Interactive comment on "Reconstructing the natural hydrology of the San Francisco Bay-Delta watershed" by P. Fox et al.

Authors Responses to Vorster Comments (SC 2029)

The comments are shown numbered below with responses in italics below each comment. Sub comments have been identified in brackets (e.g., [1], etc.) within the original comments. Those specific comments are addressed within the response section.

1. This reviewer has investigated natural and unimpaired flows in the Bay-Delta-River system over the last two decades. I was a primary author of the 1998 publication, From the Sierra to the Sea, The Ecological History of the San Francisco Bay-Delta Watershed (TBI 1998), which was partially funded by water users and agencies who provided exhaustive technical review including Dr Phyllis Fox, the paper's lead author, particularly on Delta outflow and salinity.

   Comment noted.

2. The findings from that work and subsequent analysis concurs with the observation that the unimpaired Delta outflow is not the same as the natural Delta outflow because vegetation conversion, levee building and elimination of flood basin storage altered the flow pattern. Despite the assertion that "this is the first estimate of natural Delta outflow into the San Francisco Bay-Delta estuary" I reviewed other estimates of natural or predevelopment outflow using similar simple average annual water budgets (e.g. Fox 1987, Dawdy 1987 and Williamson et al 1989) and computed one myself based upon mapping of the natural vegetation distribution. I noted a wide variation in the computed outflow estimates (from 15 billionm3yr-1 to 31 billionm3yr-1) attributable primarily to the values assigned to the areal extent of different vegetation types and their ET rates as well as assumptions about the source of water supplying the natural vegetation. Using a different approach Ingram et al 1996 converted paleosalinity estimates into a paleo-discharge value for Delta outflow that are much higher than the water budget estimates (an average of about 39.5 billionm3yr-1 for the past 700 years). This paper should note the previous water budget estimates and other methods used to estimate natural Delta outflow.

We agree that others have attempted to estimate natural Delta outflow. We specifically cite three published studies based on different techniques (Ingram et al. 1996; Malamud-Roam et al., 2006; Meko et al. 2001). These studies estimate flows under Paleolithic or distant past conditions using tree rings and isotope measurements of core samples. They are not comparable to ours as they estimate flows during specific, historic years, e.g., 869 to 5,100 years ago. Our estimate is not an estimate of actual flows that occurred in any specific year, but rather, they are an estimate of natural outflows that assumes the contemporary precipitation and inflow pattern *to the Valley Floor with the Valley Floor in a natural or undeveloped state. See manuscript, pp. 3853-3854, lines 25-30.*

The other estimates cited in this comment either have not been published anywhere (Vorster), or are only available in the grey literature (Fox 1987; Dawdy 1987) and thus have not been subject to peer review. We note that Mr. Vorster has asserted for many years that he has estimated natural Delta outflow. However, he has never published his estimate and has declined to provide a copy or any information on his estimate in response to several requests by Dr. Fox and others. The Williamson et al 1989 study simulates ground water flow in the Central Valley under natural conditions and does not claim to estimate natural Delta outflows, but does contain a pre-development water balance that was developed without any supporting natural vegetation mapping. We will revise the manuscript to clarify that this is the first "published" estimate of natural Delta outflow based on "natural vegetation mapping".

3. This paper and the paper by Howes et al in press 2015 attempts to refine the estimates of the natural vegetation assemblages and ET rates but does not fully analyze one of the fundamental simplifying assumptions of their water budget approach: all of the rim station runoff and precipitation is a potential supply source for vegetative demand. Their attempt to address this issue with the different "cases" of vegetation demand is an incremental but incomplete step in what needs to be a more refined attempt to determine where the natural vegetation assemblages were in relation to the sources of their supply and how they responded to the seasonal and yearly variation in supply. [1] Nearly half of the total area of water demanding vegetation is grasslands and vernal pools, and another 27% are seasonal wetlands and oak woodlands and savanna for a total of 75% of the total area that was either not in the floodplain of the primary surface drainages or were far enough away from the perennial water courses to be seasonally water limited. [2] The pre-development groundwater budget by Williamson et al. 1989 calculates that only about 9.2 billionm3yr-1 of the low-lying central part of the Valley where groundwater levels are less than 3 meters are derived from stream channels while this study calculates more than twice that amount (20.8 billion m3yr-1). My average annual water budget estimates a lower net ET of the rim inflow from areas of seasonal wetlands and grasslands. [3]

[1] Our cases are not an attempt to address the juxtaposition of vegetation and water supply, but rather, as we explain on page 3861, lines 1-10, a sensitivity analysis to address uncertainties in the areal extent and water use of natural vegetation. The presence of vegetation indicates the juxtaposition with a water source.

[2] We agree that most of the grasslands, vernal pools, seasonal wetlands and foothill hardwoods were seasonally water limited. This was addressed in our work using two methods.

First, as explained in Section 3.4.1 of our manuscript and in Howes et al 2015, for vegetation relying solely on precipitation (rainfed grasslands, chaparral, foothill hardwoods), a daily soil-water balance was used to estimate ET. For seasonal wetlands, we adjusted ET measured at a seasonal wetland near Upper Klamath Lake, Oregon to study area climatic conditions. For vernal pools, we estimated ET from pool stage and soil moisture in vernal pools in California. We did not assume a full water supply for any of these vegetation types. Second, as discussed in Section 3.4.3 of our manuscript, we conducted a sensitivity analysis to address the uncertainty in both natural vegetation areas and evapotranspiration rates. The cases we selected focused on grasslands (including vernal pools) and valley/foothill hardwood, as they represent the greatest portion of the Valley Floor.

[3] The commenter's flows, 9.2 vs. 20.8 billion m3/yr, are not cited nor supported with calculations. Our investigation indicates that the 9.2 billion m3/yr is apparently the "stream channels and riparian vegetation" evapotranspiration estimated in Williams et al. 1989, Figure 19 (7.5 MAF/yr x 1.2335 billion m3/yr/MAF/yr = 9.2 billion m3/yr). We did not report a corresponding number in our manuscript. However, it is roughly approximated as the sum of open water evaporation plus evapotranspiration from large stand wetlands and riparian forest. This calculation for all of our cases yields 10.0 billion m3/yr (2.3+3.3+0.1+2.8+0.0+0.1+0.6+0.7+0.1 = 10.0), which is roughly equal to Williams' estimate of 9.2 billion m3/yr. Thus, the commenter must have included vegetation types that were not directly supplied by stream channels and is thus making an irrelevant comparison.

4. The study does not include the Tulare Basin in its water balance and assumes the DWR calculated unimpaired inflow would be the natural inflow. The unimpaired inflow from the Tulare Basin calculated by DWR is not a natural inflow. It is quantified as the modern day flow in James Bypass (CDWR 2007) which are derived from the flood control release into the Kings River). Historic evidence suggest that the natural inflow from the Tulare Basin would have included semi-regular seasonal flows from the Kings River north and occasional overflow from Tulare Lake. In a report on the Tulare Lake Basin Hydrology and Hydrography for the Environmental Protection Agency (available at http://www.epa.gov/region9/water/wetlands/local-wetlands.html I conjectured, based upon historical reconstructions, that Tulare Lake would have overflowed into the San Joaquin River Basin in nearly 40% of the years in the 20th century. The DWR calculated average annual unimpaired inflow from the Tulare Basin is about 0.09 billionm3yr-1 while the above evidence suggests it would be significantly higher. Quantification of the natural inflow from the Tulare Basin should be part of future research.

We agree that the DWR calculated unimpaired inflow is not the natural inflow from Tulare Basin and that it is the measured flow in James Bypass on the Fresno Slough, which connects the two drainages. These flows are a tiny fraction of the total unimpaired flow (0.8%)

and thus do not affect our conclusion. They, were selected as they represent a worst case that would overestimate natural Delta outflow. Our research and a water balance, discussed below, suggest the long term annual average flow between these basins was close to zero.

We also agree that under natural conditions, there was periodic exchange of surface water between the Tulare Lake and San Joaquin River hydrologic regions. Surface water was generally believed to flow from south to north from the Kings River fan through Fresno Slough and other smaller channels (DPW, 1931[1]). The Kings River fan in the east and the Los Gatos Creek fan to the west create a natural ridge which separates the majority of the Tulare Lake Hydrologic Region from the northern section. The elevation difference between the low point on this ridge and the San Joaquin River at Mendota is approximately 30 feet. Under natural conditions, except in very wet years, the ridge would have separated surface waters in the San Joaquin River and Tulare Lake hydrologic regions.

Similarly, a groundwater ridge would have divided most of the Tulare Lake Hydrologic Region from the San Joaquin River Hydrologic Region, maintained by recharge from the Kings and Kaweah rivers as they enter the floor of the valley. Except in very wet years, groundwater elevations would have sloped from these rivers northwards to the San Joaquin River and southwards to what was known as "Tache Lake".

Historical accounts record that in exceptionally wet years, such as 1862, Tache Lake spilled over the ridge, described above, and drained northwards through Fresno Slough to the San Joaquin River. The following description from the Report of the Commissioner of Public Works to the Governor of California, dated 1895, supports the assumption that flow from the Tulare Lake Hydrologic River into the San Joaquin River occurred infrequently:

> *Precipitation of moisture is so light throughout the southern portions of the Sierra Nevada Mountains, the upper parts of the San Joaquin Valley, and the eastern slope of the Coast Range, that the years in which more water has reached this part of the valley than is required to replace the amount annually evaporating from the surface of the San Joaquin Valley lakes have been rare. The entire drainage basin above Tulare Lake, including a part of the flow of Kings River, therefore becomes tributary to San Joaquin River only at long intervals. This can be best illustrated by a brief history of the fluctuations of the Tulare Lake water surface.*
>
> *After several wet winters preceding 1853 the lake was found full, though possibly not quite as high as in 1862 or in 1868.*
>
> *From 1853 until 1861 the low-water plane of the lake receded – at what rate each year cannot now be determined; but in 1861 the water surface was as low as 204 feet, if the testimony of some of the residents at the lake at that time, in reference to the rise of water the following winter, can be relied upon. The heavy rainfall of 1861 to 1862 caused the water surface of the lake to rise to the highest stage at which it has been known – 220 feet above low tide in Suisun Bay. Its area was increased from 300 to nearly 800 square miles. Its contents were increased by 300,000,000,000 cubic feet [6.8 MAF] of water during this one winter.*

[1] California Department of Public Works (CDPW): San Joaquin River Basin, Bulletin No. 29, 1931.

Eye witness accounts by qualified observers before the area was developed, summarized in Fox (1987) suggest the flow could go either way, from the San Joaquin to the Tulare or vice versa, depending upon the wetness of the year.

In 1850, Lieutenant Derby, an early explorer and mapmaker in the area, explored the "Tulares Valley" in a wet year, in search for a site for a military outpost and attempted to cross between the basins at Fresno Slough in April. He reported that the ground between the lake and the San Joaquin River was "entirely cut up by small sloughs which had overflowed in every direction, making the country a perfect swamp…In all of these sloughs a strong current was running southwest, or from the San Joaquin river to the lake." (Farquhar 1932[2]).

In 1853, the U.S. War Department made surveys for a railroad route. Blake, the geologist, described the overflow area, noting that "when the level of the river [San Joaquin] is greatly raised by freshets it overflows it banks, and the water passes to the lakes by this slough [Fresno Slough]. At seasons of low water, all communication between the river and lake is prevented by a bar at the mouth of the slough." (Williamson 1853[3], p. 192).

The study cited by this commenter (ECORP Consulting 2007) does "conjecture", without any supporting calculations, that Tulare Lake would have overflowed into the San Joaquin River Basin in nearly 40% of the years in the 20th century (ECORP 2007, p. 7). However, it is silent on what happened in the other 60% of the years and fails to provide any estimate of the flows in the 40% of the years it claims there were overflows to the north. This conclusion is also inconsistent with all of the historical evidence.

A water balance suggests that over the long-term, the net water exchange between these two basins was nearly zero (Fox 1987, Table 8). Drought is more common in the Tulare Basin than in the Valley Floor, and early explorers often reported the subject lakes as dry, so no flows would be exchanged. Further, as noted above, under many conditions, water moved from the San Joaquin Basin into the Tulare Lake Basin, or in the opposite direction.

