Estuary 2015

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What are the indicators?
The Freshwater Inflow Index uses ten indicators to measure and evaluate the amounts, timing, and variability of freshwater inflow from the Sacramento-San Joaquin watershed to the Delta and the Bay. These indicators are designed specifically to look at various aspects of freshwater inflow conditions in the estuary, not the aquatic habitat conditions or ecological processes that result from or are affected by inflow. The ten indicators are also aggregated into a Freshwater Inflow Index, which combines the results of all the indicators into a single metric.

Five indicators measure aspects of the amounts of freshwater flow into the Delta and the Bay:

- Annual Delta Inflow;
- Spring Delta Inflow;
- San Joaquin River Inflow;
- Annual Bay Inflow; and
- Spring Bay Inflow.

One indicator measures the amount of water diverted directly from the Delta:

- Delta Diversions.

Four indicators measure the variability of freshwater flows into the Bay:

- Inter-annual Variation in Inflow;
- Seasonal Variation in Inflow;
- Peak Flow; and
- Dry Year Frequency.

In order to account for the watershed’s large year-to-year variations in hydrology, all of the indicators are measures of the alterations in freshwater inflow conditions, rather than measures of absolute amounts of inflow. Most of the indicators are calculated as comparisons of actual freshwater flow conditions to the freshwater flow conditions that would have occurred if there were no dams or water diversions, referred to as “unimpaired” conditions. By incorporating unimpaired inflow as a component of the indicator calculation, the indicators are “normalized” to account for natural year-to-year variations in precipitation and runoff.

Table 1.

Attribute	Indicators	Benchmarks
Water quantity (freshwater inflow to the estuary)	Alteration in the amounts, timing, patterns and variability of freshwater inflow to the Delta and the Bay.	Benchmarks (or reference conditions) are based on scientific literature on environmental flow requirements for riverine and estuarine ecosystems, including “presumptive standards” proposed by Richter et al. (2011) for river flows to maintain ecological integrity, the California’s State Water Resources Control Board 2010 Flow Criteria report that identified flows needed to protect public trust resources, historical inflow conditions, and regulatory standards for inflows, Delta diversion levels, and water quality.

Why is freshwater inflow important?

Estuaries are defined by the amounts, timing and patterns of freshwater inflow. In the San Francisco Bay estuary, freshwater inflows control the quality and quantity of estuarine habitat drive key ecological processes and significantly affect the abundance and survival of estuarine biota, from tiny planktonic plants and animals to shrimp and fish. The mixing of inflowing fresh water and saltwater from the ocean creates low salinity, or “brackish” water habitat for estuary-dependent species. Seasonal and inter-annual changes in inflow amounts trigger biological responses like 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.

Freshwater inflows to the San Francisco Bay estuary from its largest watershed, the Sacramento-San Joaquin watershed, are affected by a number of factors, including:

- Precipitation and runoff – flow amounts can vary from year to year by as much as an order of magnitude between wet and dry years;
- Dams – which capture and store runoff from the mountains for release into rivers at different times of the year and in different years);
- In-river diversions – which remove water from rivers for local agricultural or urban use or export to other regions in California, reducing the amount of water that flows to the estuary;
- Return flows and discharges – which add (or return) water to river flows, although water quality may be reduced by contaminants from agricultural runoff or wastewater;
- In-Delta diversions – which remove water from the upper reach of the estuary for local agriculture and urban use and for export to other regions in California, reducing the amount of water that flows from the Delta into the Bay;
- Climate change – warmer temperatures and shifts in precipitation from snow to rain have altered the amounts, timing and duration of seasonal flows in the estuary’s tributary rivers.

What are the benchmarks? How were they selected?

The benchmarks for the ten indicators were based on: 1) scientific literature on environmental flow requirements for riverine and estuarine ecosystems, including “presumptive standards” proposed by Richter et al (2011) for river flows to maintain ecological integrity (i.e., 80% of unimpaired flow as needed to maintain ecological integrity); 2) the California’s State Water Resources Control Board 2010 Flow Criteria report that identified flows needed to protect public trust resources (i.e., 75% of unimpaired flow during winter and spring); 3) historical inflow conditions (i.e., before completion of major dams); and 4) SWRCB regulatory standards for inflows and Delta diversion levels.

What are the status and trends of the indicators and Index?

Freshwater inflows to the Delta and Bay have been highly altered, resulting in degradation of ecological condition and function in the estuary. The magnitude of alteration has increased for 9 of the 10 indicators during the 85-year record (and since development of dams and water diversion facilities and operations) and, for 5 of 10 indicators, even further during the last decade. Current freshwater inflow conditions are “very poor” for 6 of 10 indicators, “fair” for 3 indicators and “good” for only one indicator. As measured by the Freshwater Inflow Index, which combines the results of the 10 indicators into a single metric, freshwater inflow conditions for the San Francisco Bay Estuary are “poor.”

Table 2.

Indicator	**CCMP Goals** Fully met if goal achieved in >67% of years since 1990 Partially met if goal achieved in 33-67% of years Not met if goal achieved in <33% of years	**Trend (long term; 1930-2014)**	**Trend since 1990**	**Current condition** (average for last 10 years)
Annual Delta Inflow	Partially met; goals achieved in 52% of years	Stable	Stable	Fair Inflow reduced by 26%
Spring Delta Inflow	Not met; goals achieved in 12% of years	Decline	Deteriorating	Poor Inflow reduced by 47%
San Joaquin River Inflow	Not met; goals achieved in 0% of years	Decline	Stable	Very poor Inflow reduced by 58%
Annual Bay Inflow	Not met: goals achieved in 12% of years	Decline	Deteriorating	Very poor Inflow reduced by 50%
Spring Bay Inflow	Not met; goals achieved in 12% of years	Decline	Deteriorating	Very poor Inflow reduced by 56%
Delta Diversions	Not met; goals achieved in 8% of years	Decline	Deteriorating	Poor 36% of inflow diverted
Inter-annual Variation in Inflow	Partially met; goals achieved in 40% of years	Decline	Mixed (variable)	Good Reduced by 10%
Seasonal Variation in Inflow	Not met; goals achieved in 28% of years	Decline	Deteriorating	Poor Reduced by 50%
Peak Flow	Partially met; goals achieved in 44% of years	Decline	Stable	Fair Reduced by 45 days/year

Dry Year Frequency	Partially met: goals met in 52% of years	Decline	Deteriorating	Poor Flow reductions triple dry year frequency
Freshwater Inflow Index	Not met; goals met in 12% of years	Decline	Mixed (variable)	Poor Only 1 of 10 indicators show "good" conditions

What does it mean? Why do we care?

Freshwater inflow to an estuary is a key physical and ecological driver, affecting the quality and quantity of habitat, primary and secondary productivity, and growth and survival of resident and migratory fish and wildlife. In recent years, freshwater inflows to the San Francisco Estuary have been cut by half on an annual basis and by 60% during the ecologically important spring season, and inter-annual and seasonal variability in inflows have been reduced. These man-made alterations in inflows have created chronic drought conditions in the estuary that, particularly in the estuary's upstream region, impair ecological function, degrade habitat and productivity, and are a key contributor to increasingly serious fish population declines.

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Technical Appendix

WATER QUANTITY – Freshwater Inflow Indicators and Index
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I. Background

The San Francisco Bay Estuary, which extends upstream from the Golden Gate south to the South Bay and east through San Pablo Bay, Suisun Bay and the Delta to the limit of tidal influence in the Sacramento, Mokelumne and San Joaquin rivers, is the interface between California's largest rivers and the Pacific Ocean. It 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.

Estuaries are defined by the amounts, timing and patterns of freshwater inflow. In the San Francisco Bay estuary, freshwater inflows control the quality and quantity of estuarine habitat drive key ecological processes and significantly affect the abundance and survival of estuarine biota, from tiny planktonic plants and animals to shrimp and fish (Jassby et al. 1995; Kimmerer 2002, 2004; Kimmerer et al. 2008; Feyrer et al. 2008, 2010; Moyle and Bennett, 2008; Moyle et al., 2010; SWRCB 2010; and see Open Water Habitat and Flood Events indicators). The mixing of inflowing fresh water and saltwater from the ocean creates low salinity, or "brackish" water habitat for estuary-dependent species. Seasonal and inter-annual changes in inflow amounts trigger biological responses like 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 Estuary comes from the Sacramento and San Joaquin river basins, which provide >90% of total inflow in most years and have large impacts on salinity regimes in the estuary (Kimmerer 2002, 2004). 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.

Freshwater inflows to the Delta and the Bay from the Sacramento-San Joaquin watershed are affected by a number of factors, including:

- Precipitation and runoff – flow amounts can vary from year to year by as much as an order of magnitude between wet and dry years;
- Dams – which capture and store runoff from the mountains for release into rivers at different times of the year and in different years, and can change variability of seasonal

and inter-annual flows (nine of the ten largest Sacramento-San Joaquin watershed tributaries to the estuary are dammed and managed for flood control and water supply);
- In-river diversions – which remove water from rivers for local agricultural or urban use or export to other regions in California, reducing the amount of water that flows to the estuary;
- Return flows and discharges – which add (or return) water to river flows (return flow and discharge amounts are usually smaller than the amounts of water diverted);
- In-Delta diversions – which remove water from the upper reach of the estuary for local agriculture and urban use and for export to other regions in California, reducing the amount of water that flows from the Delta into the Bay;
- Climate change – warmer temperatures and shifts in precipitation from snow to rain have altered the amounts, timing and duration of seasonal flows in the estuary's tributary rivers.

The State of the Estuary Report uses ten indicators to measure and evaluate the amounts, timing and patterns of freshwater inflow from the Sacramento-San Joaquin watershed to the Delta and the Bay. These indicators are designed specifically to look at various aspects of freshwater inflow conditions in the estuary, not the aquatic habitat conditions or ecological processes that result from or are affected by inflow. The ten indicators are also aggregated into a Freshwater Inflow Index, which combines the results of all the indicators into a single metric.

Five indicators measure aspects of the amounts of freshwater flow into the Delta and the Bay:
- Annual Delta Inflow;
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One indicator measures the amount of water diverted directly from the Delta:
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Four indicators measure the variability of freshwater flows into the Bay:
- Inter-annual Variation in Inflow;
- Seasonal Variation in Inflow;
- Peak Flow; and
- Dry Year Frequency.

In order to account for the watershed's large year-to-year variations in hydrology, all of the indicators are measures of the alterations in freshwater inflow conditions, rather than measures of absolute amounts of inflow. Except for the Delta Diversions indicator, all of the indicators are calculated as comparisons of actual freshwater flow conditions to the freshwater flow conditions that would have occurred if there were no dams or water diversions, referred to as "unimpaired" conditions. By incorporating unimpaired inflow as a component of the indicator calculation, the indicators are "normalized" to account for natural year-to-year variations in precipitation and runoff. The Delta Diversions indicator compares Delta inflows to Delta outflows.

II. Data Sources and Definitions

A. Data Sources

Because most of the fresh water that flows into the San Francisco Bay Estuary comes from the Sacramento, Mokelumne and San Joaquin river basins (collectively the Sacramento-San Joaquin watershed), which provide >90% of total inflow in most years,[1] all of the Freshwater Inflow indicators were calculated using flow data from the Sacramento-San Joaquin watershed only.

The indicators were calculated for each year[2] using data from the California Department of Water Resources (CDWR) DAYFLOW model (for "actual flows), CDWR's Central Valley Streams Unimpaired Flows, and the California Data Exchange Center's (CDEC) Full Natural Flows (FNF) datasets (for "unimpaired flows"). DAYFLOW is a computer model developed in 1978 as an accounting tool for calculating daily historical Delta inflow, outflow and other internal Delta flows.[3] DAYFLOW output is used extensively in studies by State and federal agencies, universities, and consultants. DAYFLOW output is available for the period 1930-2014.[4] Annual and monthly unimpaired flow data for total Delta inflow, Delta outflow and San Joaquin River inflow are from the CDWR California Central Valley Unimpaired Flow dataset (1921-2003).[5] For 2004-2014, annual and seasonal unimpaired flows were calculated by regressions developed from the Central Valley unimpaired flow data (using the 1930-2003 period) and the corresponding unimpaired runoff estimates from the CDEC Full Natural Flows dataset[6] for the ten largest rivers in the watershed (for Delta inflows and outflows) and the four major San Joaquin Basin rivers for San Joaquin River inflows.[7] Figure 1 shows regressions of CDWR's unimpaired flows on Full Natural Flows for annual and spring (Feb-June) Delta inflow, annual and spring Delta outflow, and San Joaquin River inflow.

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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] More information about DAYFLOW is available at www.water.ca.gov/dayflow.

[4] For actual flows, various indicators used DAYFLOW parameters for QTOT (for total Delta inflow), QOUT (net Delta outflow), and QSJR (San Joaquin River inflow).

