DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY

PREPARED IN COOPERATION WITH THE
DEPARTMENT OF HOUSING AND URBAN DEVELOPMENT

MISCELLANEOUS FIELD STUDIES
MAP MF– 333
SHEET 2 OF 2

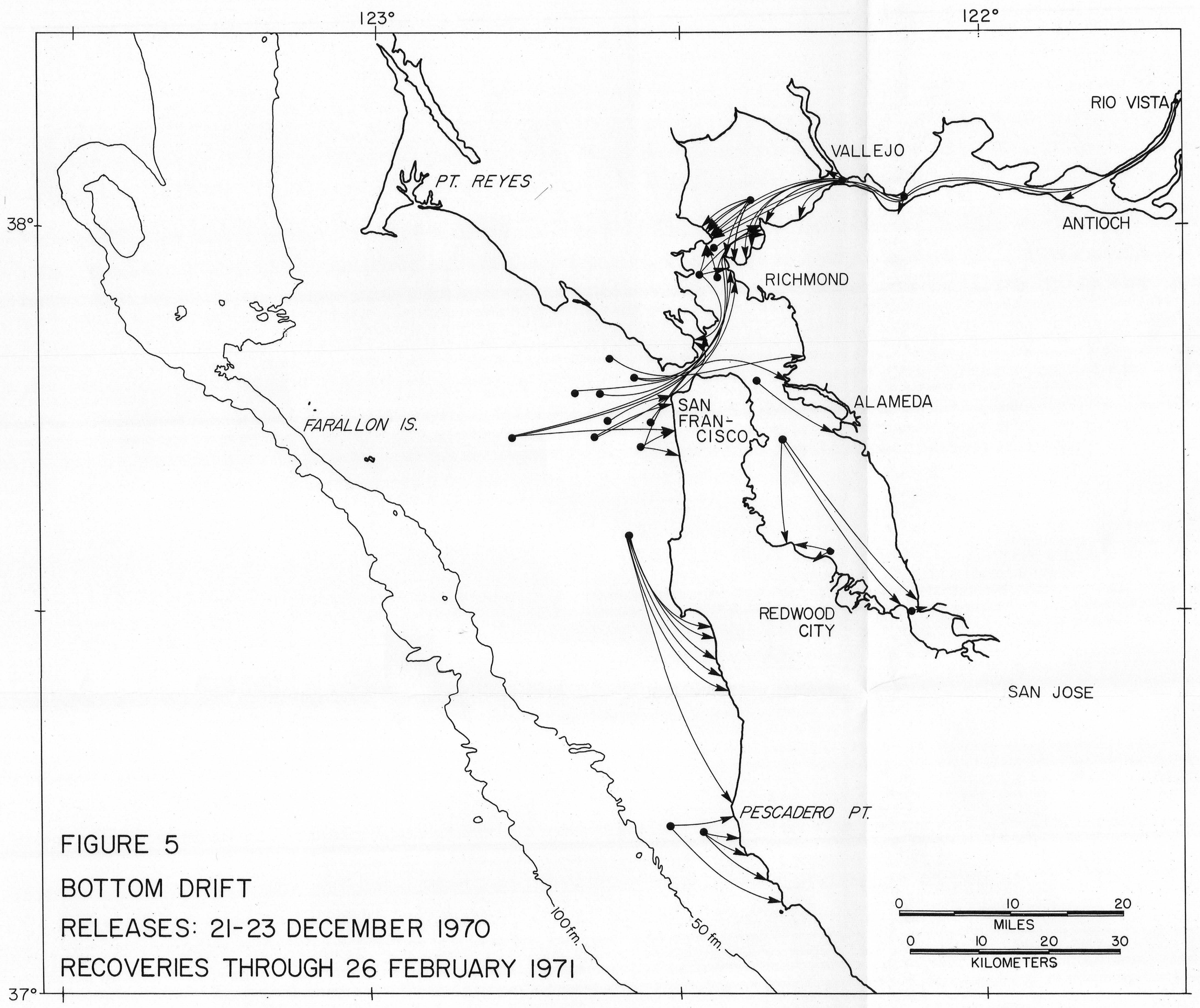

FIGURE 5
BOTTOM DRIFT
RELEASES: 21-23 DECEMBER 1970
RECOVERIES THROUGH 26 FEBRUARY 1971

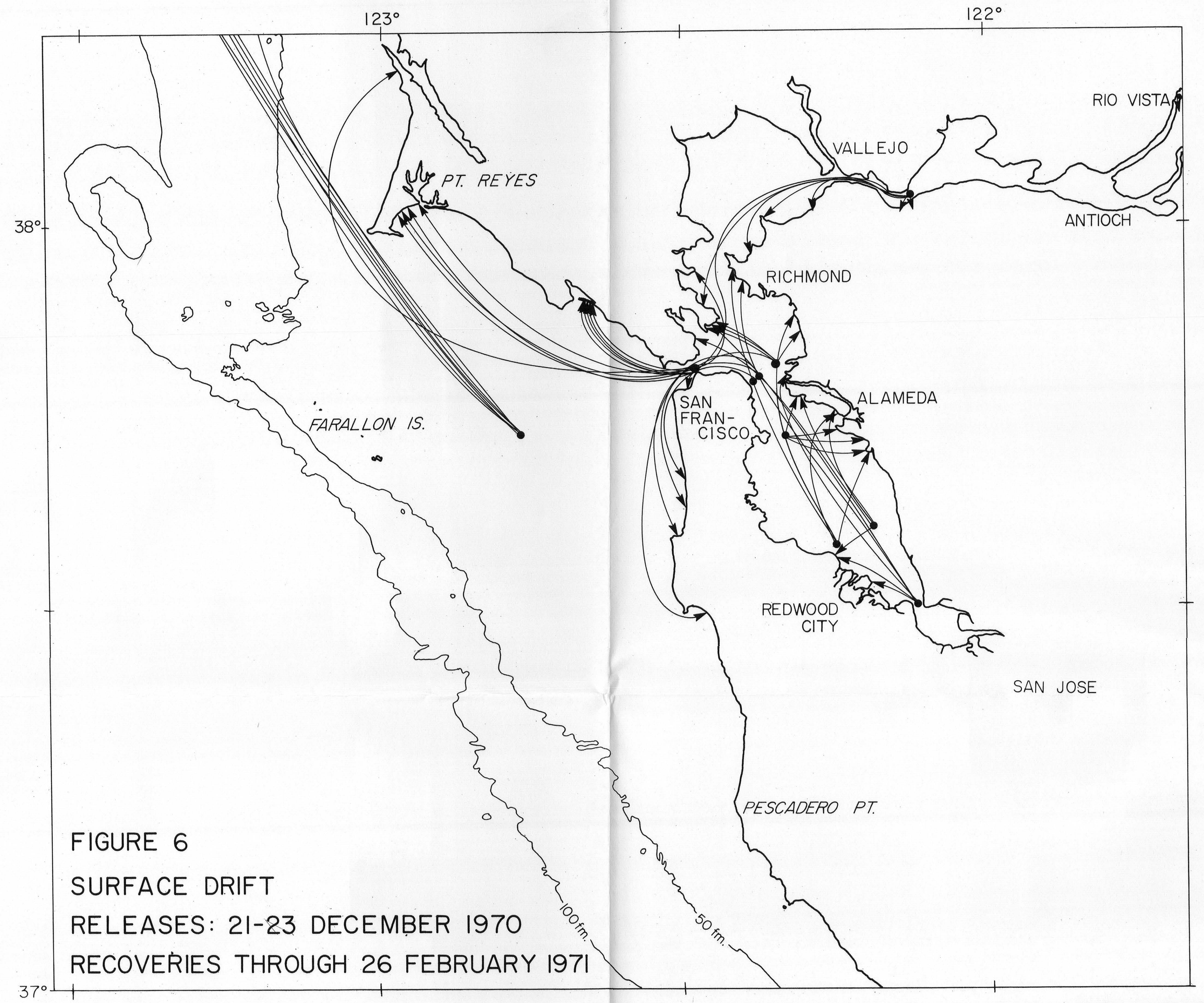

FIGURE 6
SURFACE DRIFT
RELEASES: 21-23 DECEMBER 1970
RECOVERIES THROUGH 26 FEBRUARY 1971

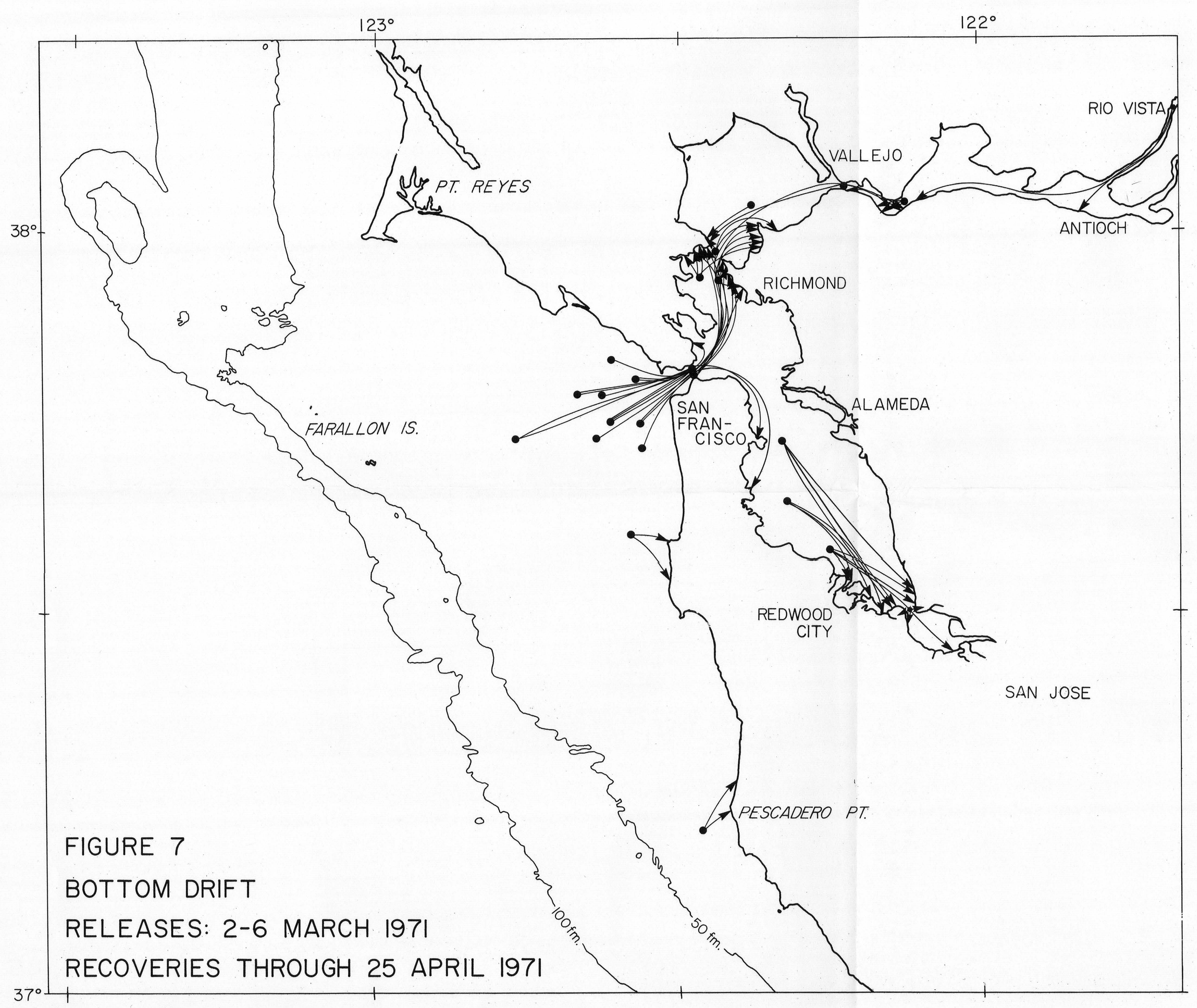

FIGURE 7
BOTTOM DRIFT
RELEASES: 2-6 MARCH 1971
RECOVERIES THROUGH 25 APRIL 1971

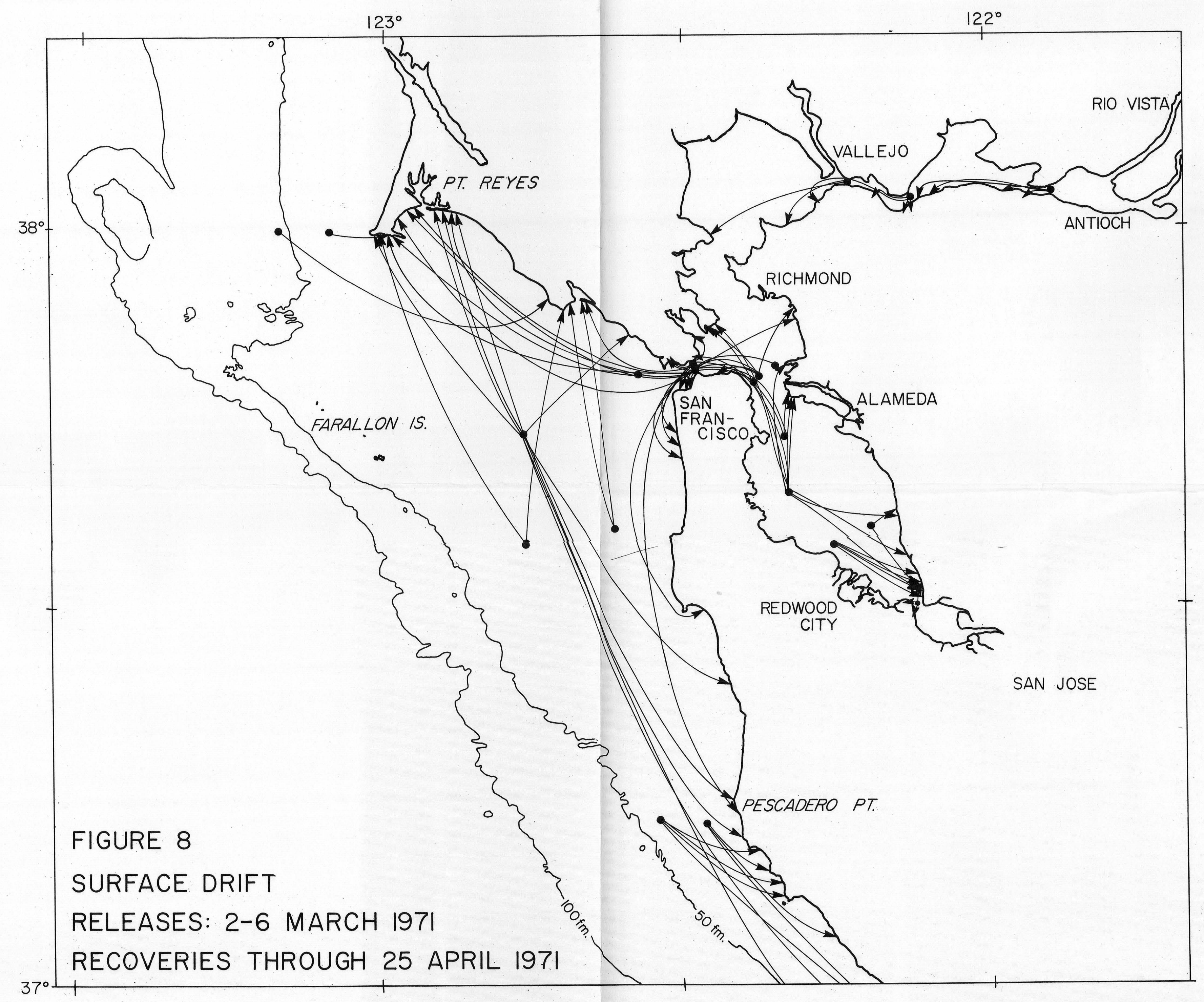

FIGURE 8
SURFACE DRIFT
RELEASES: 2-6 MARCH 1971
RECOVERIES THROUGH 25 APRIL 1971

DISCUSSION

Major factors which contribute to observable net movements of water within estuaries are river runoff, which creates density-induced circulation, and wind, which causes fluctuations