5. The average inflow and outflow should be compared to the measurements and estimates of Sacramento River at Freeport and Collinsville as well as other upstream locations by state engineer William Hammond Hall in the 1879-85 period (Hall 1986). [1] The annual flow estimates for the Collinsville location at the downstream end of the Delta (i.e., the location of Delta outflow) ranged from 22 to 40 billionm3yr-1, averaging 32 billionm3yr-1 for 1879-1885 period, which encompassed both above and below average precipitation

[2] F.P. Farquhar, The Topological Reports of Lieutenant George H. Derby, Part II. Report on the Tulare Valley of California, April and May 1850, California Historical Society, v. XI, no. 2, pp. 247-265, 1932.

[3] R.S. Williamson, Report of Exploration in California for Railroad Routes to Connect with the Routes Near the 35th and 32d Parallels of North Latitude, in Explorations and Surveys for a Railroad Route from the Mississippi River to the Pacific Ocean, U.S. War Department, 1853.

years in the watershed (see for example the annual Nevada City precipitation in the California Water Atlas p. 7 (Kahrl 1979)). [2] Although localized alterations of natural landscape by hydraulic mining and land reclamation had already occurred by 1879, particularly along the lower portions of the Sacramento and Feather Rivers, the Valley wide hydroscape was still largely representative of natural conditions making Hall's observations an important point of reference for natural flow estimates. [3]

[1] As we explain in our manuscript, pp. 3853-3854, lines 25-30, we are not estimating the flow in any specific year or years, but rather natural outflows that would occur with contemporary precipitation and inflows to the Valley Floor for 1922 to 2009 with the Valley Floor in a natural or undeveloped state. The cited Hall flows for the period 1879 to 1885 are not measured flows, but rather rough estimates. Hall (1886) states: "The flow of the Sacramento river at Collinsville – the point of its junction with the San Joaquin and entry into Suisun bay – has never been directly measured." Hall (1886, pp. 406-407) then explains why the flows at Collinsville and at Sacramento cannot be measured. Elsewhere, Hall explains why the flows in 1879 to 1885 are not representative of natural conditions. See response 5-[3]. As the cited report, Hall (1886), is not available on the web, we are attaching relevant extracts in our response to this comment.

[2] The precipitation at a single gage is not adequate to determine the relative wetness of the water years 1879 to 1885. The California Department of Water Resources developed the Four River Index (the Feather, Yuba, American, and Sacramento Rivers) from tree ring data, which can be used to assess the relative wetness or dryness of a given historic period. The mean reconstructed unimpaired Four River Index flow over the period 901 to 1977 is 21.3 billion m3/yr.[4] The mean estimated actual flow for the five years of Hall data is 31.6 billion m3/yr. Thus, these estimates were made during a relatively wet period or are overestimates, due to the crudeness of the methods employed. Further, the correlation between individual Four River Indices for each year from 1879 to 1885[5] and the estimated Hall flows is weak ($r^2 = 0.39$), confirming the very rough nature of Hall's estimates.

[3] We disagree that the valley wide hydroscape was still largely representative of natural conditions in 1879 to 1885. Another Hall report, written in 1880,[6] describes the many modifications to the natural system and their affects on flow, which are considerable. These include: significant reduction in the flood-carrying capacity of river channels by mining debris, resulting in wide spread flooding; construction of levees to keep flood waters out of the swamp and basin lands; installation of cut-offs in the upper Sacramento River; and significant harvesting of natural vegetation . For example, as to the Feather River, the major tributary to the Sacramento, Hall writes: "The channel of the Feather River has been subjected to such

[4] http://treeflow.info/cali/sacramentofour.html.
[5] http://treeflow.info/cali/sacramentofour.txt.
[6] William Ham. Hall, State Engineer, Report of the State Engineer, Legislature of the State of California – Session 1880, Part II, Sacramento, 1880, Drainage of the Valleys and the Improvement of the Navigation of Rivers, pp. 7-

considerable changes during the last 10 or 15 years, that a description of its present condition would not convey a just idea of the real character of the river." Hall 1880, p. 27. Elsewhere, Hall notes, "The Feather River () and its main tributaries, as well as the American River () for considerable distances within the foothills and at points well up in the mountains, and many of the side ravines tributary to all these main canons, are now vast reservoirs of detritus…" Hall 1880, p. 13. The modifications to the natural system were so extensive by 1879 as to bear no resemblance to the natural system. As the 1880 Hall report is not available on the web, we are posting relevant excerpts with our response to this comment.

6. The natural/unimpaired issue obfuscates the Delta outflow issue since the species declines and the X2 relationships were developed in the altered 20th century estuarine system. More relevant is the change in actual Delta outflow in the 20th century as large dams and water transfer projects significantly altered the timing and magnitude of Delta outflows. The effects of these alterations can be discerned by comparing the computed actual Delta outflow (Dayflow) in the 1922-43 (pre-project) period (prior to the construction of Shasta and Friant Dams and Federal Delta export facilities) with that of the 1968-94 (post-project) period (after the State Water Project dams and export facilities were completed). When all but the "wet" year types are examined, annual Delta outflow is 30% to 60% less than comparable years of the pre-project period, with even greater percentage reductions in spring outflows in drier year types. The average annual Delta outflow during the pre-project period was about 15% more than the post-project period, but the average rim station inflow was 17% less in the pre-project period than in the post-project period (i.e., the pre-project period had less rim inflow but more Delta outflow). Noteworthy is that the driest 11-year period in the 20th century – the 1924-34 pre-project period- had about half the runoff of the wettest post-project 11-year period (1995-2005).

While we do not agree with the reviewer's statement that "The natural/unimpaired issue obfuscates the Delta outflow issue…", we do agree that changes in Delta outflow in the 20th century is relevant and important in understanding the altered Bay-Delta system. The lead author published research on this topic:

Fox, J.P., T.R. Mongan, and W.J. Miller (1990). Trends in Freshwater Inflow to San Francisco Bay from the Sacramento-San Joaquin Delta, Water Resources Bulletin, 26 (1), 101-116.

The authors continue to research changes to flows in the Bay-Delta system and plan to submit this work for a future peer reviewed publication.

7. Unimpaired runoff can be used along with actual runoff as one of the metrics of hydrological alternations in the system since 1922, particularly on an annual and seasonal basis for Delta outflow and on a monthly time step for the rivers below the dams. Neither DWR or others who use it purport it to represent natural Delta outflow, although there is

consensus that it is an adequate representation of the magnitude and timing of natural flow peaks of the runoff into the Central Valley, with recognition that the hydrograph peaks would be reduced and the falling hydrograph limbs would be extended as flows moved down-Valley towards the Delta due to engagement of the floodplains and attenuation by the flood basins as well as groundwater contribution to the summer baseflow.

We agree with the reviewer that unimpaired runoff is an adequate representation of natural flow patterns onto the Valley floor; our water balance makes this assumption and the manuscript discusses the state of knowledge on that subject. However, we have no basis to agree with the reviewer, nor has it been demonstrated that, unimpaired runoff can be used as an effective metric of alterations to Delta outflow. Unimpaired runoff encountered a landscape that was radically different from the current landscape (Fox and Sears 2014). These differences would have altered the volume and timing of unimpaired runoff ending up as Delta outflow.

We disagree that no one uses or has used unimpaired flows as natural flows. This use has been widespread since the early 1980s when unimpaired flows were first published. This was the original motivation for our work. See, e.g., Cloern and Jassby (2012)[7]; Dynesius and Nilsson (1994)[8]; and Fleenor et al. 2010.[9]

8. This paper does not prove provide a coherent ecological explanation for how the rough equivalency of the average annual simple "natural" water balance for the 1922-2009 hydro-climate with the current (2011 level of development) average modeled outflow for the 1922-2003 period provides insight on "understanding of the biological functions provided under natural conditions" or [1] support a conclusion that "it is unlikely that reduction in annual average Delta outflow have caused the decline in native freshwater aquatic species". [2]

[1] The manuscript asserts that, and there is near-universal agreement that, knowledge of natural hydrology provides insight for understanding the biological functions provided by natural flows because native species evolved with natural hydrology. The reviewer mistakenly asserts that the manuscript argues the rough equivalency between average annual outflows under current and natural conditions provides such insight. Rather, the purpose of our work was to demonstrate that unimpaired Delta outflows are not natural outflows. This is a very important conclusion because many have erroneously assumed unimpaired flows are equivalent

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[7] Cloern, J.E., Jassby, A.D., 2012. Drivers of Change in Estuarine-Coastal Ecosystems: Discoveries from Four Decades of Study in San Francisco Bay. Reviews of Geophysics. v. 50:1-33.

[8] Dynesius, M., and Nilsson, C. Fragmentation and Flow Regulation of River Systems in the Northern Third of the World, Science, 266 (5186), 753-762, 1994.

[9] William F. Fleenor, William A. Bennett, Peter B. Moyle, and Jay R. Lund, On Developing Prescriptions for Freshwater Flows to Sustain Desirable Fishes in the Sacramento-San Joaquin Delta, Center for Watershed Sciences, University of California, Davis, 2010.

to natural flows and thus have asserted that declines in current outflows, relative to unimpaired outflows, is a cause of species declines. See responses to Swanson.

[2] Assuming one accepts the study findings of rough equivalency between average annual outflows under current and natural conditions, it follows from simple logic that it is unlikely that reduction in annual average Delta outflow have caused the decline in native freshwater aquatic species. The manuscript caveats this conclusion by acknowledging that fisheries respond to inter- and intra-annual variability in Delta outflow.

9. I agree with recommendations for additional research particularly more detailed landscape reconstruction and an assessment of the flows on a monthly time-step. In addition I also recommend assessing the impact of forest practices and land use on the quantity and seasonality of rim station inflow. Although the conclusions of the study to this point have limited relevance to the efforts by regulatory to establish flow standards to protect beneficial uses of the Bay-Delta Estuary and its tributaries, I encourage continued collaborative work to gain a better understanding of the watershed's historic landscape ecology. [1] Unfortunately the State Water Contractors and SLDMWA have politicized these efforts. Early in this study I offered to provide all of the data and information from the TBI 1998 study and to provide input and review. The funders turned down my offers despite some of the authors encouraging that input. [2]

[1] We agree with the reviewer that future research on the impact of forest practices and land use on the quantity and seasonality of rim station inflow is needed and we will add this recommendation to the manuscript. The authors understand that our findings will be controversial and will motivate scientific debate and additional research. We believe this is a good outcome and look forward to future technical debate and collaborations with the reviewer and other fellow scientists and engineers working on Bay-Delta issues. As a first step in this process, the reviewer was invited to participate in a panel discussion on natural flow at the October 2014 Bay Delta Science conference in Sacramento; unfortunately the session was not accepted by the conference organizers.

[2]Dr. Fox was a participant in the TBI 1998 study. She provided much of the information this study relied on from her extensive personal library on the history of California water, which includes many original documents and maps. Thus, our study team already had the offered information. There was no intent to "politicize" the study.

Relevant excerpts of references attached to Author's Reply to Vorster Comments

These references are not readily available so the relevant sections have been included here.

PHYSICAL DATA AND STATISTICS

OF

CALIFORNIA.

TABLES AND MEMORANDA

RELATING TO

RAINFALL, TEMPERATURE, WINDS, EVAPORATION, AND OTHER ATMOSPHERIC PHENOMENA; DRAINAGE AREAS AND BASINS, FLOWS OF STREAMS, DESCRIPTIONS AND FLOWS OF ARTESIAN WELLS,

AND OTHER FACTORS OF WATER SUPPLY;

MOUNTAIN, VALLEY, DESERT, AND SWAMP-LAND AREAS, TOPOGRAPHY OF STREAM CHANNELS, ELEVATIONS ABOVE THE SEA, AND OTHER TOPOGRAPHICAL FEATURES.

COMPILED IN THE STATE ENGINEERING DEPARTMENT OF CALIFORNIA.

WM. HAM. HALL, C.E., STATE ENGINEER.

SACRAMENTO:
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1886.

STATE ENGINEERING DEPARTMENT STATISTICS.

COLLECTION NO. 6.

FLOW OF STREAMS.

CONTENTS.

MEMORANDUM.