[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, Tuolumne, Merced and San Joaquin Rivers. For the San Joaquin basin, the four rivers are the Stanislaus, Tuolumne, Merced and San Joaquin Rivers.

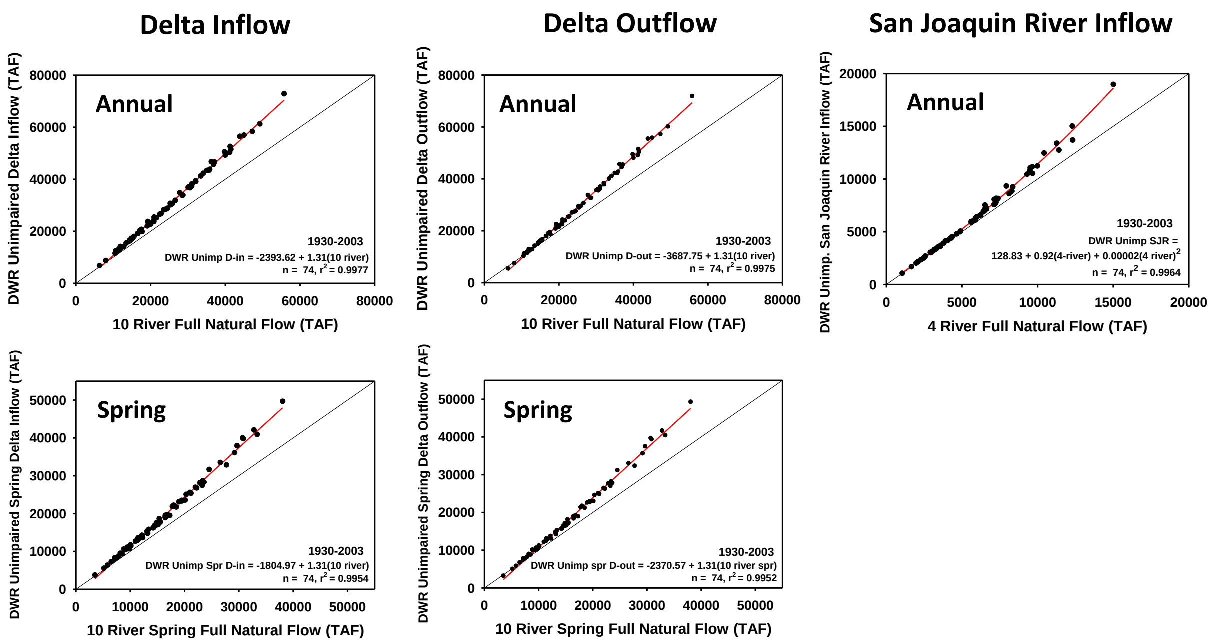

Figure 1. Regressions of CDWR unimpaired flows on Full Natural Flows for annual and spring (Feb-June) Delta inflow, annual and spring Delta outflow, and annual San Joaquin River inflow, 1930-2003.
Data sources: California Department of Water Resources, Central Valley Streams Unimpaired Flows, and California Data Exchange Center, Full Natural Flows.

B. Tidal Effects on Flows in the Delta

Flows in Delta channels and the Bay are influenced by tidal action as well as freshwater inflows from upstream and in-Delta diversions. The estuary experiences two tides every day, two high tides and two low tides, and magnitude of the high and low tides varies over a 28-day spring-neap cycle. Under conditions of low to moderate inflows, tidal flows in Delta channels can be an order of magnitude greater than the freshwater inflow and the direction of flow in the channels typically reverses twice daily with the tides. However, all daily flow data used to calculate the indicators (i.e., Dayflow data) have been filtered to remove tidal effects.

C. Definitions

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 and Delta, would have flowed into the Delta or Bay (see Figure 2). Unimpaired inflow is not the same as “natural” or “historical” inflow that would have occurred in the watershed prior to human development and land use changes; it is instead an estimate of what flows over the *existing landscape* would have been if there were no dams or diversions.

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, particularly in very wet years and during periods of high flows.

Post-water Development Inflow: Most of the major dams and water diversion facilities (such as the state and federal Delta pumping facilities) were completed and operational by 1970. Water export rates at the Delta pumping facilities increased rapidly during the 1970s, reaching "full operation" with export rates leveling off by 1980.

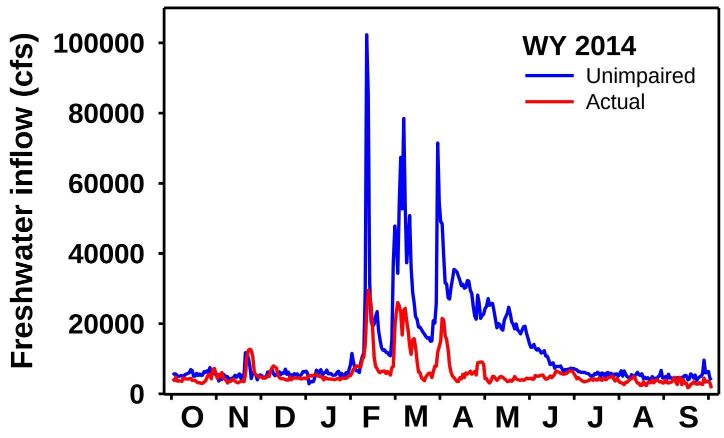

Figure 2. Unimpaired and actual freshwater inflows to the San Francisco Estuary in Water Year 2014.
Data sources: California Department of Water Resources, Dayflow, and California Data Exchange Center (CDEC), Full Natural Flows.

Delta Inflow vs. Bay Inflow: Delta inflow is the amount of water that flows into the Delta from the Sacramento-San Joaquin watershed. Bay Inflow (or Delta outflow) is the amount of water that flows from the Delta into the Suisun Bay region of San Francisco Bay. Bay inflow amounts are less than Delta inflow amounts because in-Delta diversions by local water users and the state and federal water export facilities remove of portion of Delta inflow before it reaches the Bay.

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, annual unimpaired inflows were classified for each year as one of five water year types: very wet, wet, median, dry and very dry. Year types were established based on frequency of occurrence during the period of 1930-2009, with each year

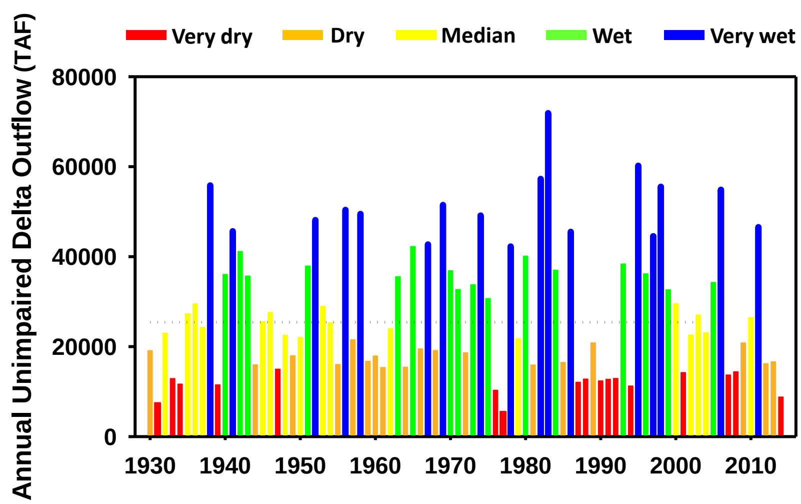

Figure 3. Annual unimpaired Delta outflow (TAF) for 1930-2014. Bars are colored to show frequency-based water year type (see text). Dotted line shows median unimpaired Delta outflow for the 1930-2003 period.
Data source: California Department of Water Resources, Central Valley Streams Unimpaired Flows.

type comprising 20% of all years. Figure 3 shows annual unimpaired Delta outflows to the Bay with year type classification shown by the different colors of the bars.

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" (SFEP 2007). These goals are non-quantitative; therefore we used information from the scientific literature, current regulatory standards and objectives, and historical and/or unimpaired conditions to identify and define levels of freshwater flows that promote restoration and enhance ecological function and resiliency.

There is a growing body of scientific literature on environmental flow requirements for riverine and estuarine ecosystems, including Arthington et al. (2006), Poff et al. (2010) and Richter et al. (2011). In particular, Richter et al. (2011) proposed conservative and precautionary "presumptive standards" for river flows to maintain ecological integrity, identifying 80% of unimpaired flow as needed to maintain ecological integrity and 90% of unimpaired to protect rivers with at-risk species.[8] In addition, 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 flow from the Sacramento-San Joaquin watershed should flow out of the Delta and into the Bay during the winter and spring seasons and that winter and spring lower San Joaquin River flows should be 60% of unimpaired San Joaquin River flow (SWRCB 2010).[9] The SWRCB has also established regulatory standards for minimum flow and maximum diversion levels for the Delta and Bay (SWRCB 2006). Information on historical conditions, prior to major water development in the watershed, was derived from DAYFLOW data from the pre-dam period.

For each indicator, a primary reference condition, the quantitative value against which the measured value of the indicator was compared, was established. For most of the indicators, this reference condition was developed based on recommendations of either Richter et al. (2011) or SWRCB (2010). The SWRCB 2006 regulatory standards (SWRCB 2006), pre-dam flow conditions and various metrics from unimpaired flow data (e.g., variability) were also used to inform development of reference conditions for some indicators. Measured indicator values that were higher than the primary reference condition were interpreted to mean that aspect of freshwater inflow condition, as measured by the indicator, met the CCMP goals and corresponded to "good" ecological conditions in that year. For the most recent 25 year period (since 1990, when the CCMP was being developed and established), CCMP goals were considered to be "fully met" is indicators met or exceeded he primary reference conditions in at

[8] The standards proposed by Richter et al. (2011) were for daily flows.

[9] 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. On an annual basis, the majority of runoff in the watershed and unimpaired flows occur in the winter and spring.

least 67% of years; “partially met” if the indicators met or exceeded this level in 33-66% of years; and “not met” if indicators met or exceeded this level in less than 33% of years.

In addition to the primary reference condition, information on the range and trends of indicator results, results from the scientific literature and other watersheds, and known relationships between freshwater inflow conditions and physical and ecological conditions in estuaries was used to develop several intermediate reference conditions. The intermediate reference conditions were used to create a five-point scale that categorized and assigned a quantitative “score” to the indicator’s measured value, ranging from zero (0), which was considered to correspond to “very poor” conditions with highly altered flow conditions, to four (4), which was considered to correspond to “excellent” conditions with minimally altered flow conditions. The primary reference condition was assigned a point value of three (3), corresponding to flow conditions that had been altered but which were sufficient to maintain ecological integrity and thus meet the CCMP goals. The size of the increments between the different 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. For each year, these scores of the ten indicators were averaged to calculate the Freshwater Inflow Index. Specific information on the primary and intermediate reference conditions for each indicator is provided in the following sections describing each of the indicators.

The results for each indicator and the Index are shown graphically, with all graphs showing the results for each year and each decade (e.g., 1950-1959). All graphs show the measured indicator (or Index) values and the indicator score using a consistent orientation on the Y axis, with values corresponding to good conditions shown above values corresponding to poorer conditions on the Y axis regardless of the unit of measure or numeric scale. To evaluate trends and differences over time and between other variables (e.g., water year types), indicator and Index results were analyzed using t-tests, analysis of variance and simple linear regression.

IV. Freshwater Inflow Indicators

A. Annual Delta Inflow

1. Rationale

The Delta receives freshwater inflow from more than a dozen rivers and streams, including the Sacramento, Mokelumne, Cosumnes, Calaveras and San Joaquin Rivers, as well as a number of smaller tributaries from the west side of the Sacramento Valley (including Putah and Cache Creeks). Collectively, these rivers drain more than 40% of the California landscape, from the Cascade Mountains in the north to the southern Sierra Nevada. From year to year, the amounts of flow from these rivers into the Delta can vary more than ten-fold, reflecting California’s temperate climate and unpredictable cycle of droughts and floods. By the mid-1900s, nearly all of these rivers were dammed for water storage, flood control and/or hydropower, altering the amounts and timing of freshwater flows into the Delta. Runoff from rainstorms and the melting mountain snowpack that formerly flowed into the Delta in the winter, spring and early summer is now captured behind massive dams, and diverted from rivers and reservoirs for local and distant use. Flow from some rivers, such as the upper San Joaquin and the Calaveras, no longer even reaches the Delta in many years. In contrast, in some years (and in some seasons), water captured and stored in reservoirs in previous years is released and flows in to the Delta in excess of what would have flowed into the Delta under unimpaired conditions.

2. Methods and Calculations

The Annual Delta Inflow indicator measures the total amount of fresh water that flowed into the Delta each year from all of its tributary rivers, compared to the amount that would have flowed into the Delta from these rivers under "unimpaired" flow conditions, without the effects of dams or water diversions, for that year. Capture and storage of watershed runoff for release in subsequent years and diversion of water from the Delta's tributary rivers reduces annual Delta inflow; release of water captured and stored in watershed reservoirs in previous years and imports of water from the Trinity River watershed increase annual Delta inflow.