in surface water transport. In tidal estuaries, strong tidal currents primarily increase the mixing rate of water; however, in some instances, tidal fluctuations can also contribute to net water movements. Because of the complex nature of the water movements in San Francisco Bay, and because of the averaging processes inherent in the use of drift methods, we have accepted the practice of other investigators and will assume that the drifter movements define primarily net nontidal water movements.

The annual permanence of the near-bottom drift pattern in the north and central bays (figs. 1 to 8) confirms the basic circulation pattern which was previously described from the initial observations in figure 1 (Conomos and others, 1970). The surface drift data (figs. 6 and 8) documents the two-dimensional estuarine circulation in the north and central bays which was postulated from the seasonal salinity distribution (McCulloch and others, 1970, fig. 10).

Reversal of near-bottom drift in south bay (figs. 3 and 4) further supports the proposed two-dimensional circulation model for the south bay (McCulloch and others, 1970). It is apparent from the data (figs. 1 through 8) that density-induced advective flow, generated largely by Sacramento and San Joaquin River discharge, occurs throughout the year; this flow exists for a wide range of river discharge (fig. 9). The timing of the hydrographic surveys and drifter releases during the winter high-discharge period (early October - late December, 1970; early March 1971) precluded detection in the south bay of stage 1 of this model (a northward flow of near-bottom water and a simultaneous southward flow of surface water). In addition, the salinity distribution observed in January 1969 and 1970 (McCulloch and