WATER SUPPLY—STREAMS.

he rivers, whose water quantities are presented in the following tables, now or will be notable irrigation feeders. The tables as printed do not lude the data of nearly all the streams of the State important in this nection. They do contain all data sufficiently complete in the indiual instances to justify arrangement in continuous tables of discharge, ich has been collected by this department. The discharge of other eams is known generally for their low-water periods only, or for times ttered through the Spring, Summer, and Fall of various years, from 1879 rward. This class of data is at hand for the principal streams of San rnardino and Los Angeles counties, and will necessarily be printed in full, ith a synopsis of the information in this volume, in the report on irrigan now in preparation. It would have been mere repetition to have inted it herein also. The streams of the southern counties last named ll all be simultaneously observed during the Spring and Summer of 86, and the results also will appear in the report.

The river observations of the Department have been made in the streams the Great Central Valley—Sacramento, San Joaquin, Tulare, and Kern lleys—of the State, and in Los Angeles, San Gabriel, and Santa Ana lleys in the southern part. The streams of the Sacramento valley, and rticularly the Sacramento river itself, have been more particularly the bjects of systematic flood-flow observations, in connection with the artel drainage questions. Those of San Joaquin, Tulare, and Kern valleys ave been the more closely observed throughout the years for purposes of e irrigation water supply study, and those of the southern valleys have een observed also for the latter purpose, but with far less precision and gularity.

The gaugings made have been of many classes and grades, according to ircumstances, purpose, and means available; ranging from those of most omplete and accurate character, conducted at much expense, by large lly equipped parties of observers, on the greater streams, to simple, rough measurings by a single observer, on the smaller streams. Supplementing these stated measurements of volume, the rise and fall of the waters has been observed and recorded from gauge rods on all the main streams, at one or more stations, and on a number of the smaller ones, daily, for periods on the various streams ranging from one to seven years; and renewed sounding sections have been at times made to ascertain the extent of change in bottom elevations, and sectional dimensions of the waterways. Data thus obtained forms the basis of the following tables. Its character, extent, degree of fullness, and value, methods of observation, and results, will be written of with due attention in a future publication of the Department, where also will appear all that is fitting should be said as to the embarrassing circumstances under which the work has been carried forward, and the disastrous effect which such influence necessarily has upon investigations of this class.

Certain of the streams were chosen for the more extended and systematic observations, in a manner to well distribute the locations geographically and hydrographically throughout the valley. Less careful and extended observations were made on intermediate streams. The actual data of observation were thus much fuller for some streams than for others. The missing data were supplied to make the tables full for average discharges by estimating the probable output of streams, upon the basis of their drainage areas, knowing from observations on them or on similarly situated streams of the same character, the discharges which they would probably have per square mile of drainage area, in years of known amounts of rainfall.

The tables are thus filled out for all the streams for a period of six years and results for the Sacramento river, which is observed daily, by this office are estimated to October, 1885. Full sets of observations for any month enabled the greatest, least, and average rates of discharge to be given for that time. Where only average volumes are given, the records have not been full, or the mean flow has simply been estimated as above explained. Wherever the discharges per square mile have been thus approximated they are marked by an asterisk (*).

The arrangement of the tables as to grouping of months follows the division of the year—from low water season to low water season—from November to October, inclusive; and each such exhibit for the twelve months is followed by a tri-monthly, seasonal, grouping of the same data.

The tables of discharges Nos. 1 to 21, of the several streams in detail, are followed by a table of averages for the whole period—November 1, 1878, to October 31, 1884.

Sacramento river.—The flow of the Sacramento river at Collinsville—the point of its junction with the San Joaquin and entry into Suisun bay—has never been directly measured, for reasons which will be discussed in the proper publication. Its flow past the city of Sacramento, 57 miles above, has been determined by a number of low, medium stage, and flood water gaugings in 1879 and 1880, and low water gaugings in 1885; and its fluctuations noted by daily rod observations from October, 1878, to the present time; and there were made occasional examinations of the channel in the interval.

Upon the basis of the gauging results, a scale of discharge was projected for the channel at Sacramento, giving the probable water quantity flowing for each foot of elevation of surface, from lowest to highest observed stage. These deduced data applied to the results of the daily rod-observations averaged generally, for five-day or longer periods when the river was not in an active state of fluctuation, have afforded the estimated volumes on which the total for each month, as given in the table, have been made.

Thus, a good result, reliable for all practical purposes, is had for the channel at Sacramento, but this does not represent the flow of the river, even from above this point, at all stages. When the water surface comes to the 18-foot mark on the Sacramento gauge, which corresponds to about 41,000 cubic feet in volume of flow (varying according to the position of the shifting bottom plane), the stream is losing an appreciable part of its volume through breaks (crevasses) in its western bank, between Knights Landing and Sacramento. This water flows down the valley over the low lands west of the river into the Cache Slough basin, whence it again joins the river between Sacramento and Collinsville. Into these low lands and

basin also collect the drainage waters from the Coast Range, brought from the west by Cache, Putah, and other creeks, which quantity, immediately after storms, is very large. In winters of heavy rainfall it is continuous flow in large volume, but in Summer and Fall it always sinks to an amount inappreciable as compared to the river flow, and frequently ceases altogether. Thus at high-water stages large volumes of Sacramento river water escape around the Sacramento channel-station, and joined by other waters enter the river below, forming with the flow past Sacramento its total output into the bay. The volume of escape from the Sacramento, and of delivery from the Coast Range, has been observed and estimated for a flood period of 1879, and is the only reliable information upon which to base a calculation of discharge to be applied as a correction to the amount of flow past Sacramento.

Furthermore, at all stages of the river, there is an appreciable escape of Sacramento waters through the Georgiana and Three-mile sloughs, below Sacramento, into the San Joaquin. In times of high flood this is generally a very large item; though at such times it varies not only with the stage of the Sacramento itself, but with that of the San Joaquin, which being low or high at periods different from the Sacramento, affords sometimes a free outlet for surplus floods, and at others scarcely an appreciable relief. Some practical knowledge is had of this output at certain times of interest, but it is not sufficient to scale its quantity for varying stages.

Hence, it has not been possible to note with any degree of accuracy the greatest and least discharges for each month. The maximum noted for February, 1881, is the maximum for the whole period. It is approximate. The least amount of flow during the period occurred in September, 1885.

The flow as given in the table is an estimate of the total output of Sacramento river and tributaries, as passing Collinsville and escaping into the San Joaquin by Georgiana and Three Mile sloughs.

Tributaries of the Sacramento.—There is a quantity of data at hand relating to the flow of the tributaries to the Sacramento, and to the main river itself at other points than at the Sacramento station, which has been acquired by observation in many instances exact and extended, but in no case is it sufficiently complete to scale the discharge of the tributary streams for tabulation. These data will also appear with the discussions of the water supply question.

Cosumnes river.—This is the most northern of the tributaries to the San Joaquin. The table presents an approximate statement of its water quantities at the point of its flow from the mountains into the valley, and does not include the output of Deer and Carson creeks, which join it below. The observations on this river were amongst the least complete and satisfactory of all whose tabulation has been attempted.

Mokelumne river.—This large stream is the next of its class which enters the valley from the east, south of the Cosumnes. Its channel has been repeatedly examined and its flow measured at a station near the Lone Star mill north of Clements. Gauge rod observations have been made at this station and at the Westmoreland bridge, 12 miles above, quite fully, for a large part of our period, and occasionally for the remaining time. These data form the basis of what is believed to be a good practical estimate of water quantities brought into the valley during each month of the period covered, as shown in the table.

Calaveras river.—This stream is situated next south of the Mokelumne. Its drainage basin does not extend back to the higher mountains as do those of the adjacent rivers north and south of it. It is a stream of medium class, less constant of flow than the Mokelumne, and more so than those ranked as creeks merely. The Department gaugings and observations were made at a station several miles above Bellota. Although not complete for the period, the data thus obtained has afforded a good basis for the estimates of water quantities embodied in the table.

Stanislaus river.—The character of the watershed of this river is similar to that of Tuolumne, more fully described below. The discharge is given for the river at Oakdale. The stage of the river was regularly recorded for only a small portion of the period covered by the table, and hence the results given are largely based upon estimates made by the method of drainage areas, as above explained. No allowance is made for water diverted from the stream above Oakdale.

Tuolumne river.—This is a river of the first class, having a large high-mountain drainage basin, situated next south of the Stanislaus. The gaugings were made at a station near the railroad bridge, south of Modesto. A scale of discharge at different stages was drawn up, as explained for the Sacramento. A rod record was kept from 1879 to 1882, inclusive, and occasional observations made since the last date. From these data, as a basis, with estimates of flow per square mile of drainage area as heretofore explained, the results in the table are presented as sufficiently exact for all purposes of a general water supply discussion.

The output includes the contributions of Dry creek, a tributary entering the river just above the point of observation. The drainage area covers only the mountain drainage basins of the river and creek, there being no appreciable contribution to their flows through the valley part of their courses. The flow of several mining ditches, taken from the Tuolumne river, in the mountains above, has not been taken into consideration. For very low-water periods this would materially affect the results. Much of this water finds its way back into the river, and the stream receives water at such times which has been stored during times of flood.

Merced river.—This is a river having a high-mountain watershed, but not in so great a proportion of its whole basin as have the Tuolumne and the San Joaquin. The results in the table apply to a station at Merced Falls, a point in the valley, but above all diversions by irrigation canals. Gaugings have been made at this station, and also at McSwain's ferry, and at the railroad bridge near Livingston (Cressey). Rod records were kept for parts of the period at McSwain's ferry, and at the railroad bridge, and occasional observations made at other times. From these data actual water quantities were calculated for much of the period, and such results have been supplemented by the method of drainage per square mile of area of basin, as elsewhere explained. These results have been corrected for quantities diverted by the canals, and so the tabulated data relate to the amount of water brought into the valley.

Bear creek and Mariposa creek.—These are small streams whose watersheds do not extend back to the regions of perennial snows. Their flow is characterized by sudden rises after heavy rains, and periods of low flow intervening. Scales of discharges for these streams were based on cross-sectional dimensions and slopes of channel-ways. For several seasons gauge rod records afforded definite data of water stages in them. Actual discharges per square mile of drainage area calculated from these data, together with ratios obtained by comparison of such results with those similar for other adjacent streams, form the basis for approximations of water quantities during the time when gauge records were not kept.

Chowchilla creek.—The station of observation was at a point near Buchanan, where a rod record was kept for portions of the period. The flow of this stream is specially characterized by sudden short freshets, of which not nearly all have been reported. A scale of discharge was estimated from channel dimensions and slopes, which with the data above named form the basis of the tabulated results.

Fresno creek (or river).—This stream is one of the largest creeks or smallest rivers whose flow has been observed. Its drainage basin is similar to those of the three creeks last mentioned. The point of observation was at the head of the Fresno River Canal and Irrigation Company's canal, about three miles above the railroad crossing near Minturn. The actual record of water fluctuations was for one season only. The figures in the table are, hence, largely estimated discharges from the drainage area, based on the results of one year's observation, and checked by occasional observations through the remainder of the period. The results presented apply to the stream as it enters the valley part of its course.

San Joaquin river.—This river is of the first class in the group, having an elevated watershed in large part within the snow-line. The points of observation have been at Hamptonville (formerly Jones' store), at the edge of the valley, and the railroad crossing near Sycamore. Gaugings and special examinations were made many times during the period from 1878 to 1884, at both of these places. A good record of water elevations was kept at the railroad bridge from 1879 to 1882, inclusive, and a similar record at Hamptonville for one season. For the period covered by the table, practically, no water was diverted from the stream above the lower station. The results of the data of that point admitted of direct application to the upper station; no account being had of loss or gain in the river channel, which is known not to be large. The results were worked out by the method of scale of discharge, and supplemented by that of drainage per square mile, as already explained, and are presented as worthy of full reliance for all purposes of a water supply study, for the period covered.

Kings river.—This is one of the most important irrigation feeders in the State, having a high watershed of the best character for plentiful and well-delivered supply, largely within the snow line. Many gaugings have been made of Kings river at a number of points between Slate Point, at its *debouchement* from the mountains, five miles above Centreville, and Tulare lake, its outfall basin about sixty-five miles below. The character of the channel of this stream at all available locations near the mountains, or in the cañon, has not admitted of a first class series of observations being made there, without the construction of a gauging section, at an expense which the known resources of the Department have at no time justified. Thus at Slate Point, the upper station where measurements were made and a rod gauge established, the flow was influenced in varying amounts by the alternate formation and washing away of cobblestone and gravel bars immediately below.