The indicator was calculated for each year (1930-2014) as the percentage of annual unimpaired Delta inflow that flowed into the Delta using the following equation:

Annual Delta Inflow indicator (% of unimpaired)
= (actual annual Delta inflow/unimp. annual Delta inflow) x 100

3. Reference Conditions

The primary reference condition for the Annual Delta Inflow indicator was established as 80%, the level identified by Richter et al. (2011) as needed to maintain the ecological integrity of most rivers. Annual inflows that were greater than 80% of unimpaired inflows were considered to reflect "good" conditions and meet the CCMP goals; annual inflows that were less than 50% of unimpaired inflows were considered to correspond to "very poor" conditions. The other reference condition levels were established based on Richter et al. (2011; 90% of unimpaired to protect rivers with at-risk species for "excellent" and minimally altered flows) and use of equal increments between the primary and lowest reference condition levels. Table 1 below shows the quantitative reference conditions that were used to evaluate the results of the Delta Inflow indicator.

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

Annual Delta Inflow		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>90% of unimpaired	"Excellent," minimal alteration	4
>80% of unimpaired	***"Good," meets CCMP goals***	***3***
>65% of unimpaired	"Fair"	2
>50% of unimpaired	"Poor"	1
≤50% of unimpaired	"Very Poor," extreme alteration	0

4. Results

Results of the Annual Delta Inflow indicator are show in Figure 4.

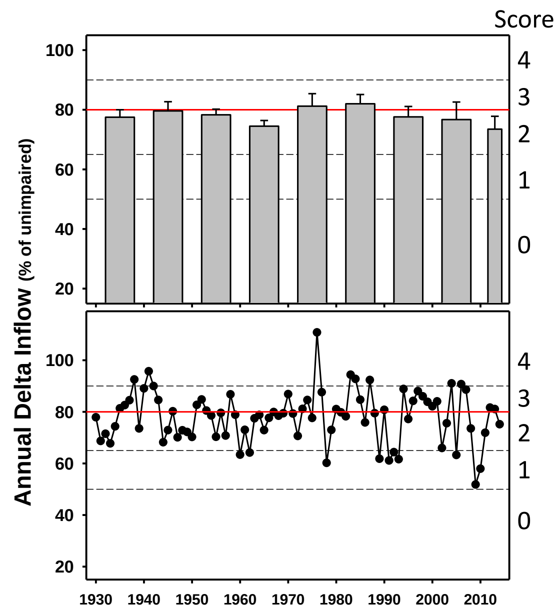

Figure 4. Results for the Annual Delta Inflow indicator, expressed as the percentage of unimpaired flow that actually flowed into the Delta for 1930 to 2014 (left Y axis) and indicator score (right Y axis). The top panel shows results as decadal averages±1 SEM (and for five years for 2010-2014) and the bottom panel shows results for each year. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

The total amount of fresh water flowing into the Delta each year has been reduced in almost all years.
On an annual basis, the percentage of the freshwater runoff from Sacramento-San Joaquin watershed that flows into the Delta has been reduced, averaging 78% of unimpaired Delta inflow for the period of 1930-2014. The greatest reduction in annual Delta inflow occurred in 2009, the third year of the recent three-year drought, when only 52% of unimpaired inflow reached the Delta. In 1976, a very dry year, annual Delta inflow was greater than it would have been under unimpaired conditions, 111% of unimpaired inflow, reflecting large releases of water stored in earlier years from Sacramento basin reservoirs. For the most recent 10-year period (2005-2014), an average of 74% of unimpaired inflow actually flowed into the Delta, similar to the amount for 2014, 75%; this level of freshwater inflow to the Delta corresponds to "fair" condition.

The proportional reductions in annual Delta inflow to the estuary differ by water year type.
In general, the annual Delta inflow is higher in very wet years than in drier years. The greatest alterations to Delta inflow occur in dry years, when an average of 26% of unimpaired flow is diverted before reaching the Delta, significantly more than the 17% of unimpaired Delta inflow diverted in very wet years (ANOVA, $p<0.05$).

Annual freshwater flow into the Delta, as a percentage of unimpaired flow, has not changed over time.
The percentage of unimpaired flow that actually flowed into the Delta has not significantly changed over the past eight decades (regression, $p=0.7$). Since 1980, an average of 5.1 (±4.1 SD) million acre feet of water was diverted from the Sacramento-San Joaquin watershed before it reached the Delta.

Based on annual Delta inflows, CCMP goals to increase fresh water availability to the estuary have been partially met.
Since 1990, annual freshwater inflows to the Delta were "good," meeting or exceeding conditions considered to satisfy CCMP goals, in 52% of years (13 of 25 years). Current

freshwater inflows to the Delta are generally comparable to the 80% of unimpaired level recommended by Richter et al. (2011) to maintain ecological integrity. However, annual Delta inflows in some recent years have been substantially below this level and lower than the lowest levels measured in previous decades. In addition, this indicator does not reflect within-year, or seasonal, alterations, which can be substantial.

B. Spring Delta Inflow

1. Rationale

Historically, two thirds of total annual freshwater inflow to the Delta occurred during the spring, as snow in the northern and central California mountain ranges melted and filled the Delta's tributary rivers. Prolonged high flows during this period are still the dominant feature of Estuary's hydrograph, the annual picture of the timing and amounts of flow (see Figure 2). However, since the early 1900s, growing numbers of large storage and flood control dams on most of the Delta's tributary rivers captured much of the snowmelt runoff for use later in the year, reducing Delta inflows during the spring (and increasing inflows during the summer and fall). Additionally, regulatory protections for flow, water quality and fisheries standards (SWRCB 2006) that reduce the percentage of Delta inflow that can be diverted by the state and federal export facilities have influenced management of seasonal reservoir releases.

2. Methods and Calculations

The Spring Delta Inflow indicator measures the total amount of fresh water that flowed into the Delta from all of its tributary rivers during the spring (February-June) of each year, compared to the amount that would have flowed into the Delta from these rivers under unimpaired flow conditions during that period, without the effects of dams or water diversions. Capture and storage of springtime watershed runoff for release later in the year or in subsequent years and diversion of water from the Delta's tributary rivers reduces spring Delta inflow; springtime release of water captured and stored in watershed reservoirs earlier in the year or in previous years and imports of water from the Trinity River watershed increase annual Delta inflow.

The indicator was calculated for each year (1930-2014) as the percentage of spring unimpaired Delta inflow that flowed into the Delta using the following equation:

> Spring Delta Inflow (% of unimpaired)
> = (actual Feb-June Delta inflow/unimpaired Feb-June Delta inflow) x 100

3. Reference Conditions

The primary reference condition for the Spring Delta Inflow indicator was established as 80%, the level identified by Richter et al. (2011) as needed to maintain the ecological integrity of most rivers. Spring inflows that were greater than 80% of unimpaired inflows were considered to reflect "good" conditions and meet the CCMP goals; annual inflows that were less than 50% of unimpaired inflows were considered to correspond to "very poor" conditions. The other reference condition levels were established based on Richter et al. (2011; 90% of unimpaired to protect rivers with at-risk species for “excellent” and minimally altered flows) and use of equal increments between the primary and lowest reference condition levels. Table 2 below shows the quantitative reference conditions that were used to evaluate the results of the Spring Delta Inflow indicator.

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

Spring Delta Inflow		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>90% of unimpaired	“Excellent,” minimal alteration	4
>80% of unimpaired	***“Good,” meets CCMP goals***	***3***
>65% of unimpaired	“Fair”	2
>50% of unimpaired	“Poor”	1
<u><</u>50% of unimpaired	“Very Poor,” extreme alteration	0

4. Results

Results of the Spring Delta Inflow indicator are show in Figure 5.

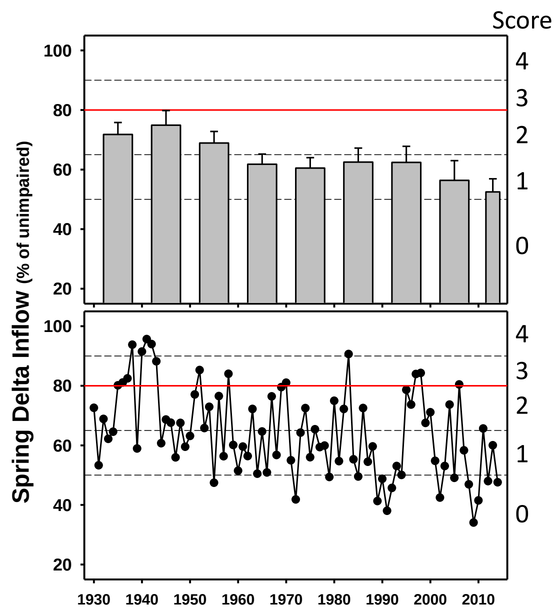

Figure 5. Results for the Spring Delta Inflow indicator, expressed as the percentage of spring (Feb-June) unimpaired flow that actually flowed into the Delta for 1930 to 2014 (left Y axis) and indicator score (right Y axis). The top panel shows results as decadal averages<u>+</u>1 SEM (and for five years for 2010-2014) and the bottom panel shows results for each year. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

The amount of fresh water flowing into the Delta during the spring has been reduced.

The percentage of the springtime runoff from Sacramento-San Joaquin watershed that flows into the Delta has been significantly reduced. The greatest alteration in spring Delta inflow occurred in 2009, the third year of the recent three-year drought, when only 34% of unimpaired spring inflow reached the Delta. For the most recent 10-year period (2005-2014), on average only 53% of springtime unimpaired Delta inflow actually flowed into the Delta during the spring. During this period, spring Delta inflows were “good,” greater than 80% of unimpaired, in only one year and “very poor,” less than 50% of unimpaired in six years. In 2014, only 48% of unimpaired spring inflow reached the Delta, corresponding to “very poor” conditions.

The proportional reductions in spring inflow to the Delta differ by water year type.

The greatest alterations to freshwater inflows occur in dry years when springtime inflows are reduced by nearly half, 47%, on average compared to the average 20% reduction in very wet years (for the 1930-2014 period). Since 1970, the percentages of springtime unimpaired flow that reached the Delta during the spring averaged 52% in very dry years, 47% in dry years, 55% in median years, 63% in wet years and 76% in very wet years.

Spring flow into the Delta, as a percentage of unimpaired flow, has declined over time.
The percentage of unimpaired flow that actually flowed into the Delta during the spring has declined significantly over the past several decades (regression, $p<0.001$). Significant declines have occurred in all water years types except very wet years (regression, all tests, $p<0.05$; very wet year regression, $p=0.054$). Before construction of most of the major dams on the Delta's watershed (1930-1943, the pre-dam period), an average of 78% of springtime unimpaired flow actually reached the Delta. By the 1980s, the percentage had decreased significantly to just 63% (1980-1989 average; t-test, $p<0.05$). The average for the most recent 10-year period (2005-2014), 53%, is lower than spring Delta inflows during the 1980s but, because of large year-to-year variations, not significantly different (t-test, $p=0.15$).

Based on spring inflows, CCMP goals to increase fresh water availability to the estuary have not been met.
Since 1990, springtime freshwater inflows to the Delta were "good," meeting or exceeding conditions considered to satisfy CCMP goals, in just 12% of years (3 of 25 years). Current spring inflows to the Delta are well below the 80% level recommended by Richter et al. (2011) as well as 75% level for Delta outflows identified by the SWRCB as necessary to protect public trust resources and estuarine health. Recent spring inflows are also frequently lower than those measured in the 1990s, when the CCMP was developed and established.

C. San Joaquin River Inflow

1. Rationale

The Delta's vast watershed extends more than 500 miles north to south, from the headwaters of the Sacramento River to the southern end of the San Joaquin basin. Historically, the southern portion of the watershed, San Joaquin River basin, provided just under a quarter (21%) of the total freshwater inflow to the Delta on average.[10] However, since the early 1900s, flows on most San Joaquin basin rivers have been stored behind increasingly large dams and diverted to supply water for San Joaquin Valley agriculture. Even before Friant Dam on the upper San Joaquin River near Fresno began operation in 1949, local water diversions dried up long stretches of the basin's mainstem river in some years. Since the 1950s, additional water has been imported into the San Joaquin Valley from the Delta and, in some areas, agricultural drainage water discharged into the river has added to flow levels, although the quality of drainage water can be very poor and even toxic.

2. Methods and Calculations

The San Joaquin River Inflow indicator measures the amount of water that flowed into the Delta from the San Joaquin River compared to the amount of water that would have flowed into the

[10] In some years, hydrological conditions (i.e., whether it's a wet or dry year) can differ between the basins. The San Joaquin River's contribution was higher in years when it was wetter in the southern basin than in the north and lower when the San Joaquin was drier than the Sacramento basin.