others, 1970, and unpublished data) suggests that rather than a two-layer flow, there appears to be a period of three-layer flow similar to the salinity-induced three-layer flow described in Baltimore Harbor (Pritchard and Carpenter, 1960). The divergences in the south bay surface drift during March-April 1970 (fig. 8) may indicate a progressive weakening of the density-induced circulation and relative strengthening of surface water effects due to wind; our summer data for 1971 may clarify this.

Wind, which may be important in defining the seasonal water circulation of the south bay, is a dominant factor in the adjacent ocean. During spring and summer, the northerly winds cause an offshore movement of surface water which is replaced by an onshore transport of deep waters (Reid, Roden, and Wyllie, 1958). This wind-induced upwelling may be reinforced by river-induced upwelling (Conomos and Gross, 1968) due to the high fresh-water discharge during early spring, and together they can produce a strong onshore component in the movement of near-bottom water. These upwellings, together with the additive nearshore effects of winter-spring storm waves, could explain the increased numbers of ocean beach drifter recoveries found during these periods (table 1; figs. 1, 2, 3, 5, and 7). The well-defined north-setting surface drift, away from the direct effects of seaward-flowing bay water during December-February (fig. 6), presumably shows the effects of the temporary winter coastal (Davidson) current (Reid and Schwartzlose, 1962). The variable surface drift pattern during the March-April 1971 period (fig. 8) suggests the influence of the Davidson Current is waning, or may be due to short-term transient phenomena caused by rapidly shifting local wind patterns.