At the railroad bridge crossing, south of Kingsburgh, a good gauge-rod record has been kept for the entire period, and its results, with those of the gaugings, have afforded the data for what is believed to be a fair approximation to the actual water quantities which passed that point. But between this station and the mountains a number of canals take water from the stream, in volumes which at ordinary stages together constitute a large part of the flow. These canals have been repeatedly gauged and records kept, or observations made of their flow during one or more seasons, so that the amounts of their abstraction from the river are approximately known, and have been applied to the data of flow at the Kingsburgh bridge in preparing the table of water quantities delivered by the river into the valley. The methods employed throughout have been similar to those for the San Joaquin.

Kaweah river.—This is an important stream, but its watershed is much less elevated and snow-covered than that of Kings river, and its flow far less steady. It receives several tributaries below the point of opening of its cañon, itself divides into several channels, widely separated, soon after entering upon the plain, and is tapped by a number of irrigation ditches. Several gauging stations were established on Kaweah river. Reliable records were made, however, only at the station near Three Rivers. This point is above Lime Kiln and Horse creeks—tributaries of importance at some seasons. The gauging and rod record data afforded a basis for an estimate of flow for all ordinary stages, which could be applied as for Watchumna Point, and this was corrected for additional drainage area tributary below, and for higher stages, by the method of estimated discharges per square mile. The data of the table is presented therefore as a fair approximation to the actual water quantities entering the valley by this river, and the creeks which enter its system in the plains.

Tule river.—This stream is of the character of Kaweah in the matter of watershed, but somewhat lower in the scale. The observations were made at a point several miles above Porterville but below the head of the Pioneer canal. A number of gaugings, an imperfect rod record, and other occasional observations, formed the basis of calculating the flow past the station. Results thus obtained and expanded by the method of drainage per square mile, and corrected by the approximately known amounts of intake of the canal, give the data of the delivery of the river into the valley, as presented in the table upon a footing considered to average well with all others taken together.

Deer, White, and Posa creeks.—The estimate of flow of these creeks is based on a number of special observations, general information from residents near them, and the method of discharge per square mile of drainage area.

Kern river.—This is a stream of the first class, in the extent and character of its drainage basin, taking water as it does from between two very high mountain ranges behind the basins of the Kaweah and Tule rivers and the creeks above named. But the unfavorable exposure of the basin of the Kern, and other reasons which will be discussed in the proper place, prevent its receiving precipitation, and delivering water in nearly the same ratio to its basin area as other streams north of it.

This stream has been gauged chiefly at the Rio Bravo ranch station, a point just below the *debouchement* from the mountain cañon, and above all canals of diversion in the valley. A continuous gauge rod record was kept at this station from 1878 to 1883. This data formed the basis for making, by the method of scale of discharge for the channel, a calculation for the three years named, and then by the method of drainage per square mile as compared to rainfall, the results given were estimated for the remainder of the period covered by the table.

Caliente creek.—This is a stream of which no actual measurements of discharge was had as a basis for calculation. Furthermore, the exposure of its basin is different, and other causes combine to make the application of data of drainage per square mile of area, obtained on similar streams farther north, not strictly applicable. Hence, the results shown in the table are amongst the least reliable.

Allowances for seasonal scouring and silting-up of channel beds have in cases been made where not mentioned above, as also other influences which will be discussed in the proper publication.

Flow of Streams.

SACRAMENTO AND SAN JOAQUIN VALLEYS.

1878 TO 1884.

TABLES NOS. 1 TO 22.

S. E. DEPT. STATISTICS, COLLECTION NO. 6.

WATER SUPPLY—STREAMS.

TABLE No. 1.

SACRAMENTO RIVER.

At Collinsville. *Drainage Area, 26,187 square miles.*

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge, Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
	1878-1879.					
November	8,000			20,726,000,000		0.30
December	9,000			24,102,000,000		0.34
January	12,000			32,136,000,000		0.46
February	30,000			72,570,000,000		1.14
March	110,000			294,580,000,000		4.18
April	110,000			285,120,000,000		4.18
May	75,000			200,850,000,000		2.86
June	45,000			116,640,000,000		1.72
July	16,000			42,848,000,000		0.61
August	8,500			22,763,000,000		0.32
September	6,500			16,848,000,000		0.25
October	8,000			21,424,000,000		0.30
I Per.: Nov.-Jan.	9,680			76,964,000,000	0.093	0.37
II Per.: Feb.-April	84,820			652,270,000,000	0.786	3.22
III Per.: May-July	45,290			360,338,000,000	0.434	1.73
IV Per.: Aug.-Oct.	7,680			61,035,000,000	0.074	0.29
November 1 to October 31	36,490			1,150,607,000,000	1.386	1.39
	1879-1880.					
November	7,500			19,440,000,000		0.29
December	27,000			72,306,000,000		1.03
January	28,000			74,984,000,000		1.07
February	21,000			50,790,000,000		0.80
March	22,000			58,916,000,000		0.84
April	95,000			246,240,000,000		3.61
May	135,000			361,530,000,000		5.15
June	110,000			285,120,000,000		4.19
July	53,000			141,934,000,000		2.02
August	18,000			48,201,000,000		0.69
September	9,000			23,328,000,000		0.34
October	7,500			20,085,000,000		0.29
I Per.: Nov.-Jan.	20,980			166,730,000,000	0.201	0.80
II Per.: Feb.-April	46,780			355,955,000,000	0.429	1.75
III Per.: May-July	99,210			788,584,000,000	0.950	3.79
IV Per.: Aug.-Oct.	11,520			91,617,000,000	0.110	0.44
November 1 to October 31	44,370			1,402,886,000,000	1.690	1.69

TABLE No. 1—Continued.

SACRAMENTO RIVER.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge, Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
	1880-1881.					
November	7,000			18,144,000,000		0.27
December	20,000			53,560,000,000		0.76
January	95,000			254,410,000,000		3.62
February	115,000	160,000		278,185,000,000		4.38
March	77,000			206,206,000,000		2.93
April	90,000			233,280,000,000		3.43
May	70,000			187,460,000,000		2.67
June	25,000			64,800,000,000		0.95
July	14,000			37,492,000,000		0.53
August	8,000			21,424,000,000		0.30
September	6,500			16,848,000,000		0.25
October	7,000			18,746,000,000		0.27
I Per.: Nov.-Jan.	41,030			326,114,000,000	0.393	1.57
II Per.: Feb.-April	93,300	160,000		717,671,000,000	0.865	3.56
III Per.: May-July	36,440			289,752,000,000	0.349	1.39
IV Per.: Aug.-Oct.	7,200			57,018,000,000	0.069	0.28
November 1 to October 31	44,080	160,000		1,390,555,000,000	1.675	1.68
	1881-1882.					
November	8,200			21,254,000,000		0.31
December	16,000			42,848,000,000		0.61
January	24,000			64,272,000,000		0.92
February	22,000			53,218,000,000		0.84
March	55,000			147,290,000,000		2.09
April	90,000			233,280,000,000		3.43
May	92,000			246,376,000,000		3.50
June	74,000			191,808,000,000		2.82
July	17,000			45,526,000,000		0.65
August	8,000			21,424,000,000		0.30
September	6,500			16,848,000,000		0.25
October	10,000			26,780,000,000		0.38
I Per.: Nov.-Jan.	16,150			128,374,000,000	0.155	0.62
II Per.: Feb.-April	56,410			433,788,000,000	0.523	2.15
III Per.: May-July	60,850			483,710,000,000	0.583	2.32
IV Per.: Aug.-Oct.	8,180			65,052,000,000	0.078	0.31
November 1 to October 31	35,230			1,110,924,000,000	1.339	1.35

Table No. 1—Continued.

SACRAMENTO RIVER.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1882-1883.			
November	14,000			36,288,000,000		0.5[illegible]
December	11,000			29,458,000,000		0.4[illegible]
January	12,000			32,136,000,000		0.46
February	17,000			41,123,000,000		0.65
March	21,000			56,238,000,000		0.80
April	73,000			189,216,000,000		2.78
May	80,000			214,240,000,000		3.05
June	32,000			82,914,000,000		1.22
July	12,000			32,136,000,000		0.46
August	7,000			18,746,000,000		0.27
September	6,500			16,848,000,000		0.25
October	7,000			18,746,000,000		0.27
I Per.: Nov.-Jan.	12,300			97,882,000,000	0.118	0.47
II Per.: Feb.-April	37,270			286,577,000,000	0.345	1.43
III Per.: May-July	41,420			329,320,000,000	0.397	1.58
IV Per.: Aug.-Oct.	6,840			54,340,000,000	0.065	0.26
November 1 to October 31	24,360			768,110,000,000	0.925	0.93
			1883-1884.			
November	7,500			19,440,000,000		0.29
December	7,400			19,817,000,000		0.28
January	12,000			32,136,000,000		0.46
February	24,000			60,144,000,000		0.91
March	80,000			214,240,000,000		3.05
April	105,000			272,160,000,000		4.00
May	111,000			297,258,000,000		4.23
June	90,000			233,280,000,000		3.43
July	31,000			83,018,000,000		1.18
August	12,000			32,136,000,000		0.46
September	7,500			19,440,000,000		0.29
October	8,000			21,424,000,000		0.30
I Per.: Nov.-Jan.	8,950			71,393,000,000	0.086	0.34
II Per.: Feb.-April	70,280			546,544,000,000	0.658	2.68
III Per.: May-July	77,190			613,556,000,000	0.739	2.95
IV Per.: Aug.-Oct.	9,180			73,000,000,000	0.088	0.35
November 1 to October 31	41,250			1,304,493,000,000	1.572	1.57

Table No. 1—Continued.

SACRAMENTO RIVER.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1884-1885.			
November	7,000			18,144,000,000		0.27
December	31,000			83,018,000,000		1.18
January	90,000			241,020,000,000		3.43
February	52,000			125,788,000,000		1.98
March	30,000			80,340,000,000		1.14
April	29,000			75,168,000,000		1.11
May	23,000			61,594,000,000		0.88
June	14,000			36,288,000,000		0.53
July	6,500			17,407,000,000		0.25
August	5,500			14,729,000,000		0.21
September	5,200		5,050	13,478,000,000		0.20
October	5,200			13,926,000,000		0.20
I Per.: Nov.-Jan.	43,050			342,182,000,000	0.412	1.65
II Per.: Feb.-April	36,580			281,296,000,000	0.339	1.40
III Per.: May-July	14,500			115,289,000,000	0.139	0.55
IV Per.: Aug.-Oct.	5,300		5,050	42,133,000,000	0.051	0.20
November 1 to October 31	24,700		5,050	780,900,000,000	0.941	0.94

TABLE No. 2.

COSUMNES RIVER.

At Live Oak Suspension Bridge. *Drainage Area, 580* [illegible]

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	[illegible]
1878–1879.						
November	29			81,000,000		[illegible]
December	29			78,000,000		[illegible]
January	290			777,000,000		[illegible]
February	1,218			2,916,000,000		[illegible]
March	1,740			4,660,000,000		[illegible]
April	3,132			8,118,000,000		[illegible]
May	3,248			8,698,000,000		[illegible]
June	3,480			9,020,000,000		[illegible]
July	422			1,130,000,000		[illegible]
August	116			311,000,000		[illegible]
September	23			60,000,000		[illegible]
October	17			46,000,000		[illegible]
I Per.: Nov.–Jan.	118			939,000,000	0.058	[illegible]
II Per.: Feb.–April	2,014			15,721,000,000	0.972	[illegible]
III Per.: May–July	2,371			18,848,000,000	1.167	[illegible]
IV Per.: Aug.–Oct.	54			427,000,000	0.026	[illegible]
November 1 to October 31	1,110			35,938,000,000	2.222	[illegible]
1879–1880.						
November	52			150,000,000		*0.[illegible]
December	406			1,087,000,000		*0.[illegible]
January	232			621,000,000		*0.4[illegible]
February	411			1,105,000,000		*0.7[illegible]
March	686			1,861,000,000		*1.[illegible]
April	4,582			12,077,000,000		*7.[illegible]
May	5,101			13,669,000,000		*8.[illegible]
June	6,090			15,785,000,000		*10.[illegible]
July	2,726			7,300,000,000		*4.7[illegible]
August	318			932,000,000		*0.60
September	29			75,000,000		*0.05
October	17			46,000,000		*0.03
I Per.: Nov.–Jan.	231			1,858,000,000	0.116	0.41
II Per.: Feb.–April	1,935			15,046,000,000	0.930	3.34
III Per.: May–July	4,623			36,754,000,000	2.274	7.97
IV Per.: Aug.–Oct.	133			1,053,000,000	0.065	0.23
November 1 to October 31	1,759			54,711,000,000	3.383	8.03

TABLE No. 2—Continued.