Delta from this river under unimpaired conditions, without the effects of dams, water diversions or water imports.[11] Capture, storage and diversion of San Joaquin watershed runoff by dams and on-river diversions reduces San Joaquin River inflow to the Delta; discharge of return water derived from water imported to the San Joaquin basin from the Sacramento River basin via the Delta increases San Joaquin River inflows.

The indicator was calculated for each year (1930-2014) as the percentage of annual unimpaired freshwater inflow from the San Joaquin Basin using the following equation:

San Joaquin River Inflow (% of unimpaired)
= (actual San Joaquin River inflow/unimpaired San Joaquin River inflow) x 100

3. Reference Conditions

The primary reference condition for the San Joaquin River Inflow indicator was established as 80%, the conservative level identified by Richter et al. (2011) as needed to maintain the ecological integrity of most rivers. Annual inflows that were greater than 80% of unimpaired inflows were considered to reflect "good" conditions and meet the CCMP goals; annual inflows that were less than 50% of unimpaired inflows were considered to correspond to "very poor" conditions. The other reference condition levels were established based on Richter et al. (2011; 90% of unimpaired to protect rivers with at-risk species for "excellent" and minimally altered flows) and use of equal increments between the primary and lowest reference condition levels. This primary reference condition is higher than the flow level identified by the SWRCB for seasonal San Joaquin River inflows to the Delta, 60% of unimpaired, and for Delta outflow, 75% of unimpaired, as needed to protect public trust resources (SWRCB 2010). However, the rationale used by the SWRCB for the lower flow levels was based only on minimum requirements to protect migrating salmonids, rather than the broader based objective of protecting ecological integrity used by Richter et al. (2011). Therefore, and for consistency with the other inflow indicators, the work of Richter et al. (2011) was used as the basis for the primary reference condition for this indicator. Table 3 below shows the quantitative reference conditions that were used to evaluate the results of the San Joaquin River Inflow indicator.

Table 3. Quantitative reference conditions and associated interpretations for results of the San Joaquin Inflow indicator. The primary reference condition, which corresponds to "good" conditions, is in bold italics.

San Joaquin River Inflow		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>90% change in SJR inflow	"Excellent," minimal alteration	4
>80% change in SJR inflow	***"Good," meets CCMP goals***	***3***
>65% change in SJR inflow	"Fair"	2
>50% change in SJR inflow	"Poor"	1
≤50% change in SJR inflow	"Very Poor," extreme alteration	0

[11] San Joaquin River inflow is measured at Vernalis.

4. Results

Results of the San Joaquin River Inflow indicator are show in Figure 6.

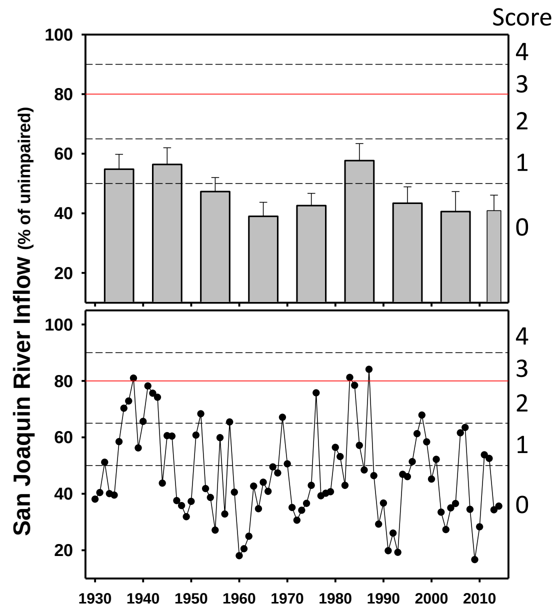

Figure 6. Results for the San Joaquin River Inflow indicator, expressed as the percent change in the San Joaquin River's contribution to total Delta inflow for 1930 to 2014 (left Y axis) and indicator score (right Y axis). The top panel shows results as decadal averages±1 SEM (and for five years for 2010-2014) and the bottom panel shows results for each year. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

The amount of fresh water flowing into the Delta from the San Joaquin River has been reduced. The percentage of the annual runoff from San Joaquin River watershed that flows into the Delta has been substantially reduced, averaging just 47% of unimpaired inflow for the 1930-2014 period. The greatest reduction in San Joaquin River inflow occurred in 2009, the third year of the recent three-year drought, when only 17% of unimpaired inflow reached the Delta. Inflows were lower than 20% of unimpaired in several other years: 18% in 1960 (a dry year following a dry year), 19% in 1993 (a very wet year following a multi-year drought) and 20% in 1990 (a very dry year following several other very dry years). For the most recent 10-year period (2005-2014), on average only 42% of unimpaired San Joaquin River inflow actually flowed into the Delta. During this period San Joaquin River inflows were "very poor," less than 50% of unimpaired, in six of the ten years; in the other four years inflow were "poor," less than 65% of unimpaired. San Joaquin River inflows were at least 60% of unimpaired, the level identified by the SWRCB (2010) as necessary to protect public trust resources, in only two years during the last decade, and only nine years in the last 50 years (18% of years). In 2014, only 36% of unimpaired San Joaquin River flow reached the Delta, corresponding to "very poor" conditions.

The proportional reductions in San Joaquin River inflow to the Delta differ by water year type.
The greatest alterations to San Joaquin River inflows occur in dry years when annual inflows are reduced by nearly two thirds, averaging just 36% of unimpaired, significantly lower than inflows in very wet and wet years (ANOVA for the 1930-2014 period, $p<0.05$). Since 1930, the percentages of San Joaquin River inflow that reached the Delta averaged 46% in very dry years, 36% in dry years, 45% in median years, 52% in wet years and 59% in very wet years.

San Joaquin River flow into the Delta, as a percentage of unimpaired flow, has declined over time.
The percentage of unimpaired flow that actually flowed into the Delta from the San Joaquin River has declined significantly since the 1930s; inflows before most of the major dams were

completed (the pre-dam period, 1930-1943) were significantly higher, 60% of unimpaired, than those measured since 1970, which have averaged 46% (t-test, $p<0.01$).

The contribution of the San Joaquin River to total Delta inflow has been reduced.
Compared to unimpaired flow conditions, the fractional contribution of the San Joaquin River to total Delta inflow has been reduced by an average of 41% (1930-2014).[12] For the most recent ten-year period, 2005-2014, San Joaquin River's contributions to total Delta inflow were reduced by an average of 45%; in 2014 the San Joaquin River's contribution to total Delta inflow was less than half of what it would have been under unimpaired conditions.

San Joaquin River diversions constitute the majority of Sacramento-San Joaquin watershed runoff that is diverted before reaching the Delta.
Since 1980, an average of 3.3 ($\pm$1.9 SD) million acre feet of freshwater inflow was diverted from the San Joaquin River before it reached the Delta. This constitutes 65% of the reduction in Delta inflow from water diverted from the Sacramento-San Joaquin watershed prior to flowing in to the Delta and 30% of the total reduction in freshwater inflow to the Bay.

Based on San Joaquin River inflows to the Delta, CCMP goals to increase fresh water availability to the estuary have not been met.
Since 1990, freshwater inflows to the Delta from the San Joaquin River have not been "good," meeting or exceeding conditions considered to satisfy CCMP goals, in any year (0 of 25 years). Current San Joaquin River inflows to the Delta are much lower than the 80% level recommended by Richter et al. (2011) to maintain ecological integrity. They are also well below the 60% of unimpaired level identified by the SWRCB as necessary to protect public trust resources and estuarine health (SWRCB 2010). In 16 of the past 25 years (64% of years), San Joaquin River inflows were "very poor," cut by more than 50%.

D. Annual Bay Inflow

1. Rationale

Fresh water that flows out of the Delta, the upstream region of the estuary, provides >90% of the total freshwater inflow to the San Francisco Bay. As it enters the Bay, inflowing fresh water mixes with salt water from the Pacific Ocean and lower Bay, creating brackish water[13] habitat that is a key characteristic of estuaries, and the amounts, timing and seasonal and inter-annual variability of inflows function as physical and ecological drivers that stimulate productivity, reproduction and movement (Jassby et al. 1995; Kimmerer 2002; 2004 Feyrer et al. 2008; Moyle et al., 2010). In the Bay's Sacramento-San Joaquin watershed, annual runoff varies substantially

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[12] Change in the proportional contribution of the San Joaquin River to total Delta inflow as calculated as:

$$\text{SJR Inflow indicator} = \frac{\{[(\text{SJR-in as \%D-in})-(\text{unimp. SJR-in as \%unimp. D-in})]\}}{(\text{unimp. SJR-in as\%unimp. D-in})} \times 100$$

where SJR-in as %D-in is the percent contribution of total annual actual SJR inflow to total annual actual Delta inflow, and Unimp. SJR as %unimp. D-in is the percent contribution of total annual unimpaired SJR inflow to total annual unimpaired Delta inflow. The San Joaquin River's proportional contribution to Delta inflow is highly correlated to San Joaquin River inflow expressed as percent of unimpaired ($p<0.001$, Pearson product moment correlation coefficient=0.953).

[13] Brackish water is defined as water that has more salinity than fresh water, but not as much as seawater.

for year-to-year, but during the past century, freshwater inflows into the Delta and the Bay downstream have been greatly altered by upstream dams and water diversions. Nine of the ten largest rivers in the 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 rivers 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 Bay have affected the estuarine ecosystem and the plants and animals that depend on it.

2. Methods and Calculations

The Annual Bay Inflow[14] indicator measures the amount of fresh water from the Sacramento-San Joaquin watershed that flows into San Francisco Bay from the Delta each year compared to the amount that would have flowed into the Bay under unimpaired conditions. Capture and storage of watershed runoff for release in subsequent years and diversion of water from the estuary's tributary rivers and the Delta reduces annual Bay inflow; release of water captured and stored in watershed reservoirs in previous years and imports of water from the Trinity River watershed increase annual Bay inflow.

The indicator was calculated for each year (1930-2014) using data for total annual actual freshwater inflow and estimated total annual unimpaired inflow as:

Annual Bay Inflow (% of unimpaired)
= (actual annual Bay inflow/unimpaired annual Bay inflow) x 100

3. Reference Conditions

The primary reference condition for the Annual Bay Inflow indicator was established as 75%, a level based on the SWRCB's recommendation for freshwater inflows (or Delta outflows) needed to support public trust resources in the estuary. This level also corresponds to an average annual in-Delta flow depletion of 2.4 million acre-feet (approximately 10% of unimpaired Delta inflow) a level that is more than twice the amount of unimpaired in-Delta depletion.[15] Annual inflows that were greater than 75% of unimpaired inflows were considered to reflect "good" conditions and meet the CCMP goals; annual inflows that were less than 50% of unimpaired inflows were considered to correspond to "very poor" conditions. The other reference condition levels were based on equal increments between these two levels. Table 4 below shows the quantitative reference conditions that were used to evaluate the results of the Annual Bay Inflow indicator.

[14] Bay inflow is measured and frequently expressed as Delta outflow, or net Delta outflow.
[15] Unimpaired in-Delta depletion was calculated as (unimpaired Delta inflow – unimpaired Delta outflow).

Table 4. Quantitative reference conditions and associated interpretations for results of the Annual Bay Inflow indicator. The primary reference condition, which corresponds to "good" conditions, is in bold italics.

Annual Bay Inflow		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>87.5% of unimpaired	"Excellent," minimal alteration	4
>75% of unimpaired	***"Good," meets CCMP goals***	***3***
>62.5% of unimpaired	"Fair"	2
>50% of unimpaired	"Poor"	1
<u>≤</u>50% of unimpaired	"Very Poor," extreme alteration	0

4. Results

Results of the Annual Bay Inflow indicator are show in Figure 7.

The amount of fresh water flowing into the San Francisco Bay from the Delta each year has been reduced.
On an annual basis, the percentage of the freshwater runoff from estuary's largest watershed that flows into the Bay has been substantially reduced. For the most recent 10-year period (2005-2014), on average only 50% of unimpaired inflow actually flowed into the Bay, with inflows less than 50% in seven of those years. In 2009, a dry year that followed two consecutive very dry years, annual Bay inflow was only 32% of unimpaired, the third lowest percentage of freshwater inflow in the 85-year data record. In 2014, a very dry year, only 49% of unimpaired inflow reached the Bay.