The relative speeds of near-bottom drift are apparently predictable. The south bay water movements (~1 km per day) are relatively slow when compared to those in other parts of the bay system. The fastest speeds, 4 km per day, characterize the north and central bays as the most dynamic part of the circulation system and are attributable primarily to the Sacramento and San Joaquin River inflow. These speeds, if we assume a 1:1 ratio of water speed to drifter speed (Woodhead and Lee, 1960), are comparable to those values measured in other estuaries and coastal oceans (table 2). Further data are needed to more clearly define seasonal variations in speed of both surface and near-bottom water.

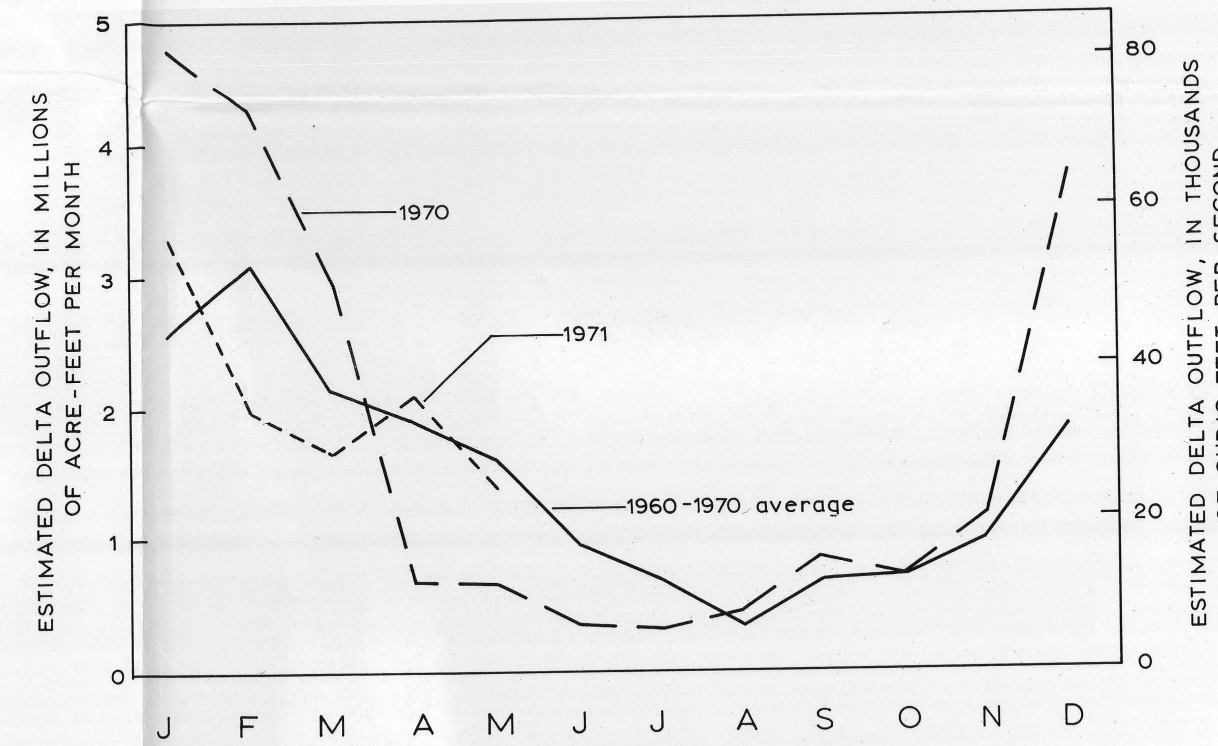

Figure 9. Comparison of the estimated Sacramento-San Joaquin Delta outflow for the survey period, versus a ten-year average. Estimated outflow from U.S. Bureau of Reclamation.

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DRIFT OF SURFACE AND NEAR-BOTTOM WATERS OF THE SAN FRANCISCO BAY SYSTEM, CALIFORNIA: MARCH 1970 THROUGH APRIL 1971

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