COSUMNES RIVER.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
1880–1881.						
November	12			35,000,000		*0.02
December	290			777,000,000		*0.50
January	1,624			4,349,000,000		*2.80
February	3,074			7,436,000,000		*5.30
March	1,102			2,951,000,000		*1.90
April	3,190			8,268,000,000		*5.50
May	3,074			8,232,000,000		*5.30
June	1,218			3,157,000,000		*2.10
July	174			466,000,000		*0.30
August	87			233,000,000		*0.15
September	87			226,000,000		*0.15
October	58			155,000,000		*0.10
I Per.: Nov.–Jan.	650			5,161,000,000	0.320	1.12
II Per.: Feb.–April	2,425			18,655,000,000	1.154	4.18
III Per.: May–July	1,619			12,855,000,000	0.795	2.79
IV Per.: Aug.–Oct.	77			614,000,000	0.037	0.13
November 1 to October 31	1,182			37,285,000,000	2.306	2.04
1881–1882.						
November	174			503,000,000		*0.30
December	522			1,398,000,000		*0.90
January	522			1,398,000,000		*0.90
February	522			1,263,000,000		*0.90
March	1,740			4,660,000,000		*3.00
April	2,320			6,013,000,000		*4.00
May	4,524			12,115,000,000		*7.50
June	2,900			7,517,000,000		*5.00
July	696			1,864,000,000		*1.20
August	580			1,553,000,000		*1.00
September	52			135,000,000		*0.09
October	232			621,000,000		*0.40
I Per.: Nov.–Jan.	416			3,299,000,000	0.204	0.72
II Per.: Feb.–April	1,552			11,936,000,000	0.738	2.67
III Per.: May–July	2,701			21,496,000,000	1.329	4.67
IV Per.: Aug.–Oct.	291			2,300,000,000	0.143	0.50
November 1 to October 31	1,238			39,040,000,000	2.414	2.13

Table No. 2—Continued.

COSUMNES RIVER.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	[illegible]
			1882–1883.			
November	100	....	....	289,000,000	....	[illegible]
December	100	....	....	268,000,000	....	[illegible]
January	348	....	....	932,000,000	....	[illegible]
February	290	....	....	702,000,000	....	[illegible]
March	522	....	....	1,398,000,000	....	[illegible]
April	1,740	....	....	4,510,000,000	....	[illegible]
May	3,480	....	....	9,319,000,000	....	[illegible]
June	2,320	....	....	6,013,000,000	....	[illegible]
July	580	....	....	1,553,000,000	....	[illegible]
August	232	....	....	621,000,000	....	[illegible]
September	87	....	....	226,000,000	....	[illegible]
October	87	....	....	233,000,000	....	[illegible]
I Per.: Nov.–Jan.	220	....	....	1,480,000,000	0.092	[illegible]
II Per.: Feb.–April	859	....	....	6,610,000,000	0.409	[illegible]
III Per.: May–July	2,124	....	....	16,885,000,000	1.044	[illegible]
IV Per.: Aug.–Oct.	136	....	....	1,080,000,000	0.066	[illegible]
November 1 to October 31	826	....	....	26,061,000,000	1,611	[illegible]
			1883–1884.			
November	116	....	....	335,000,000	....	[illegible]
December	116	....	....	311,000,000	....	[illegible]
January	145	....	....	388,000,000	....	[illegible]
February	1,740	....	....	4,360,000,000	....	[illegible]
March	3,480	....	....	9,319,000,000	....	[illegible]
April	3,480	....	....	9,020,000,000	....	[illegible]
May	2,900	....	....	7,766,000,000	....	[illegible]
June	2,320	....	....	6,013,000,000	....	[illegible]
July	2,320	....	....	6,213,000,000	....	[illegible]
August	580	....	....	1,553,000,000	....	[illegible]
September	116	....	....	301,000,000	....	[illegible]
October	87	....	....	233,000,000	....	[illegible]
I Per.: Nov.–Jan.	130	....	....	1,031,000,000	0.064	[illegible]
II Per.: Feb.–April	2,919	....	....	22,[illegible],000,000	1.401	[illegible]
III Per.: May–July	2,515	....	....	19,902,000,000	1.230	[illegible]
IV Per.: Aug.–Oct.	263	....	....	2,087,000,000	0.129	[illegible]
November 1 to October 31	1,449	....	....	45,812,000,000	2.833	2.50

Table No. 3.

DRY CREEK.

[illegible]se of Foothills. *Drainage Area, 283 square miles.*

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1878–1879.			
[illegible]ember	0	....	....	0	....	*0.00
[illegible]ember	0	....	....	0	....	*0.00
[illegible]uary	84	....	....	225,000,000	....	*0.30
[illegible]ruary	425	....	....	1,028,000,000	....	*1.50
[illegible]ch	849	....	....	2,274,000,000	....	*3.00
[illegible]il	425	....	....	1,102,000,000	....	*1.50
[illegible]y	113	....	....	303,000,000	....	*0.40
[illegible]e	57	....	....	148,000,000	....	*0.20
[illegible]y	15	....	....	40,000,000	....	*0.05
[illegible]gust	0	....	....	0	....	*0.00
[illegible]tember	0	....	....	0	....	*0.00
[illegible]ober	0	....	....	0	....	*0.00
[illegible] Per.: Nov.–Jan.	28	....	....	225,000,000	0.028	0.10
[illegible] Per.: Feb.–April	573	....	....	4,404,000,000	0.559	2.03
[illegible] Per.: May–July	62	....	....	491,000,000	0.062	0.22
[illegible] Per.: Aug.–Oct.	0	....	....	0	0.000	0.00
[illegible]ovember 1 to October 31	162	....	....	5,120,000,000	0.649	0.57
			1879–1880.			
[illegible]ovember	0	....	....	0	....	*0.00
[illegible]ecember	198	....	....	530,000,000	....	*0.70
[illegible]anuary	127	....	....	340,000,000	....	*0.45
[illegible]ebruary	140	....	....	351,000,000	....	*0.50
[illegible]arch	354	....	....	918,000,000	....	*1.25
[illegible]pril	2,264	....	....	5,868,000,000	....	*8.00
[illegible]ay	879	....	....	2,348,000,000	....	*3.00
[illegible]une	113	....	....	293,000,000	....	*0.40
[illegible]uly	15	....	....	40,000,000	....	*0.05
[illegible]ugust	6	....	....	16,000,000	....	*0.02
[illegible]eptember	0	....	....	0	....	*0.00
[illegible]ctober	0	....	....	0	....	*0.00
I Per.: Nov.–Jan.	109	....	....	870,000,000	0.110	0.39
II Per.: Feb. April	922	....	....	7,167,000,000	0.908	3.26
III Per.: May–July	337	....	....	2,681,000,000	0.343	1.19
IV Per.: Aug.–Oct.	2	....	....	16,000,000	0.002	0.01
November 1 to October 31	340	....	....	10,734,000,000	1.361	1.20

Table No. 3—Continued.

DRY CREEK.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge, Cubic Feet.	Depth of Water Drained off, Feet.	[illegible]
			1880-1881.			
November	0	....	....	0	....	[illegible]
December	142	....	....	380,000,000	....	[illegible]
January	879	....	....	2,348,000,000	....	[illegible]
February	1,557	....	....	3,766,000,000	....	[illegible]
March	566	....	....	1,516,000,000	....	[illegible]
April	566	....	....	1,467,000,000	....	[illegible]
May	113	....	....	303,000,000	....	[illegible]
June	42	....	....	109,000,000	....	[illegible]
July	0	....	....	0	....	[illegible]
August	0	....	....	0	....	[illegible]
September	0	....	....	0	....	[illegible]
October	0	....	....	0	....	[illegible]
I Per.: Nov.-Jan.	343	....	....	2,728,000,000	0.346	[illegible]
II Per.: Feb.-April	877	....	....	6,749,000,000	0.855	[illegible]
III Per.: May-July	52	....	....	412,000,000	0.052	[illegible]
IV Per.: Aug.-Oct.	0	....	....	0	0.000	[illegible]
November 1 to October 31	314	....	....	9,880,000,000	1.253	[illegible]
			1881-1882.			
November	57	....	....	148,000,000	....	[illegible]
December	254	....	....	680,000,000	....	[illegible]
January	254	....	....	680,000,000	....	[illegible]
February	283	....	....	685,000,000	....	[illegible]
March	849	....	....	2,274,000,000	....	[illegible]
April	566	....	....	1,467,000,000	....	[illegible]
May	57	....	....	153,000,000	....	[illegible]
June	0	....	....	0	....	[illegible]
July	0	....	....	0	....	[illegible]
August	0	....	....	0	....	[illegible]
September	15	....	....	39,000,000	....	[illegible]
October	57	....	....	153,000,000	....	[illegible]
I Per.: Nov.-Jan.	170	....	....	1,508,000,000	0.191	[illegible]
II Per.: Feb.-April	575	....	....	4,426,000,000	0.561	[illegible]
III Per.: May-July	19	....	....	153,000,000	0.019	[illegible]
IV Per.: Aug.-Oct.	21	....	....	192,000,000	0.024	[illegible]
November 1 to October 31	190	....	....	6,279,000,000	0.796	[illegible]

Table No. 3—Continued.

DRY CREEK.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge, Cubic Feet.	Depth of Water Drained off, Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1882-1883.			
November	84	....	....	218,000,000	....	*0.30
December	84	....	....	225,000,000	....	*0.30
January	168	....	....	450,000,000	....	*0.60
February	141	....	....	341,000,000	....	*0.50
March	254	....	....	680,000,000	....	*0.90
April	283	....	....	734,000,000	....	*1.00
May	168	....	....	450,000,000	....	*0.60
June	0	....	....	0	....	*0.00
July	0	....	....	0	....	*0.00
August	0	....	....	0	....	*0.00
September	0	....	....	0	....	*0.00
October	15	....	....	40,000,000	....	*0.05
I Per.: Nov.-Jan.	112	....	....	893,000,000	0.113	0.40
II Per.: Feb.-April	228	....	....	1,755,000,000	0.222	0.81
III Per.: May-July	57	....	....	450,000,000	0.057	0.20
IV Per.: Aug.-Oct.	5	....	....	40,000,000	0.005	0.02
November 1 to October 31	100	....	....	3,138,000,000	0.397	0.35
			1883-1884.			
November	0	....	....	0	....	*0.00
December	15	....	....	40,000,000	....	*0.05
January	142	....	....	380,000,000	....	*0.50
February	1,132	....	....	2,837,000,000	....	*4.00
March	1,132	....	....	3,031,000,000	....	*4.00
April	879	....	....	2,276,000,000	....	*3.00
May	168	....	....	450,000,000	....	*0.60
June	283	....	....	734,000,000	....	*1.00
July	0	....	....	0	....	*0.00
August	0	....	....	0	....	*0.00
September	0	....	....	0	....	*0.00
October	0	....	....	0	....	*0.00
I Per.: Nov.-Jan.	53	....	....	420,000,000	0.053	0.19
II Per.: Feb.-April	1,047	....	....	8,144,000,000	1.032	3.71
III Per.: May-July	149	....	....	1,184,000,000	0.150	0.53
IV Per.: Aug.-Oct.	0	....	....	0	0.000	0.00
November 1 to October 31	308	....	....	9,748,000,000	1.235	1.09

TABLE No. 4.

MOKELUMNE RIVER.