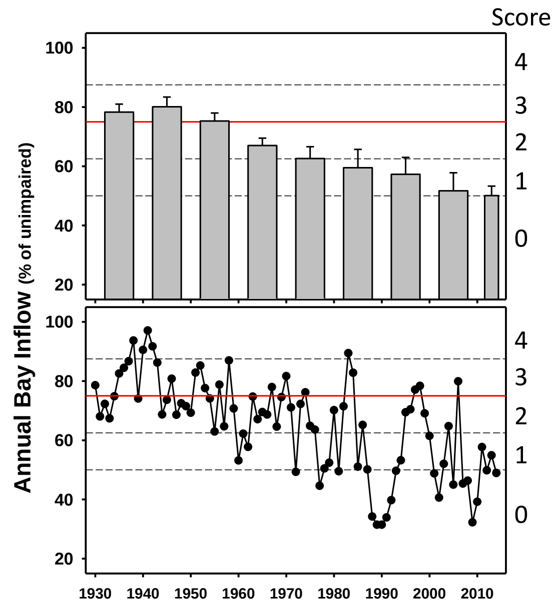

Figure 7. Results for the Annual Bay Inflow indicator, expressed as the percentage of unimpaired flow that actually flowed into the Bay from the Delta for 1930 to 2014(left Y axis) and indicator score (right Y axis). The top panel shows results as decadal averages±1 SEM (and for five years for 2010-2014) and the bottom panel shows results for each year. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

The proportional alteration in annual freshwater inflow to the Bay differs by water year type.
The greatest alterations to freshwater inflows (expressed as a percentage of estimated unimpaired inflow) occur in drier years. Since the 1970s, the percentages of unimpaired flow that reached the estuary averaged 45% in very dry and dry years, 52% in median years, 68% in wet years and 72% in very wet years.

Freshwater flow into the Bay, as a percentage of unimpaired flow, has declined over time.
The percentage of unimpaired flow that actually flows into the Bay has declined significantly over the past several decades (regression, p<0.001). Significant declines in the percentage of unimpaired inflow reaching the Bay have occurred in all water years types (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 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, 50%, is somewhat lower but, due to the large inter-annual variability associated with hydrology, not significantly different than flows during the 1980s. Since 1980, an average of 10.9 ($\pm$4.3 SD) million acre feet of freshwater inflow was diverted from either the Sacramento-San Joaquin watershed or Delta before it reached the Bay. Of this amount, reductions in Delta inflow constitute 48% percent of the reduction in Bay inflow and in-Delta diversions 53% percent.

Based on annual inflows, CCMP goals to increase fresh water availability to the estuary have not been met.
Since 1990, freshwater inflows to the Bay were "good," meeting or exceeding conditions considered to satisfy CCMP goals, in just 12% of years (3 of 25 years). 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 1990s, the period during which the CCMP was developed and established. In 13 of the past 25 years (52% of years), Bay inflows were "very poor," cut by more than 50%.

E. Spring Bay Inflow

1. Rationale

Freshwater inflows to the Bay 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 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. Capture and storage of spring runoff for release later in the year or in subsequent years, and springtime diversion of water from the estuary's tributary rivers and the Delta reduces spring Bay inflows; springtime release of water captured and stored in watershed reservoirs in previous years and imports of water from the Trinity River watershed increase spring Bay inflow.

The indicator was calculated for each year (1930-2014) using data for February-June actual freshwater inflow and estimated total annual unimpaired inflow as:

Spring Inflow (% of unimpaired)
= (actual Feb-June inflow/unimpaired Feb-June inflow) x 100

3. Reference Conditions

The primary reference condition for the Spring Bay 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 and meet the CCMP goals; annual inflows that were less than 50% of unimpaired inflows were considered to correspond to "very poor" conditions. The other reference condition levels were based on equal increments between these two levels. Table 5 below shows the quantitative reference conditions that were used to evaluate the results of the Spring Inflow indicator.

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

Spring Bay Inflow		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
>87.5% of unimpaired	"Excellent," minimal alteration	4
>75% of unimpaired	***"Good," meets CCMP goals***	***3***
>62.5% of unimpaired	"Fair"	2
>50% of unimpaired	"Poor"	1
≤50% of unimpaired	"Very Poor," extreme alteration	0

4. Results

Results of the Spring Bay Inflow indicator are show in Figure 8.

The amount of fresh water flowing in the Bay during the spring has been reduced.
The percentage of the springtime runoff from estuary's largest watershed that flows into the Bay has been significantly reduced. For the most recent 10-year period (2005-2014), on average only 44% of unimpaired inflow actually flowed into the estuary. In 2009, spring inflow only 27% of unimpaired, the seventh lowest percentage of freshwater inflow in the 85-year data record. In 11 of the past 20 years (55% of years), the percentage of unimpaired flow that flowed into the Bay during the spring was less than 50%. In 2014, only 36% of unimpaired inflow reached the estuary.

The proportional alteration in spring inflow to the estuary differs by water year type.
The greatest alterations to springtime freshwater inflows occur in drier years. Since the 1970s, the percentages of unimpaired flow that reached the estuary averaged 33% in very dry and dry years, 44% in median years, 67% in wet years and 72% in very wet years.

Spring flow into the Bay, 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 (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 springtime unimpaired flow actually reached the Bay. 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, 44%, is somewhat lower but, due to the large inter-annual variability associated with hydrology, not significantly different than flows during the 1980s.

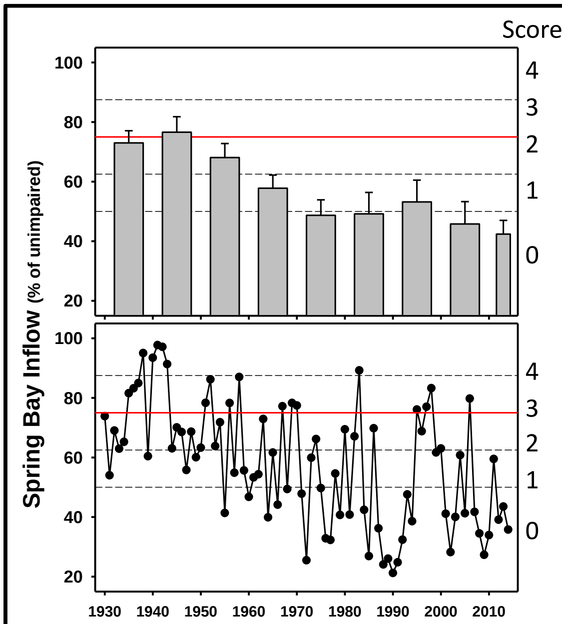

Figure 8. Results for the Spring Bay Inflow indicator, expressed as the percentage of spring (Feb-June) unimpaired flow that actually flowed into the Delta for 1930 to 2014 (left Y axis) and indicator score (right Y axis). The top panel shows results as decadal averages±1 SEM (and for five years for 2010-2014) and the bottom panel shows results for each year. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

Based on spring inflows, CCMP goals to increase fresh water availability to the estuary have not been met.
Since 1990, springtime freshwater inflows to the Bay were "good," meeting or exceeding conditions considered to satisfy CCMP goals, in just 12% of years (3 of 25 years). Current spring inflows to the Bay are well below the 75% level identified by the SWRCB as necessary to protect public trust resources and estuarine health. In 64% of the past 25 years, spring inflows to the Bay have been cut by more than 50% and recent inflows are also somewhat lower than those measured in the 1990s.

F. Delta Diversions

1. Rationale

The Delta, now a complex network of interconnected river channels, sloughs, canals and islands, has been a site for water diversion for more than a century (CDWR 1995). The first Delta diverters were farmers irrigating the rich island soils and small local communities like Antioch. Today, there are more than 2,200 of these agricultural and local urban water diversions scattered throughout the Delta's 1152-square mile area. Beginning in the 1950s, the Delta also became the main "switching station" for much of California's managed water supply. Two giant pumping facilities located in the southern Delta – the Central Valley Project (CVP) operated by the U.S. Bureau of Reclamation and the State Water Project (SWP) operated by the California Department of Water Resources – divert and export large amounts of water into man-made canals for delivery to the San Francisco Bay area, San Joaquin Valley and Southern California.

Removal of water from Delta channels at a pipe or diversion canal can alter flow patterns and kill fish and other small animals trapped in the diverted water, particularly if the diversion rate is high relative to flow in the channel (Kimmerer 2008).

2. Methods and Calculations

The Delta Diversions indicator measures Delta diversions as the percentage of total Delta inflow that is diverted from the Delta for each year (1930-2014). Diversion of water from Delta channels reduces the amount of fresh water that flows into the Bay and can alter flow velocity and direction in Delta channels.

The indicator was calculated for each year (1930-2014) using data for actual annual Delta inflow and actual annual Delta outflow (or Bay inflow) as:

Delta Diversions indicator
= [(actual Delta inflow – actual Delta outflow)/actual Delta inflow]*100.

3. Reference Conditions

The primary reference condition for the Delta Diversions indicator was established as 13%. This level corresponds to the amount of in-Delta diversions that would result in Bay inflows that met or exceeded the primary reference condition for the Annual Bay Inflow indicator, 75% of unimpaired, when the primary reference condition for the Annual Delta Inflow indicator, 80% of unimpaired, was met or exceeded. This level is also more than double the average unimpaired in-Delta depletion rate (4%),[15] the average pre-dam in-Delta diversion rates (5% for the 1930-1943 period) and average pre-export pumping facilities period (6% for 1930-1958 period). In-Delta diversions that were less than 13% of actual annual Delta inflow were considered to reflect “good” conditions and meet the CCMP goals; annual diversions that were three times greater than this level, 39%, and more than six times greater than pre-export pumping facility in-Delta depletion rates and which would approach current regulatory standards limiting state and federal pumping facility exports to protect fish and wildlife (SWRCB 2006) in most years were considered to correspond to “very poor” conditions. The intermediate reference condition (“fair”) was based on equal increments between these two levels and the upper (“excellent”) reference condition was based on the average pre-export pumping facilities level. Table 6 below shows the quantitative reference conditions that were used to evaluate the results of the Delta Diversions indicator.

Table 6. Quantitative reference conditions and associated interpretations for results of the Delta Diversions indicator. The primary reference condition, which corresponds to “good” conditions, is in bold italics.

Delta Diversions		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
<6% of Delta inflow	“Excellent,” minimal alteration	4
<13% of Delta inflow	***“Good,” meets CCMP goals***	***3***
<26% of Delta inflow	“Fair”	2
<39% of Delta inflow	“Poor”	1
≥39% of Delta inflow	“Very Poor,” extreme alteration	0

4. Results

Results of the Delta Diversions indicator are show in Figure 9.

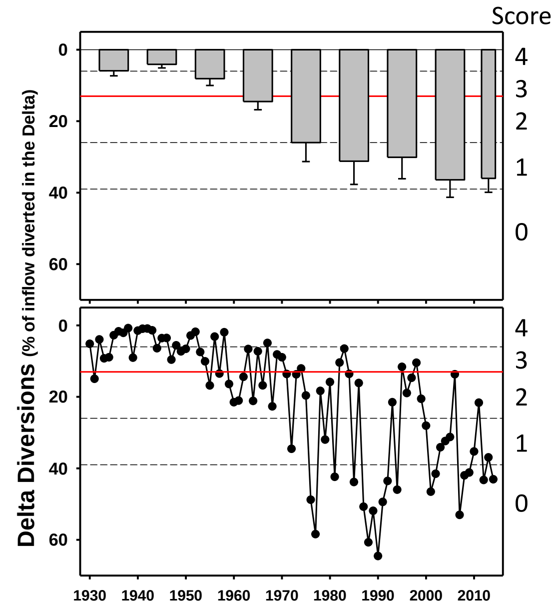

Figure 9. Results for the Delta Diversions indicator, expressed as the percentage of Delta inflow that is diverted in the Delta for 1930 to 2014(left Y axis) and indicator score (right Y axis). The top panel shows results as decadal averages±1 SEM (and for five years for 2010-2014) and the bottom panel shows results for each year. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

A large percentage of the fresh water that flows into the Delta is diverted.
The amount of fresh water diverted from the Delta, expressed as percentage of annual Delta inflow, reached record highs during the past three decades. The highest proportional diversion rates occurred during droughts, exceeding 50% of inflow diverted in several years and a record 65% of inflow diverted in 1990. During the past ten years, Delta diversion rates have averaged 36% and, in 2014, 43% of total Delta inflow was diverted and did not flow into the Bay.

The percentage of Delta inflow that is diverted in the Delta differs with water year type.
Since 1970, when both the state and federal export facilities were operational, the percentage of Delta inflow diverted from the Delta differed significantly among all years types except very wet years compared to wet years (ANOVA, $p<0.05$ all comparisons except very wet v wet). The highest proportional diversions occur in very dry years, averaging 51%. Diversion rates are progressively lower with wetter years, averaging 42%, 34%, 18% and 14% for dry, median, wet and very wet years respectively.

The percentage of Delta inflow diverted from the Delta has increased over time.
The percentage of inflow diverted from the Delta has increased significantly during the past eight decades (regression, $p<0.001$) and since the 1970s, when both state and federal export facilities became operational (Mann Whitney, 1930-1969 v 1970-2014, $p<0.001$). Significant increases in Delta diversion rates occurred in all water year types (regression, all tests, $p<0.001$). Before construction of most of the major dams on the Delta's tributary rivers (1930-1943, the pre-dam period), an average of 5% of Delta inflow was diverted in the Delta. Not until the federal and then the state export facilities became operational in the 1950s and 1960s did Delta diversion rates begin to increase substantially.

Based on Delta diversion rates, CCMP goals to increase fresh water availability to the estuary have not been met.
Since 1990, Delta diversion rates were "good," meeting or exceeding conditions considered to satisfy CCMP goals, in just 8% of years (2 of 25 years). Current Delta diversion rates, combined with upstream diversions that reduce Delta inflow, reduce freshwater inflows to the Bay to well

below the 75% of unimpaired level identified by the SWRCB as necessary to protect public trust resources and estuarine health. Since the 1990s, Delta diversion rates have increased, reducing freshwater availability to the estuary rather than increasing it; in 11 of the past 25 years (44% of years), total Delta diversions exceeded 39% of total Delta inflows.

G. 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), 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 (Moyle et al. 2010).

2. Methods and Calculations

The Inter-annual Variation in Inflow indicator measures the ratio, expressed as percentage, of the inter-annual variation in actual annual inflow to Bay (or Delta outflow) and that of unimpaired annual Bay 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.[16] Reductions in inflows from upstream and in-Delta diversions, particularly in median and wetter years, reduce the differences between annual inflow amounts in very wet years and dry years, making successive years more similar to each other in annual inflow amounts.

The indicator was calculated for each year (1939-2010) using actual annual Bay inflow (or Delta outflow) and unimpaired annual Bay inflow as:

Inter-annual Variation in Inflow (% of unimpaired)
= [(SD actual Bay inflow for $\text{year}_{(0 \text{ to } -9)}$)/(SD unimpaired Bay inflow for $\text{year}_{(0 \text{ to } -9)}$)] x 100.

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 Bay inflows and calculated unimpaired inflows that had been reduced by 25%, the level of inflow reduction used for the primary reference condition for the Annual Bay Inflow indicator, for the same period. Based on this calculation, the reference condition was set at 75%. Levels that were greater than this were considered to reflect “good” conditions and meet the CCMP goals; levels

[16] Inter-annual variation in inflow was not measured using the coefficient of variation (i.e., SD/mean) because for comparisons of actual to unimpaired inflows both the mean (of monthly inflow levels) and the variation around the mean (SD of monthly inflows) change.

that were less than 50%, more than double the reduction in inter-annual variability compared the primary reference condition, were considered to correspond to "very poor" conditions. The other reference condition levels were established based on equal increments of values based from these two levels. Table 7 below shows the quantitative reference conditions that were used to evaluate the results of the Inter-annual Variation in Inflow indicator.

Table 7. 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 italics.

Inter-annual Variation in Inflow		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
> 87.5%	"Excellent," minimal alteration	4
> 75%	***"Good," meets CCMP goals***	***3***
> 62.5%	"Fair"	2
> 50%	"Poor"	1
≤ 50%	"Very Poor," extreme alteration	0

4. Results

Results of the Inter-annual Variation in Inflow indicator are show in Figures 10 and 11.

Inter-annual variability in inflows to the San Francisco Bay has varied substantially over time.

The magnitude of inter-annual variability of unimpaired and actual freshwater inflows to the San Francisco Bay 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 similar annual flows (i.e., low inter-annual variation and low small standard deviation) (Figure 10). Beginning in the early 1980s, the unimpaired annual inflows became substantially more variable (1980-2004 average variability: 18,038 TAF) than annual unimpaired inflows during the earlier 40 years (1939-1979 average variability: 12,908 TAF). For the most recent decade, inter-annual variability levels have declined to level to levels comparable to the earlier period (2005-2014 average variability: 13,400 TAF). Inter-annual variation in actual annual flows showed a similar pattern (1939-1980 average: 12,082 TAF; 1980-2004 average: 15,579 TAF; and 2005-2014 average: 12,037 TAF).

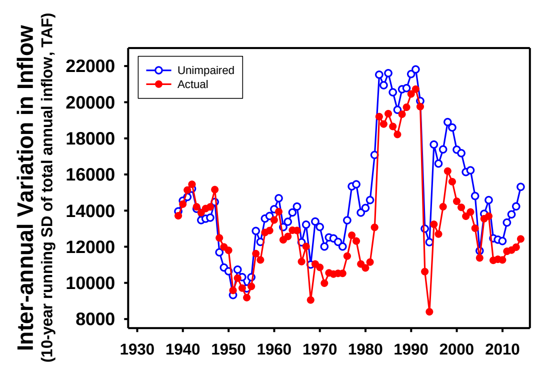

Figure 10. Inter-annual variation in actual and unimpaired freshwater inflows to the Bay for 1939-2014. Each point is the standard deviation for running 10-year periods ending in that year..

Inter-annual variability in inflows to the San Francisco Bay has been reduced. Inter-annual variability has decreased significantly during the past eight decades (regression, $p<0.01$). For the 1939-1967 period (the first 25 years of record), prior to completion of the most of the large dams in the watershed, the inter-annual variability of Bay inflows was essentially the same as for unimpaired inflows during the period, averaging 99% of unimpaired inter-annual variability. In contrast, the inter-annual variability of Bay inflows for the most recent 25 years, 1990-2014, is significantly lower than that of unimpaired inflows, averaging just 87% (t-test, $p<0.001$). The greatest reductions in inter-annual variation in Bay inflows occurred in the mid-1990s, following a prolonged drought when actual Bay inflows were reduced to record low levels (see Annual Bay Inflow indicator). In 2014, inter-annual variation in the most recent 10 years of Bay inflows was 81% of unimpaired inter-annual variation for that period.

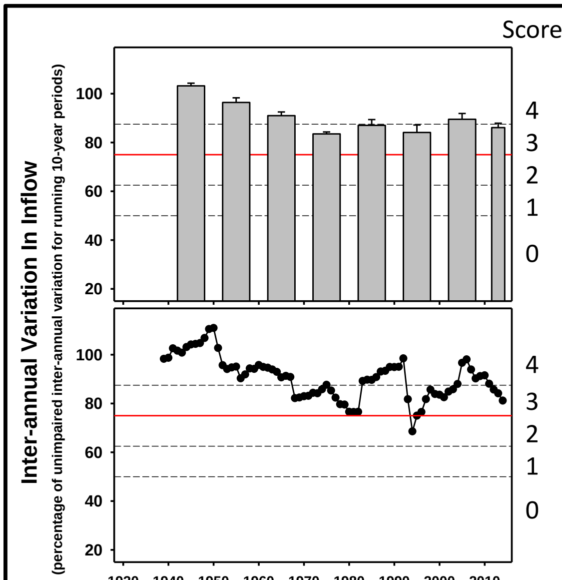

Figure 11. Results for the Inter-annual Variation in Inflow indicator, expressed as the percentage of unimpaired inter-annual variation of Bay inflows (calculated as the ratio of 10-year SD for actual inflow to the 10-year running SD for unimpaired inflows) for 1939 to 2014 (left Y axis) and indicator score (right Y axis). The top panel shows results as decadal averages±1 SEM (and for five years for 2010-2014) and the bottom panel shows results for each year. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

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 fully met.

Since 1990, inter-annual variation in freshwater inflows to the Bay was "good," meeting or exceeding conditions considered to satisfy CCMP goals in all but two years, 1994 and 1995, 92% of years (23 of 25 years). However, this recent period also saw the greatest reductions in inter-annual variability measured during the past 85 years and, since the mid-2000s, inter-annual variation in Bay inflows has been declining.

H. Seasonal Variation in Inflow

1. Rationale

Freshwater inflow to the San Francisco Bay 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 2). These seasonal variations in inflow create different kinds of habitat, for example, seasonal high inflows create 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 ratio, expressed as a percentage, of the seasonal (or intra-annual) variation in actual monthly average inflow to the San Francisco Bay 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).[17] The standard deviation of monthly inflows is large in years with large seasonal changes in inflow, such as from a strong springtime snowmelt pulse, and low in years when springtime flows are low compared to summer and fall flows.

The indicator was calculated for each year (1930-2014) using average monthly unimpaired and actual Bay inflow (or Delta outflow) as:

Seasonal Variation in Inflow (% of unimpaired)
= [(SD of actual average monthly Bay inflow)/(SD in unimpaired monthly Bay inflow)] x 100.

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 Bay inflows and calculated unimpaired monthly inflows that had been reduced by 25%, the level of inflow reduction used for the primary reference condition for the Annual and Spring Bay Inflow indicators, for the same period. Based on this calculation, the reference condition was set at 75%. Levels that were greater than this were considered to reflect "good" conditions and meet the CCMP goals; levels that were less than 50%, more than double the reduction in seasonal variability compared the primary reference condition, were considered to correspond to "very poor" conditions. The other reference condition levels were established based on equal increments of values based from these two levels. Table 8 below shows the quantitative reference conditions that were used to evaluate the results of the Seasonal Variation in Inflow indicator.

[17] Seasonal inflow variation was not measured using the coefficient of variation (i.e., SD/mean) because for comparisons of actual to unimpaired inflows both the mean (of monthly inflow levels) and the variation around the mean (SD of monthly inflows) change.

Table 8. 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 italics.

Seasonal Variation in Inflow		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
> 87.5%	"Excellent," minimal alteration	4
> 75%	***"Good," meets CCMP goals***	***3***
> 62.5%	"Fair"	2
> 50%	"Poor"	1
≤ 50%	"Very Poor," extreme alteration	0

4. Results

Results of the Seasonal Variation in Inflow indicator are show in Figures 12 and 13.

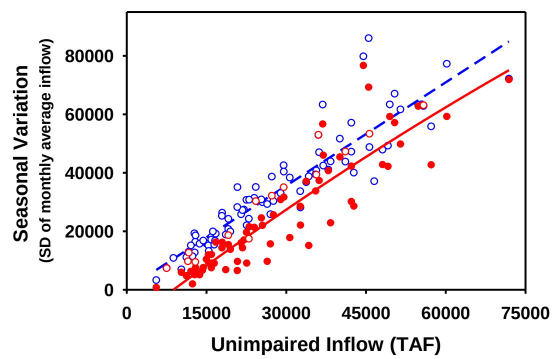

Figure 12. Seasonal variation in Bay inflows (SD of average monthly inflows, cfs, Y axis) is directly related to hydrology, as expressed by unimpaired inflow to the Bay (TAF, X axis). Seasonal variation in unimpaired inflows is shown in open blue circles. Seasonal variation in actual inflows is shown in open red circles (pre-dam period, (1930-1943) and solid red circles (1944-2014).

Seasonal variability in inflows to the San Francisco Estuary is directly related to hydrology.
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 very wet years and low in dry years (regression, both tests, $p<0.001$) (Figure 12).

Seasonal variability in inflows to the San Francisco Estuary has been reduced.
Seasonal variability of freshwater inflows to the Bay has declined significantly (regression, $p<0.001$) (Figure 13). The decline began in the mid-1940s, when the first of large storage dams in the estuary's watershed were completed, and since then each decade has seen progressive reductions in seasonal variation in Bay inflows. In the pre-dam period (1930-1943), actual seasonal variation in Bay inflows were 90% of seasonal variation of unimpaired inflows; by the 1980s the actual seasonal variation in inflows was significantly lower, averaging 66% of unimpaired seasonal variation (Mann Whitney Rank Sum test, $p<0.05$). Since then, seasonal variation has continued to decline, from an average of 62% in the 1990s to just 50% in the most recent 10 years (2005-2014). The greatest reduction in seasonal variation was in 1990, when actual seasonal variation was just 17% of unimpaired seasonal variation. In 2014, seasonal variation in Bay inflow was 28% of unimpaired seasonal inflow, the 5th lowest in the 85-year record.

Changes in seasonal variation in freshwater inflows to the Bay differ by water year type.
Seasonal variation in Bay inflows have significantly declined in all water year types except very wet years (regression, all tests except very wet, $p<0.01$). The greatest reductions in seasonal variation have occurred very dry and dry years, although in large reductions in seasonal variation have occurred in some recent wet years (e.g., seasonal variation was reduced by 61% in 2005, a

wet year). Since 1970, compared to unimpaired condition, seasonal variation in Bay inflows have averaged 39% in very dry years, 42% in dry years, 57% in median years, 77% in wet years and 86% in very wet years.

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.

Since 1990, seasonal variability of freshwater inflows to the Bay were "good," meeting or exceeding conditions considered to satisfy CCMP goals, in just 32% of years (8 of 25 years). In 13 of the past 25 years (52% of years), seasonal variability of Bay inflows have been "very poor."