At Lone Star Mill (base of foothills). *Drainage Area, 657 square miles.*

PERIOD.	DISCHARGE IN CUBIC FEET PER SECOND. Mean.	Max.	Min.	Total Discharge, Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1878-1879.			
November	33	....	....	86,000,000	....	*0.05
December	33	....	....	88,000,000	....	*0.05
January	328	2,107	....	878,000,000	....	*0.50
February	1,198	7,575	134	2,900,000,000	....	1.82
March	1,369	3,420	676	3,667,000,000	....	2.08
April	3,065	5,072	1,579	7,944,000,000	....	4.67
May	3,247	6,170	1,348	8,698,000,000	....	4.94
June	3,629	5,610	1,579	9,406,000,000	....	5.53
July	538	1,117	288	1,441,000,000	....	0.82
August	164	....	....	439,000,000	....	*0.25
September	26	....	....	67,000,000	....	*0.04
October	19	....	....	51,000,000	....	*0.03
I Per.: Nov.-Jan.	132	2,107	....	1,052,000,000	0.051	0.20
II Per.: Feb.-April	1,886	7,575	134	14,511,000,000	0.816	2.87
III Per.: May-July	2,469	6,170	288	19,545,000,000	1.100	3.75
IV Per.: Aug.-Oct.	70	....	....	557,000,000	0.031	0.11
November 1 to October 31	1,131	6,170	....	35,665,000,000	2.000	1.72
			1879-1880.			
November	59	....	....	153,000,000	....	*0.09
December	465	624	224	1,245,000,000	....	0.71
January	279	288	256	746,000,000	....	0.43
February	396	520	288	993,000,000	....	0.60
March	644	728	520	1,725,000,000	....	0.98
April	4,553	9,642	728	11,801,000,000	....	6.89
May	5,031	8,071	3,018	13,475,000,000	....	7.66
June	6,054	7,326	4,685	15,691,000,000	....	9.21
July	2,745	5,201	572	7,375,000,000	....	4.18
August	365	480	134	946,000,000	....	0.55
September	29	134	....	75,000,000	....	0.05
October	164	....	....	439,000,000	....	*0.25
I Per.: Nov.-Jan.	270	624	....	2,144,000,000	0.121	0.41
II Per.: Feb.-April	1,868	9,642	288	14,520,000,000	0.818	2.85
III Per.: May-July	4,597	8,071	572	36,541,000,000	2.057	6.99
IV Per.: Aug.-Oct.	184	480	....	1,460,000,000	0.083	0.28
November 1 to October 31	1,728	9,642	....	54,674,000,000	3.079	2.63

TABLE No. 4—Continued.

MOKELUMNE RIVER.

PERIOD.	DISCHARGE IN CUBIC FEET PER SECOND. Mean.	Max.	Min.	Total Discharge, Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1880-1881.			
November	98	....	....	254,000,000	....	*0.15
December	291	998	....	781,000,000	....	0.44
January	1,037	8,536	192	2,777,000,000	....	1.58
February	3,049	8,852	624	7,375,000,000	....	4.64
March	1,126	2,701	728	3,015,000,000	....	1.71
April	3,195	4,556	1,810	8,282,000,000	....	4.86
May	3,034	4,298	1,579	8,125,000,000	....	4.60
June	1,237	2,701	572	3,207,000,000	....	1.88
July	159	520	....	526,000,000	....	0.26
August	98	....	....	262,000,000	....	*0.15
September	98	....	....	254,000,000	....	*0.15
October	66	....	....	177,000,000	....	*0.10
I Per.: Nov.-Jan.	480	8,536	....	3,812,000,000	0.215	0.73
II Per.: Feb.-April	2,427	8,852	624	18,672,000,000	1.051	3.70
III Per.: May-July	1,618	4,298	....	12,858,000,000	0.724	2.46
IV Per.: Aug.-Oct.	87	....	....	693,000,000	0.039	0.13
November 1 to October 31	1,143	8,852	....	36,035,000,000	2.029	1.74
			1881-1882.			
November	207	....	....	537,000,000	....	*0.30
December	624	....	....	1,671,000,000	....	*0.95
January	591	....	....	1,583,000,000	....	*0.90
February	624	....	....	1,509,000,000	....	*0.95
March	1,971	....	....	5,278,000,000	....	*3.00
April	2,628	....	....	6,812,000,000	....	*4.00
May	4,927	....	....	13,195,000,000	....	*7.50
June	3,285	....	....	8,515,000,000	....	*5.00
July	788	....	....	2,110,000,000	....	*1.20
August	66	....	....	177,000,000	....	*0.10
September	59	....	....	153,000,000	....	*0.09
October	230	....	....	616,000,000	....	*0.35
I Per.: Nov.-Jan.	477	....	....	3,791,000,000	0.213	0.73
II Per.: Feb.-April	1,768	....	....	13,599,000,000	0.766	2.70
III Per.: May-July	2,997	....	....	23,820,000,000	1.341	4.55
IV Per.: Aug.-Oct.	119	....	....	946,000,000	0.053	0.18
November 1 to October 31	1,305	....	....	42,156,000,000	2.373	1.98

Table No. 4—Continued.

MOKELUMNE RIVER.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge, Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1882-1883.			
November	207	....	....	537,000,000	....	[illegible]
December	207	....	....	554,000,000	....	[illegible]
January	414	....	....	1,108,000,000	....	[illegible]
February	328	....	....	793,000,000	....	[illegible]
March	591	....	....	1,583,000,000	....	[illegible]
April	1,971	....	....	5,109,000,000	....	[illegible]
May	3,912	....	....	10,557,000,000	....	[illegible]
June	2,628	....	....	6,812,000,000	....	[illegible]
July	657	....	....	1,759,000,000	....	[illegible]
August	263	....	....	704,000,000	....	[illegible]
September	98	....	....	251,000,000	....	[illegible]
October	98	....	....	262,000,000	....	[illegible]
I Per.: Nov.-Jan.	277	....	....	2,199,000,000	0.124	[illegible]
II Per.: Feb.-April	973	....	....	7,485,000,000	0.421	[illegible]
III Per.: May-July	2,406	....	....	19,128,000,000	1.077	[illegible]
IV Per.: Aug.-Oct.	153	....	....	1,220,000,000	0.068	[illegible]
November 1 to October 31	952	....	....	30,032,000,000	1.691	[illegible]
			1883-1884.			
November	132	....	....	342,000,000	....	*0.20
December	132	....	....	353,000,000	....	*0.20
January	164	....	....	439,000,000	....	*0.25
February	1,971	....	....	4,939,000,000	....	*3.00
March	3,942	....	....	10,557,000,000	....	*6.00
April	3,942	....	....	10,218,000,000	....	*6.00
May	3,285	....	....	8,797,000,000	....	*5.00
June	2,957	....	....	7,665,000,000	....	*4.50
July	2,628	....	....	7,038,000,000	....	*4.00
August	657	....	....	1,759,000,000	....	*1.00
September	131	....	....	340,000,000	....	*0.20
October	98	....	....	262,000,000	....	*0.15
I Per.: Nov.-Jan.	143	....	....	1,134,000,000	0.064	0.22
II Per.: Feb.-April	3,307	....	....	25,714,000,000	1.448	5.03
III Per.: May-July	2,956	....	....	23,500,000,000	1.323	4.51
IV Per.: Aug.-Oct.	297	....	....	2,361,000,000	0.133	0.45
November 1 to October 31	1,667	....	....	52,709,000,000	2.968	2.54

Table No. 5.

CALAVERAS RIVER.

[illegible] *Bellota.* *Drainage Area, 401 square miles.*

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge, Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1878-1879.			
November	0	....	....	0	....	*0.00
December	0	....	....	0	....	*0.00
January	220	....	....	614,000,000	....	0.47
February	648	....	....	1,568,000,000	....	1.32
March	1,068	....	....	2,861,000,000	....	2.17
April	680	....	....	1,762,000,000	....	1.38
May	166	....	....	445,000,000	....	0.34
June	98	....	....	254,000,000	....	*0.20
July	24	....	....	64,000,000	....	*0.05
August	0	....	....	0	....	*0.00
September	0	....	....	0	....	*0.00
October	0	....	....	0	....	*0.00
I Per.: Nov.-Jan.	77	....	....	614,000,000	0.044	0.16
II Per.: Feb.-April	805	....	....	6,191,000,000	0.452	1.64
III Per.: May-July	96	....	....	763,000,000	0.056	0.19
IV Per.: Aug.-Oct.	0	....	....	0	0.000	0.00
November 1 to October 31	240	....	....	7,568,000,000	0.553	0.49
			1879-1880.			
November	0	....	....	0	....	*0.00
December	295	....	....	790,000,000	....	*0.60
January	221	....	....	592,000,000	....	*0.45
February	393	....	....	985,000,000	....	*0.80
March	614	....	....	1,644,000,000	....	*1.25
April	4,174	....	....	10,819,000,000	....	*8.50
May	1,473	....	....	3,945,000,000	....	*3.00
June	190	....	....	508,000,000	....	*0.40
July	24	....	....	64,000,000	....	*0.05
August	10	....	....	27,000,000	....	*0.02
September	0	....	....	0	....	*0.00
October	0	....	....	0	....	*0.00
I Per.: Nov.-Jan.	174	....	....	1,382,000,000	0.100	0.35
II Per.: Feb.-April	1,729	....	....	13,448,000,000	0.975	3.51
III Per.: May-July	568	....	....	4,517,000,000	0.328	1.16
IV Per.: Aug.-Oct.	3	....	....	27,000,000	0.002	0.01
November 1 to October 31	613	....	....	19,374,000,000	1.404	1.25

TABLE No. 5—Continued.

CALAVERAS RIVER.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	[illegible]
			1880-1881.			
November	0	-------	-------	0	-------	[illegible]
December	246	-------	-------	659,000,000	-------	[illegible]
January	1,473	-------	-------	3,915,000,000	-------	[illegible]
February	2,700	-------	-------	6,531,000,000	-------	[illegible]
March	982	-------	-------	2,630,000,000	-------	[illegible]
April	982	-------	-------	2,545,000,000	-------	[illegible]
May	196	-------	-------	525,000,000	-------	[illegible]
June	74	-------	-------	192,000,000	-------	[illegible]
July	49	-------	-------	131,000,000	-------	[illegible]
August	0	-------	-------	0	-------	[illegible]
September	0	-------	-------	0	-------	[illegible]
October	0	-------	-------	0	-------	[illegible]
I Per.: Nov.-Jan.	579	-------	-------	1,604,000,000	0.334	[illegible]
II Per.: Feb.-April	1,522	-------	-------	11,706,000,000	0.842	[illegible]
III Per.: May-July	107	-------	-------	848,000,000	0.061	[illegible]
IV Per.: Aug.-Oct.	0	-------	-------	0	0.000	[illegible]
November 1 to October 31	544	-------	-------	17,158,000,000	1.244	1.1[illegible]
			1881-1882.			
November	0	-------	-------	0	-------	*0.0[illegible]
December	74	-------	-------	198,000,000	-------	*0.1[illegible]
January	344	-------	-------	921,000,000	-------	*0.7[illegible]
February	442	-------	-------	1,069,000,000	-------	*0.9[illegible]
March	1,719	-------	-------	4,603,000,000	-------	*3.50
April	1,719	-------	-------	4,456,000,000	-------	*3.50
May	2,946	-------	-------	7,889,000,000	-------	*6.00
June	246	-------	-------	658,000,000	-------	*0.50
July	0	-------	-------	0	-------	*0.00
August	0	-------	-------	0	-------	*0.00
September	0	-------	-------	0	-------	*0.00
October	98	-------	-------	262,000,000	-------	*0.20
I Per.: Nov.-Jan.	141	-------	-------	1,119,000,000	0.081	0.29
II Per.: Feb.-April	1,317	-------	-------	10,128,000,000	0.734	2.08
III Per.: May-July	1,072	-------	-------	8,527,000,000	0.618	2.18
IV Per.: Aug.-Oct.	33	-------	-------	262,000,000	0.090	0.07
November 1 to October 31	635	-------	-------	20,036,000,000	1.453	1.29

TABLE No. 5—Continued.

CALAVERAS RIVER.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1882-1883.			
[illegible]ovember	147	-------	-------	391,000,000	-------	*0.30
[illegible]ecember	147	-------	-------	394,000,000	-------	*0.30
[illegible]nuary	491	-------	-------	1,315,000,000	-------	*1.00
[illegible]ebruary	393	-------	-------	1,568,000,000	-------	*0.80
[illegible]arch	737	-------	-------	1,974,000,000	-------	*1.50
[illegible]pril	982	-------	-------	2,545,000,000	-------	*2.00
[illegible]ay	491	-------	-------	1,315,000,000	-------	*1.00
[illegible]une	196	-------	-------	508,000,000	-------	*0.40
[illegible]uly	0	-------	-------	0	-------	*0.00
[illegible]ugust	0	-------	-------	0	-------	*0.00
[illegible]eptember	0	-------	-------	0	-------	*0.00
October	74	-------	-------	198,000,000	-------	*0.15
I Per.: Nov.-Jan.	264	-------	-------	2,100,000,000	0.152	0.54
II Per.: Feb.-April	791	-------	-------	6,087,000,000	0.441	1.61
III Per.: May-July	229	-------	-------	1,823,000,000	0.132	0.47
IV Per.: Aug.-Oct.	25	-------	-------	198,000,000	0.014	0.05
November 1 to October 31	324	-------	-------	10,208,000,000	0.740	0.66
			1883-1884.			
November	24	-------	-------	62,000,000	-------	*0.05
December	49	-------	-------	131,000,000	-------	*0.10
January	196	-------	-------	525,000,000	-------	*0.40
February	2,455	-------	-------	6,152,000,000	-------	*5.00
March	2,946	-------	-------	7,889,000,000	-------	*6.00
April	2,455	-------	-------	6,368,000,000	-------	*5.00
May	491	-------	-------	1,315,000,000	-------	*1.00
June	491	-------	-------	1,273,000,000	-------	*1.00
July	196	-------	-------	525,000,000	-------	*0.40
August	0	-------	-------	0	-------	*0.00
September	0	-------	-------	0	-------	*0.00
October	0	-------	-------	0	-------	*0.00
I Per.: Nov.-Jan.	92	-------	-------	728,000,000	0.053	0.19
II Per.: Feb.-April	2,623	-------	-------	20,404,000,000	1.480	5.33
III Per.: May-July	392	-------	-------	3,113,000,000	0.226	0.80
IV Per.: Aug.-Oct.	0	-------	-------	0	0.000	0.00
November 1 to October 31	767	-------	-------	24,245,000,000	1.758	1.56

TABLE No. 6.

STANISLAUS RIVER.

At Oakdale. *Drainage Area, 1,051 sq*[illegible]

PERIOD.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	[illegible]
			1878-1879.			
November	42	....	....	100,000,000	....	[illegible]
December	42	....	....	112,000,000	....	[illegible]
January	525	....	....	1,406,000,000	....	[illegible]
February	1,994	9,830	350	4,824,000,000	....	[illegible]
March	4,523	6,960	....	12,116,000,000	....	[illegible]
April	4,307	7,390	3,200	11,163,000,000	....	[illegible]
May	4,098	6,060	2,950	10,798,000,000	....	[illegible]
June	4,387	6,720	3,160	11,371,000,000	....	[illegible]
July	1,584	2,230	1,320	4,243,000,000	....	[illegible]
August	126	....	....	337,000,000	....	[illegible]
September	21	....	....	55,000,000	....	[illegible]
October	21	....	....	56,000,000	....	[illegible]
I Per.: Nov.-Jan.	205	....	....	1,627,000,000	0.055	[illegible]
II Per.: Feb.-April	3,653	9,830	....	28,103,000,000	0.960	[illegible]
III Per.: May-July	3,323	6,720	1,320	26,412,000,000	0.901	[illegible]
IV Per.: Aug.-Oct.	56	....	....	448,000,000	0.015	[illegible]
November 1 to October 31	1,794	9,830	....	56,590,000,000	1.931	[illegible]
			1879-1880.			
November	74	....	....	192,000,000	....	*0.07
December	630	....	....	1,687,000,000	....	*0.60
January	315	....	....	844,000,000	....	*0.30
February	526	....	....	1,318,000,000	....	*0.50
March	630	....	....	1,687,000,000	....	*0.60
April	5,781	....	....	14,984,000,000	....	*5.50
May	7,251	10,980	4,370	19,421,000,000	....	6.89
June	7,742	10,820	5,240	20,067,000,000	....	7.37
July	3,255	4,630	1,680	8,717,000,000	....	3.10
August	735	....	....	1,968,000,000	....	0.70
September	74	....	....	192,000,000	....	0.07
October	32	....	....	86,000,000	....	0.03
I Per.: Nov.-Jan.	343	....	....	2,723,000,000	0.093	0.33
II Per.: Feb.-April	515	....	....	17,989,000,000	0.611	4.90
III Per.: May-July	6,064	10,980	1,680	48,205,000,000	1.645	5.76
IV Per.: Aug.-Oct.	283	....	....	2,246,000,000	0.077	0.27
November 1 to October 31	2,250	10,980	....	71,163,000,000	2,429	2.14

TABLE No. 6—Continued.

STANISLAUS RIVER.

PERIOD.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1880-1881.			
November	21	....	....	54,000,000	....	*0.02
December	630	....	....	1,687,000,000	....	*0.60
January	2,102	....	....	5,629,000,000	....	*2.00
February	5,255	....	....	12,712,000,000	....	*5.00
March	2,102	....	....	5,629,000,000	....	*2.00
April	4,729	....	....	12,258,000,000	....	*4.50
May	5,255	....	....	14,073,000,000	....	*5.00
June	2,733	....	....	7,084,000,000	....	*2.60
July	960	....	....	2,570,000,000	....	0.91
August	360	....	....	964,000,000	....	0.34
September	140	....	....	363,000,000	....	0.13
October	120	....	....	321,000,000	....	0.11
I Per.: Nov.-Jan.	927	....	....	7,370,000,000	0.251	0.88
II Per.: Feb.-April	3,978	....	....	30,599,000,000	1.044	3.78
III Per.: May-July	2,965	....	....	23,727,000,000	0.809	2.82
IV Per.: Aug.-Oct.	207	....	....	1,648,000,000	0.056	0.20
November 1 to October 31	2,008	....	....	63,344,000,000	2.159	1.98
			1881-1882.			
November	150	....	....	389,000,000	....	0.14
December	1,488	2,460	....	3,986,000,000	....	1.42
January	398	930	....	1,066,000,000	....	0.38
February	908	2,150	330	2,198,000,000	....	0.86
March	1,771	9,930	660	12,779,000,000	....	4.54
April	3,782	5,470	2,650	9,802,000,000	....	3.60
May	5,155	5,470	4,760	13,806,000,000	....	4.91
June	5,255	....	....	13,621,000,000	....	*5.00
July	1,892	....	....	5,067,000,000	....	*1.80
August	105	....	....	281,000,000	....	*0.10
September	105	....	....	272,000,000	....	*0.10
October	473	....	....	1,267,000,000	....	*0.45
I Per.: Nov.-Jan.	684	2,460	....	5,441,000,000	0.186	0.65
II Per.: Feb.-April	3,221	9,930	330	24,779,000,000	0.846	3.07
III Per.: May-July	4,088	....	....	32,494,000,000	1.109	3.88
IV Per. Aug.-Oct.	229	....	....	1,820,000,000	0.062	0.22
November 1 to October 31	2,046	9,930	....	64,534,000,000	2.203	1.94

TABLE No. 6—Continued.

STANISLAUS RIVER.

PERIOD.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	[illegible]
			1882–1883.			
November	368			954,000,000		[illegible]
December	210			562,000,000		[illegible]
January	525			1,406,000,000		[illegible]
February	420			1,016,000,000		[illegible]
March	840			1,675,000,000		[illegible]
April	2,102			5,448,000,000		[illegible]
May	5,255			14,073,000,000		[illegible]
June	4,204			10,897,000,000		[illegible]
July	1,051			2,815,000,000		[illegible]
August	315			844,000,000		[illegible]
September	210			545,000,000		[illegible]
October	168			450,000,000		[illegible]
I Per.: Nov.–Jan.	368			2,922,000,000	0.099	[illegible]
II Per.: Feb.–April	1,058			8,139,000,000	0.278	[illegible]
III Per.: May–July	3,495			27,785,000,000	0.949	[illegible]
IV Per.: Aug.–Oct.	231			1,839,000,000	0.063	[illegible]
November 1 to October 31	1,290			40,685,000,000	1.389	[illegible]
			1883–1884.			
November	210			545,000,000		*0.20
December	210			562,000,000		*0.20
January	263			701,000,000		*0.25
February	3,153			7,901,000,000		*3.00
March	4,204			11,258,000,000		*4.00
April	4,729			12,258,000,000		*4.50
May	4,729			12,664,000,000		*4.50
June	5,255			13,621,000,000		*5.00
July	4,204			11,258,000,000		*4.00
August	1,051			2,815,000,000		*1.00
September	210			545,000,000		*0.20
October	158			423,000,000		*0.15
I Per.: Nov.–Jan.	228			1,811,000,000	0.063	0.22
II Per.: Feb.–April	4,010			31,417,000,000	1.072	3.84
III Per.: May–July	4,723			37,543,000,000	1.281	4.48
IV Per.: Aug.–Oct.	477			3,783,000,000	0.125	0.45
November 1 to October 31	2,358			74,551,000,000	2.544	2.24

TABLE No. 7.

TUOLUMNE RIVER.

Drainage Area, 1,635 square miles.

...odesto.

PERIOD.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1878–1879.			
November	65			170,000,000		*0.04
December	65			174,000,000		*0.04
January	478			1,280,000,000		0.29
February	1,876	14,230		4,540,000,000		1.15
March	2,707	6,920	830	7,909,000,000		1.70
April	4,456	8,360	2,350	11,552,000,000		2.73
May	5,086	8,230	2,740	13,623,000,000		3.09
June	7,061	11,870	4,670	18,101,000,000		4.30
July	1,977	4,670	570	5,295,000,000		1.21
August	183			490,000,000		0.11
September	39			102,000,000		0.02
October	30			80,000,000		0.02
I Per.: Nov.–Jan.	205			1,624,000,000	0.035	0.13
II Per.: Feb.–April	3,120	14,230		24,001,000,000	0.526	1.92
III Per.: May–July	4,658	11,870		37,019,000,000	0.812	2.85
IV Per.: Aug.–Oct.	85			672,000,000	0.015	0.05
November 1 to October 31	2,008	14,230		63,316,000,000	1.388	1.27
			1879–1880.			
November	101			262,000,000		0.06
December	903	4,790	140	2,426,000,000		0.55
January	409	1,290	170	1,096,000,000		0.25
February	625	5,150	130	1,566,000,000		0.38
March	832	1,550	370	2,229,000,000		0.50
April	7,141	19,300	770	19,118,000,000		4.35
May	10,371	16,300	6,280	27,778,000,000		6.31
June	14,075	17,050	10,340	36,484,000,000		8.60
July	7,618	13,220	3,295	20,405,000,000		4.65
August	1,233	2,960	300	3,304,000,000		0.75
September	134			347,000,000		0.08
October	56			151,000,000		0 03
I Per.: Nov.–Jan.	4,760	4,790		3,784,000,000	0.083	2.00
II Per.: Feb.–April	2,947	19,300	130	22,913,000,000	0.502	1.79
III Per.: May–July	10,650	17,050	3,295	84,667,000,000	1.857	6.51
IV Per.: Aug.–Oct.	479	2,960		3,802,000,000	0.083	0.29
November 1 to October 31	3,642	19,300		115,166,000,000	2.525	2.22

Table No. 7—Continued.

TUOLUMNE RIVER.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
	1880–1881.					
November	35			93,000,000		0.02
December	1,095	5,020		2,926,000,000		0.67
January	2,884	22,900	2,640	7,725,000,000		1.76
February	6,755	5,020	2,440	16,341,000,000		4.12
March	2,879	10,340	3,290	7,709,000,000		1.76
April	6,260	10,200	4,790	16,285,000,000		3.82
May	7,271	8,630	3,540	19,482,000,000		4.44
June	5,225	3,970	690	13,543,000,000		3.19
July	1,996	1,380		5,346,000,000		1.22
August	391			1,047,000,000		0.24
September	125			224,000,000		0.08
October	130			317,000,000		0.08
I Per.: Nov.-Jan.	1,352	22,900		10,741,000,000	0.235	0.83
II Per.: Feb.-April	5,244	10,340	2,440	40,335,000,000	0.884	3.20
III Per.: May-July	4,827	8,630		38,371,000,000	0.841	2.95
IV Per.: Aug.-Oct.	2,036			1,618,000,000	0.035	1.24
November 1 to October 31	2,888	22,900		91,068,000,000	1.997	1.76
	1881–1882.					
November	193			508,000,000		0.12
December	620			1,660,000,000		*0.38
January	620			1,600,000,000		*0.38
February	573	1,360		1,386,000,000		0.35
March	2,164	11,410	430	5,896,000,000		1.32
April	3,543	5,780	2,270	9,383,000,000		2.15
May	7,461	11,250	4,670	19,982,000,000		4.55
June	8,046	13,670	4,550	20,854,000,000		4.91
July	2,745	5,650	890	7,352,000,000		1.67
August	574			1,536,000,000		0.35
September	225			584,000,000		0.14
October	873			2,337,000,000		0.53
I Per.: Nov.-Jan.	482			3,828,000,000	0.084	0.29
II Per.: Feb.-April	2,166	11,410		16,665,000,000	0.365	1.33
III Per.: May-July	6,062	13,670	890	48,188,000,000	1.057	3.70
IV Per.: Aug.-Oct.	561			4,457,000,000	0.098	0.84
November 1 to October 31	2,319	13,670		73,138,000,000	1.603	1.42

Table No. 7—Continued.