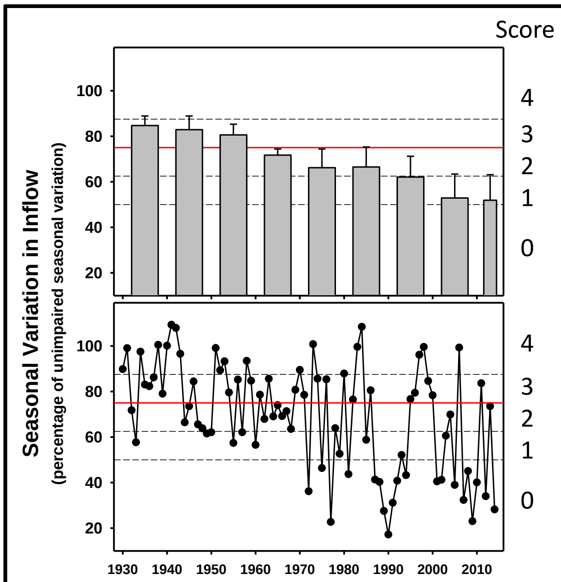

Figure 13. Results for the Seasonal Variation in Inflow indicator, expressed as the percentage of unimpaired seasonal variation of Bay inflows (calculated as the ratio of the SD for actual monthly inflows to the SD for unimpaired monthly inflows) for 1930 to 2014 (left Y axis) and indicator score (right Y axis). The top panel shows results as decadal averages±1 SEM (and for five years for 2010-2014) and the bottom panel shows results for each year. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

I. Peak Flow

1. Rationale

High, or "peak", freshwater inflows to the San Francisco Bay 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 Bay, 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 Bay 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[18] 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 the more prolonged spring snowmelt; therefore this indicator evaluated the estuary's responses to a key aspect of seasonal flow variation in its watershed.

[18] 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 indicator is calculated for each year (1930-2014) using the 5-day running average of actual Bay inflow (or Delta outflow) as:

> Peak flow (days)
> = (# days actual Bay inflow>50,000 cfs) – (# days predicted Bay inflow >50,000 cfs)

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 14). 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 14. 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.[19]

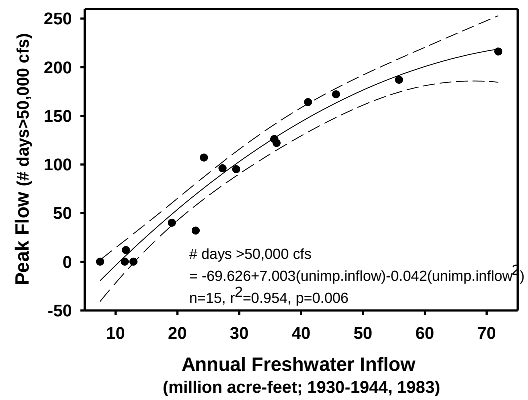

Figure 14. Actual (symbols) and predicted (regression with confidence limits) number of days with peak flow per year in relation to total annual Bay inflow for 1930-1944 and 1983. This relationship was used to establish the reference conditions for the Peak Inflows indicator.

3. Reference Conditions

Reference conditions were established based on the 95% confidence interval for the polynomial regression developed from pre-dam and 1983 data (see Figure 14 above). Over most of the range of annual freshwater inflows, the maximum value for the 95% confidence interval for predicted days of peak flows was 15 days; the primary 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 pre-dam inflows). 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 and meet the CCMP goals; reductions in days of peak flows that were more than double this level (or four times greater than the 95% confidence interval) were considered to correspond to "very poor" conditions. The other reference condition levels were established based on equal increments of values based from these two levels, with the upper reference conditions ("excellent") set at -15 days. Table 9 below shows the quantitative reference conditions that were used to evaluate the results of the Peak Flow indicator.

[19] This occurred in only four years: 1931, 1976, 1977 and 2014.

Table 9. 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 italics.

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

4. Results

Results of the Peak Flow indicator are show in Figure 15.

The frequency of peak flows into the San Francisco Bay varies with water year type. Actual peak flow frequency (as number of days per year) is highest in very wet years, when there are of 140 days of peak flow per year on average for the 85 year data record, lowest in very dry years (<2 days/year). Dry years have an average of 12 days/years, median years an average of 48 days/year and wet years an average of 85 days.

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 85-year period of record (regression, $p<0.001$). The decline began after 1943, immediately following completion of many of the large dams on the estuary's largest tributaries. Peak flow frequency has significantly declined in all water year types except very dry years (regression, $p<0.05$ all tests, regression for very dry years, $p=0.16$). On average, there are 36 fewer days of peak flows per year since the mid-1940s than during the 1930-1943 period. In the most recent ten year period (2005-2014), peak flow frequency was reduced by an average of 45 days per year. In 2014, a critical dry year in which no peak flows were predicted based on total annual Bay inflow, there were no days in which the 5-day average Bay inflow exceeded 50,000 cfs and the difference between actual and predicted peak flow frequency was zero.

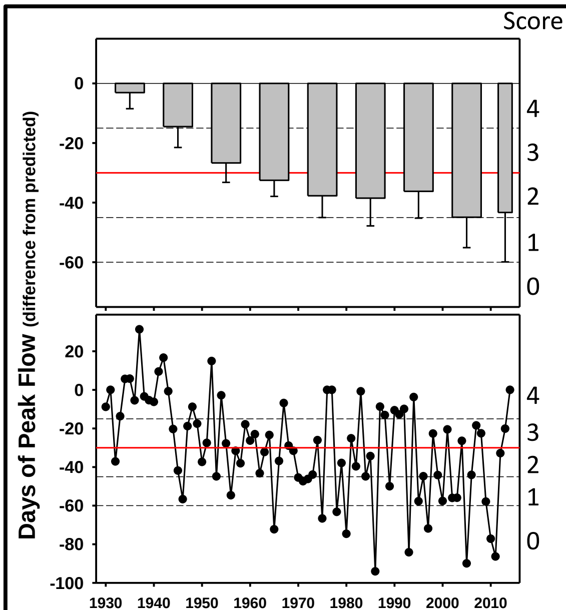

Figure 15. Results for the Peak Flows indicator, expressed as the number of days of peak flow different from predicted for 1930 to 2014 (left Y axis) and indicator score (right Y axis). The top panel shows results as decadal averages±1 SEM (and for five years for 2010-2014) and the bottom panel shows results for each year. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

Decreases in peak flow frequency differ with water year type.
Since 1943, the largest decreases in peak flow frequency have occurred in wet years, which have 55 fewer days of peak than predicted, a 43% decrease. In very wet years there are an average of 41 fewer days of peak flow in very wet years (24% decrease), 42 fewer days in median years (53% decrease), and 31 fewer days in dry years (75% decrease). Peak flows have been eliminated in most very dry years, cut by 95% to less than two day per year, compared to the predicted average of 11 days per year predicted.

Based on recent peak flow frequency, CCMP goals to increase freshwater availability to the estuary and restore healthy estuarine habitat and function have been partially met.
Since 1990, peak flow conditions in the Bay were "good," meeting or exceeding conditions considered to satisfy CCMP goals, in 44% of years (11 of 25 years). However, peak flows were completely eliminated in 7 of 25 years (i.e., 0 days of peak flow in 28% of years) in which they would have occurred based on predictions from estimates of unimpaired conditions from pre-dam inflows.

J. Dry Year Frequency

1. Rationale

California's Mediterranean climate is characterized 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). 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, whether the result of hydrological drought or "man-made" drought from water diversion, 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 very 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 very dry years experienced by the estuary based on actual annual freshwater Bay inflow amounts. very dry (VD) years were defined as the driest 20% of years in the 80-year unimpaired Delta outflows dataset (1930-2009), with total annual unimpaired inflows to the estuary of less than 15,000 thousand acre-feet (TAF) (see Table 10).

Table 10. Frequency-based classification of water years based on estimated unimpaired annual San Francisco Bay inflow (Delta outflow) from 1930-2009.

Water Year Type	Unimpaired inflow to the San Francisco Bay (total annual, TAF)	Years (1930-2009)
Very dry (driest 20% of years)	≤15,000 TAF	1931, 1933, 1934, 1939, 1947, 1976, 1977, 1987, 1988, 1990, 1991, 1992, 1994, 2001, 2007, 2008
Dry	>15,000-21,500 TAF	1930, 1944, 1949, 1955, 1957, 1959, 1960, 1961, 1964, 1966, 1968, 1972, 1981, 1985, 1989, 2009
Median	>21,500-29,500 TAF	1932, 1935, 1936, 1937, 1945, 1946, 1948, 1950, 1953, 1954, 1962, 1979, 2000, 2002, 2003, 2004
Wet	>29,500-42,000 TAF	1940, 1942, 1943, 1951, 1963, 1965, 1970, 1971, 1973, 1975, 1980, 1984, 1993, 1996, 1999, 2005
Very Wet (wettest 20% of years)	>42,000 TAF	1938, 1941, 1952, 1956, 1958, 1967, 1969, 1974, 1978, 1982, 1983, 1986, 1995, 1997, 1998, 2006

For the indicator, actual annual freshwater inflows to the Bay for each year were categorized using this water year type classification scale; for example, a year with actual annual Bay inflow of less than 15,000 TAF was categorized as "very dry" even if the unimpaired inflow for that year was higher and placed that year in a different water year category based on its unimpaired inflow. For each year, the number of very dry years (i.e., inflow<15,000 TAF) 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 was calculated for each year (1939-2014) as the difference between the number of very dry (VD) years that occurred under unimpaired conditions and the number that occurred in actual conditions as:

Dry Year Frequency
= (# VD years, actual Bay inflow <15,000 TAF for year$_{(0 \text{ to } -9)}$) – (# VD years, unimpaired Bay inflow <15,000 TAF for year$_{(0 \text{ to } -9)}$)

3. Reference Conditions

The reference condition for the Dry Year Frequency indicator was established by calculating the average difference between very dry year frequency in unimpaired Bay inflows and for unimpaired Bay inflows that had been reduced by 15-25% (depending on water year type).[20] The results of this analysis showed that reductions in unimpaired Bay inflows at the level specified increased the frequency of very dry years by 1.5 years. Therefore, the primary reference condition was set at 2 years. Differences in the numbers of very dry years between 10-year sequences of actual and unimpaired flows that were 2 years or less were considered to reflect "good" conditions and meet the CCMP goals; differences in the numbers of very dry years between 10-year sequences of actual and unimpaired flows that were more than double this level were considered to correspond to "very poor" conditions. The other reference condition levels were established based on equal increments of values based from these two levels. Table

[20] 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%.

11 below shows the quantitative reference conditions that were used to evaluate the results of the Dry Year Frequency indicator.

Table 11. 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 italics.

Dry Year Frequency		
Quantitative Reference Condition	**Evaluation and Interpretation**	**Score**
≤1 additional year of VD conditions	"Excellent," minimal alteration	4
≤2 additional years of VD conditions	***"Good," meets CCMP goals***	***3***
≤3 additional years of VD conditions	"Fair"	2
≤4 additional years of VD conditions	"Poor"	1
>5 additional years of VD conditions	"Very Poor," extreme alteration	0

4. Results

Results of the Dry Year Frequency indicator are show in Figures 16 and 17.

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

While the classification of very dry (VD) year inflows is based on the bottom quintile from the 80-year unimpaired dataset, the frequency of very dry hydrological conditions (i.e., hydrological conditions that result in VD unimpaired freshwater inflow to the estuary) has been more variable over that period (Figure 16, upper panel). The number of VD 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 VD years under unimpaired conditions, was higher (Figure 16, bottom panel, and Figure17). The largest increases in VD year frequency occurred in the 1960s, a period during which there were no VD years based on hydrological conditions in the estuary's

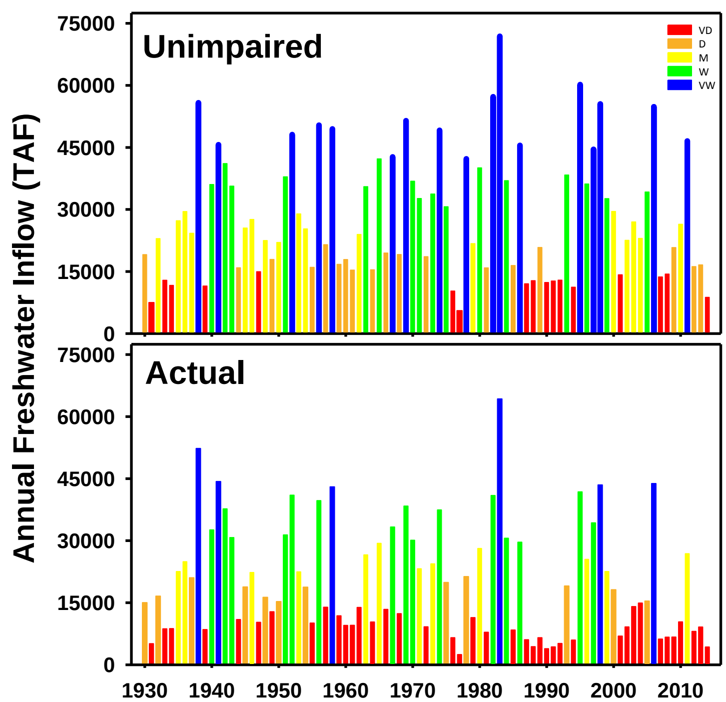

Figure 16. Freshwater inflow to the San Francisco Bay under unimpaired conditions (top panel) and actual conditions (bottom panel). Each histogram bar has been colored to the show the water year type, for example, red for very dry years with inflows<15,000 TAF and blue for very wet years with inflows >42,000 TSF. Water year type is based on frequency for unimpaired inflows and actual annual inflow amounts for actual inflows. See text for more details.

watershed, but during which the estuary received freshwater inflows comparable to VD conditions in an average of six out of 10 years. In the 1980s, an average of 1.8 years were very dry in the watershed but in the estuary an average of 4.4 years were very dry (i.e., there were an average of 2.6 more VD years out of 10 years than there were based on hydrological conditions in the estuary's watershed). Conditions during the most recent decade (2005-2014) were similar, with an average of 6.2 VD years out of 10 years for the estuary compared to just 2.2 VD years based on unimpaired conditions in the estuary's watershed. In 2014, the Bay had experienced critically low inflows in 70% of years in the past decade, a level of chronic, man-made drought conditions that had persisted since 2009.

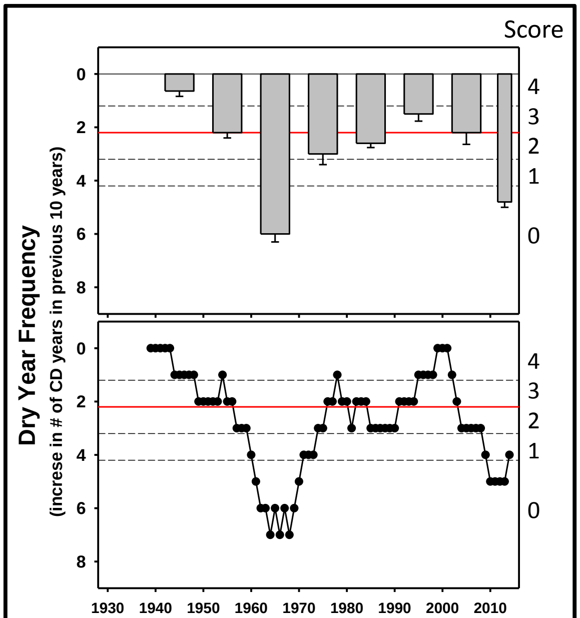

Figure 17. Results for the Dry Year Frequency indicator, expressed as the increase in the number of years of very dry actual inflow conditions (inflows<15,000 TAF) during the immediate past 10-year period, compared to the number of very dry years during that period under unimpaired conditions, for 1939 to 2014 (left Y axis) and indicator score (right Y axis). The top panel shows results as decadal averages±1 SEM (and for five years for 2010-2014) and the bottom panel shows results for each year. The horizontal red line shows the primary reference condition. The horizontal dashed lines show the other reference conditions used for evaluation.

The frequency of freshwater inflow conditions in the San Francisco Estuary that are comparable to very 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 VD years has increased significantly (Wilcoxon Signed Rank test, $p<0.001$) (Figure 16). On average, the estuary experienced 2.8 more VD 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, man-made drought conditions, particularly during the 1960s and 2000s when conditions in the estuary's watershed were not chronically dry.

Based on recent very dry year frequencies in the estuary, CCMP goals to increase freshwater availability to the estuary and restore healthy estuarine habitat and function have been partially met.

Since 1990, dry year frequency conditions in the Bay were "good," meeting or exceeding conditions considered to satisfy CCMP goals, in 52% of years (13 of 25 years). However, all of these years occurred during the 1990s and early 2000s and reflected a sequence of several consecutive extremely dry years followed by several consecutive extremely very wet years. Since the early 2000s, when hydrological conditions were more moderate, the frequency of man-made drought conditions has increased. The CCMP goal has not been met in any of the past 11 years and, in the past decade, the Bay has experienced very dry inflow conditions in more than 60% of years.

V. Freshwater Inflow Index

The Freshwater Inflow Index combines the results of the ten indicators into a single number to measure the aggregate degree of alteration to the freshwater inflows to the San Francisco Bay Estuary.

A. Index Calculation

For each year, the Freshwater Inflow Index was calculated by averaging the quantitative scores of the ten indicators. Each indicator is weighted equally. For any single year, an index score that was between 2.5 and 3.5 was interpreted to represent "good" conditions in which, collectively (or an average), the different aspects of freshwater inflow conditions met the CCMP goals.

B. Results

Results of the Freshwater Inflow Index are shown in Figures 18, 19 and 20.

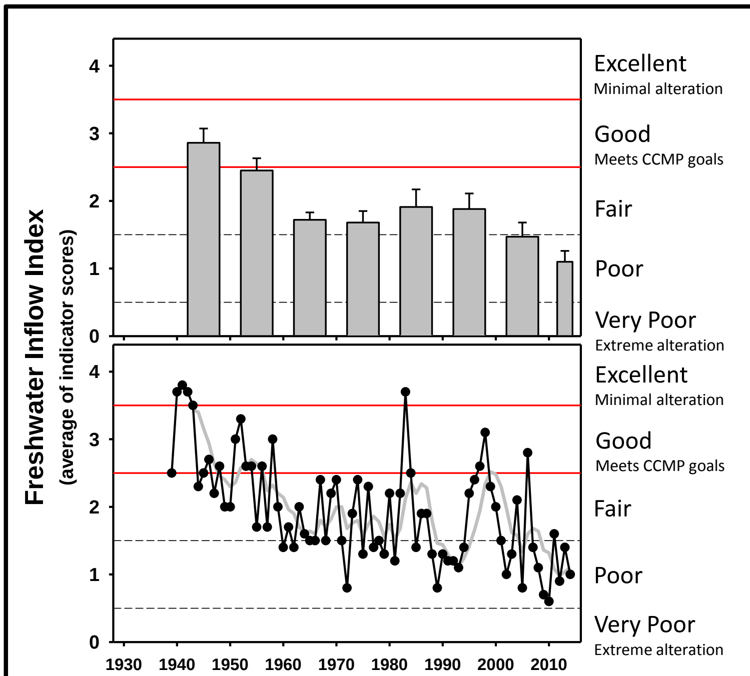

Figure 18. Results for the Freshwater Inflow Index for 1939 to 2014, expressed as the average score of the 10 component indicators. The top panel shows results as decadal averages±1 SEM (and for five years for 2010-2014) and the bottom panel shows results for each year, with the 5-year running average shown as the grey line. The horizontal red lines and dashed lines show the reference conditions and Index evaluation.

Freshwater inflows to the San Francisco Estuary are highly altered.
All of the ten indicators, which measured different aspects of freshwater inflow conditions, showed alteration in flows compared to estimated unimpaired conditions. Measured collectively using the Freshwater Inflow Index, the degree of flow alteration corresponds to "poor" conditions in most years since the 1970s.

Freshwater inflow conditions in the estuary have declined over time.
Freshwater inflow conditions to the estuary have been increasingly altered over time; the Index has declined significantly (regression, $p<0.001$). The decrease in the Index is driven by declines in nine of the ten indicators of freshwater inflow conditions (i.e., all indicators except Annual Delta Inflow). 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 2.9 in the 1940s (1939-1949 average), to 2.4 in the 1950s, and 1.7

in the 1960s. The Index was relatively stable during the 1970s, averaging 1.7, somewhat higher and more variable during the 1980s and 1990s (1980-1989 average: 1.91; 1990-1999: 1.9) before declining again to an average of 1.5 in the 2000s and an average of 1.1 for the most recent five years. The Index has declined significantly in all water year types except very wet years (regression, $p<0.01$ for all year types except very wet; very wet years, $p=0.09$) (Figure 19). The lowest Index value, 0.6, occurred in 2010, a median year that immediately followed a dry year, 2009, which with an Index of 0.7 and was the second lowest in the 76 year record. With the exception of 2005, most of the other years with Index values below 1.0 were dry (1972, 1989, and 2012). Water Year 2005, a wet year following a median year, stands out however with an Index of 0.8, indicating that, in recent years, high levels of alteration to freshwater inflows can occur. The 2014 Index value, 1.0, was the same as in 2012 and the seventh lowest Index in the 76-year period for which it was measured.

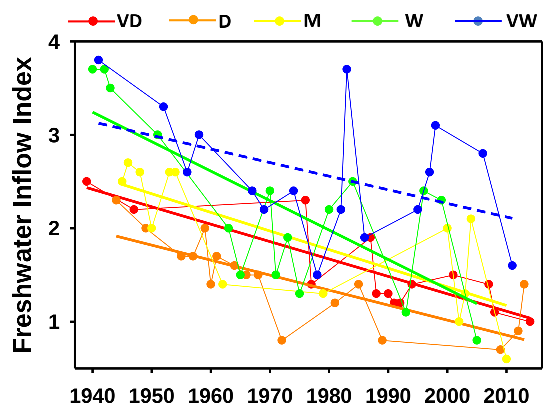

Figure 19. Results for the Freshwater Inflow Index for each water year type, from 1939 to 2014. Each color-coded plot shows the results for individual years (symbols) and the trend over time (connecting lines and regression line). Regressions (heavy solid lines) are significant for all years ($p<0.01$) except very wet years (heavy dashed line).

The Freshwater Inflow Index differs by water year type.

Since 1970, after most of the major dams in the estuaries watershed were completed and the Delta water export facilities became operational, the degree to which freshwater inflow conditions have been altered is significantly greater in dry, median and very dry years, compared to in very wet years and, for dry years, compared to wet years (ANOVA, all tests, $p<0.05$) (Figure 20).

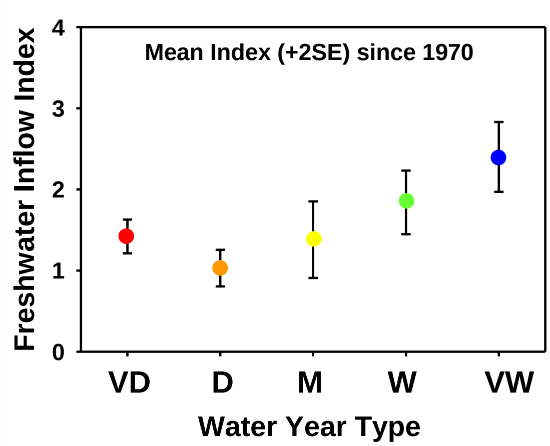

Figure 20. Post-water development (1970-2014) Freshwater Inflow Index for each water year type (mean$\pm$2 SE). Dry, Median and Very Dry years had significantly lower Index values than very wet years, and dry years have significantly lower index values that wet years (ANOVA, all tests $p<0.05$).

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 rarely "good" (12% of years since 1990), "fair" in some years (28% of years), and "poor" in most years (60% of years). Degraded inflow conditions reflect severe reductions in the amounts of freshwater inflow in most years, substantial reductions in seasonal variability of inflows, severe reductions in the frequency of peak flows and high frequencies of inflows comparable to very dry conditions, in effect, chronic man-made drought conditions resulting from water management operations in the estuary's watershed and upstream Delta region.

C. Summary and Conclusions

Collectively the ten indicators of the Freshwater Inflow Index provide a comprehensive assessment of the status and trends for freshwater inflow conditions to the San Francisco Bay and Sacramento-San Joaquin Delta from it largest watershed. Each of the indicators shows significant alterations to inflows to the 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 very dry hydrological conditions in the watershed. Table 12 summarizes the indicator results relative to the CCMP goals (as they are expressed by the reference conditions).

Table 12. Summary of results for the ten freshwater inflow indicators.

Indicator	CCMP Goals Fully met if goal achieved in >67% of years since 1990 Partially met if goal achieved in 33-67% of years Not met if goal achieved in <33% of years	Trend since 1990	Current condition (average for last 10 years)
Annual Delta Inflow	Partially met; goals achieved in 52% of years	Stable	Fair Inflow reduced by 26%
Spring Delta Inflow	Not met; goals achieved in 12% of years	Deteriorating	Poor Inflow reduced by 47%
San Joaquin River Inflow	Not met; goals achieved in 0% of years	Stable	Very poor Inflow reduced by 58%
Annual Bay Inflow	Not met: goals achieved in 12% of years	Deteriorating	Very poor Inflow reduced by 50%
Spring Bay Inflow	Not met; goals achieved in 12% of years	Deteriorating	Very poor Inflow reduced by 56%
Delta Diversions	Not met; goals achieved in 8% of years	Deteriorating	Poor 36% of inflow diverted
Inter-annual Variation in Inflow	Fully met; goals achieved in 92% of years	Mixed (variable)	Good Reduced by 10%
Seasonal Variation in Inflow	Not met; goals achieved in 32% of years	Deteriorating	Poor Reduced by 50%
Peak Flow	Partially met; goals achieved in 44% of years	Stable	Fair Reduced by 45 days/year
Dry Year Frequency	Partially met: goals met in 52% of years	Deteriorating	Poor Flow reductions triple dry year frequency
Freshwater Inflow Index	Not met; goals met in 12% of years	Mixed (variable)	Poor Only 1 of 10 indicators show “good” conditions

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