TUOLUMNE RIVER.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
	1882–1883.					
November	570			1,477,000,000		*0.35
December	327			876,000,000		*0.20
January	654			1,752,000,000		*0.40
February	490			1,185,000,000		*0.30
March	1,310			3,508,000,000		*0.80
April	3,270			9,496,000,000		*2.00
May	8,180			21,906,000,000		*5.00
June	6,540			17,952,000,000		*4.00
July	1,635			4,379,000,000		*1.00
August	490			1,312,000,000		*0.30
September	327			848,000,000		*0.20
October	262			702,000,000		*0.16
I Per.: Nov.-Jan.	517			4,105,000,000	0.090	0.32
II Per.: Feb.-April	1,845			14,189,000,000	0.311	1.13
III Per.: May-July	5,565			44,237,000,000	0.970	3.39
IV Per.: Aug.-Oct.	361			2,862,000,000	0.063	0.22
November 1 to October 31	2,074			65,393,000,000	1.434	1.27
	1883–1884.					
November	327			848,000,000		*0.20
December	327			876,000,000		*0.20
January	410			1,098,000,000		*0.25
February	490			1,228,000,000		*3.00
March	6,540			17,524,000,000		*4.00
April	7,360			19,077,000,000		*4.50
May	7,360			19,710,000,000		*4.50
June	8,180			21,203,000,000		*5.00
July	6,540			17,524,000,000		*4.00
August	1,635			4,379,000,000		*1.00
September	327			848,000,000		*0.20
October	245			656,000,000		*0.15
I Per.: Nov.-Jan.	356			2,822,000,000	0.062	0.22
II Per.: Feb.-April	4,806			37,829,000,000	0.829	2.98
III Per.: May-July	7,351			58,437,000,000	1.281	4.49
IV Per.: Aug.-Oct.	740			5,883,000,000	0.129	0.45
November 1 to October 31	3,178			104,971,000,000	2.302	1.94

Table No. 8.

MERCED RIVER.

At Merced Falls. *Drainage Area, 1,076 squ*

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge, Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
	1878–1879.					
November	65	....	....	168,000,000	....	[illegible]
December	65	....	....	174,000,000	....	[illegible]
January	354	....	....	948,000,000	....	[illegible]
February	1,506	....	....	3,643,000,000	....	[illegible]
March	2,098	....	....	5,618,000,000	....	[illegible]
April	3,120	....	....	8,087,000,000	....	[illegible]
May	3,336	....	....	8,934,000,000	....	[illegible]
June	3,336	....	....	8,647,000,000	....	[illegible]
July	968	....	....	2,592,000,000	....	[illegible]
August	172	....	....	461,000,000	....	[illegible]
September	75	....	....	194,000,000	....	[illegible]
October	75	....	....	201,000,000	....	[illegible]
I Per.: Nov.-Jan.	162	....	....	1,290,000,000	0.043	[illegible]
II Per.: Feb.-April	2,265	....	....	17,348,000,000	0.579	[illegible]
III Per.: May-July	2,538	....	....	20,173,000,000	0.672	[illegible]
IV Per.: Aug.-Oct.	108	....	....	856,000,000	0.028	[illegible]
November 1 to October 31	1,258	....	....	39,667,000,000	1.322	1.1[illegible]
	1879–1880.					
November	172	....	....	446,000,000	....	†0.16
December	646	....	....	1,730,000,000	....	†0.60
January	387	....	....	1,036,000,000	....	†0.36
February	753	....	....	1,887,000,000	....	†0.70
March	807	....	....	2,161,000,000	....	†0.75
April	4,250	....	....	11,016,000,000	....	†3.95
May	4,842	....	....	12,937,000,000	....	†4.50
June	5,111	....	....	13,248,000,000	....	†4.75
July	2,744	....	....	7,348,000,000	....	†2.55
August	753	....	....	2,017,000,000	....	†0.70
September	323	....	....	837,000,000	....	†0.30
October	269	....	....	720,000,000	....	†0.25
I Per.: Nov.-Jan.	404	....	....	3,212,000,000	0.107	0.38
II Per.: Feb.-April	1,941	....	....	15,064,000,000	0.502	1.71
III Per.: May-July	4,222	....	....	33,563,000,000	1.119	3.92
IV Per.: Aug.-Oct.	449	....	....	3,574,000,000	0.119	0.42
November 1 to October 31	1,758	....	....	55,413,000,000	1.847	1.63

† Estimated in part from rod records.

Table No. 8—Continued.

MERCED RIVER.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge, Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
	1880–1881.					
November	237	....	....	614,000,000	....	†0.22
December	1,291	....	....	3,457,000,000	....	†1.20
January	2,044	....	....	5,474,000,000	....	†1.90
February	3,443	....	....	8,329,000,000	....	†3.20
March	1,560	....	....	4,178,000,000	....	†1.45
April	2,798	....	....	7,252,000,000	....	†2.60
May	4,412	....	....	11,815,000,000	....	*4.10
June	3,336	....	....	8,647,000,000	....	*3.10
July	1,506	....	....	4,033,000,000	....	*1.40
August	377	....	....	1,009,000,000	....	†0.35
September	129	....	....	334,000,000	....	†0.12
October	75	....	....	201,000,000	....	†0.07
I Per.: Nov.-Jan.	1,201	....	....	9,545,000,000	0.318	1.12
II Per.: Feb.-April	2,569	....	....	19,759,000,000	0.658	2.39
III Per.: May-July	3,094	....	....	24,595,000,000	0.820	2.87
IV Per.: Aug.-Oct.	194	....	....	1,544,000,000	0.051	0.18
November 1 to October 31	1,760	....	....	55,443,000,000	1.848	1.64
	1881–1882.					
November	75	....	....	194,000,000	....	†0.07
December	323	....	....	865,000,000	....	†0.30
January	172	....	....	461,000,000	....	†0.16
February	753	....	....	1,822,000,000	....	†0.23
March	1,506	....	....	4,033,000,000	....	†1.40
April	2,260	....	....	5,858,000,000	....	†2.10
May	3,658	....	....	9,796,000,000	....	†3.40
June	3,336	....	....	8,647,000,000	....	†3.10
July	1,076	....	....	2,882,000,000	....	†1.00
August	215	....	....	576,000,000	....	†0.20
September	129	....	....	334,000,000	....	†0.12
October	481	....	....	1,296,000,000	....	†0.45
I Per.: Nov.-Jan.	191	....	....	1,520,000,000	0.051	0.18
II Per.: Feb.-April	1,523	....	....	11,713,000,000	0.390	1.42
III Per.: May-July	2,646	....	....	21,325,000,000	0.711	2.45
IV Per.: Aug.-Oct.	277	....	....	2,206,000,000	0.073	0.26
November 1 to October 31	1,166	....	....	36,764,000,000	1.225	1.08

† Estimated in part from rod records.

TABLE No. 8—Continued.

MERCED RIVER.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
				1882–1883.		
November	387			1,003,000,000		*0.3[illegible]
December	237			635,000,000		*0.2[illegible]
January	344			921,000,000		*0.3[illegible]
February	355			859,000,000		*0.3[illegible]
March	915			2,450,000,000		*0.8[illegible]
April	2,260			5,858,000,000		*2.10
May	5,488			14,597,000,000		*5.10
June	4,412			11,436,000,000		*4.10
July	1,184			3,171,000,000		*1.10
August	377			1,010,000,000		*0.35
September	237			614,000,000		*0.2[illegible]
October	183			474,000,000		*0.17
I Per.: Nov.-Jan.	322			2,559,000,000	0.085	0.30
II Per.: Feb.-April	1,192			9,167,000,000	0.306	1.11
III Per.: May-July	3,674			29,204,000,000	0.973	3.42
IV Per.: Aug.-Oct.	264			2,098,000,000	0.699	0.24
November 1 to October 31	1,365			43,028,000,000	1.434	1.27
				1883–1884.		
November	161			397,000,000		*0.15
December	172			461,000,000		*0.16
January	237			635,000,000		*0.22
February	2,712			6,796,000,000		*2.52
March	3,820			10,230,000,000		*3.55
April	4,896			12,690,000,000		*4.55
May	5,434			14,552,000,000		*5.05
June	6,510			16,874,000,000		*6.05
July	4,358			11,645,000,000		*4.05
August	1,130			3,026,000,000		*1.05
September	237			614,000,000		*0.22
October	172			460,000,000		*0.16
I Per.: Nov.-Jan.	188			1,493,000,000	0.048	0.18
II Per.: Feb.-April	3,825			29,716,000,000	0.991	3.55
III Per.: May-July	5,428			43,071,000,000	1.436	5.05
IV Per.: Aug.-Oct.	515			4,090,000,000	0.136	0.56
November 1 to October 31	2,479			78,370,000,000	2.612	2.3[illegible]

TABLE No. 9.

BEAR CREEK.

At Base of Foothills. *Drainage Area, 166 square miles.*

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
				1878–1879.		
November	0	0	0	0		0.00
December	0	0	0	0		0.00
January	0	0	0	0		0.00
February	25	312	0	61,000,000		0.15
March	57	570	0	151,000,000		0.34
April	54	197	5	140,000,000		0.32
May	0	0	0	0		0.00
June	0	0	0	0		0.00
July	0	0	0	0		0.00
August	0	0	0	0		0.00
September	0	0	0	0		0.00
October	0	0	0	0		0.00
I Per.: Nov.-Jan.	0	0	0	0	0.000	0.00
II Per.: Feb.-April	46	570	0	352,000,000	0.076	0.28
III Per.: May-July	0	0	0	0	0.000	0.00
IV Per.: Aug.-Oct.	0	0	0	0	0.000	0.00
November 1 to October 31	11	570	0	352,000,000	0.076	0.07
				1879–1880.		
November	0	0	0	0		0.00
December	18	257	0	49,000,000		0.11
January	25	217	0	66,000,000		0.15
February	61	700	0	153,000,000		0.36
March	31	85	10	84,000,000		0.19
April	321	2,080	25	831,000,000		0.93
May	23	47	0	61,000,000		0.14
June	0	0	0	0		0.00
July	0	0	0	0		0.00
August	0	0	0	0		0.00
September	0	0	0	0		0.00
October	0	0	0	0		0.00
I Per.: Nov.-Jan.	15	257	0	115,000,000	0.025	0.09
II Per.: Feb.-April	137	2,080	0	1,068,000,000	0.231	0.83
III Per.: May-July	77	47	0	61,000,000	0.013	0.05
IV Per.: Aug.-Oct.	0	0	0	0	0.000	0.00
November 1 to October 31	40	2,080	0	1,244,000,000	0.269	0.24

TABLE No. 9—Continued.

BEAR CREEK.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1880-1881.			
November	0	0	0	0	--------	0.00
December	115	421	0	307,000,000	--------	0.69
January	169	1,920	20	454,000,000	--------	1.03
February	214	1,423	47	520,000,000	--------	1.29
March	48	197	13	130,000,000	--------	0.29
April	6	20	0	16,000,000	--------	0.04
May	0	0	0	0	--------	0.00
June	0	0	0	0	--------	0.00
July	0	0	0	0	--------	0.00
August	0	0	0	0	--------	0.00
September	0	0	0	0	--------	0.00
October	0	0	0	0	--------	0.00
I Per.: Nov.-Jan.	96	1,920	0	761,000,000	0.164	0.58
II Per.: Feb.-April	87	1,123	0	666,000,000	0.144	0.52
III Per.: May-July	0	0	0	0	0.000	0.00
IV Per.: Aug.-Oct.	0	0	0	0	0.000	0.00
November 1 to October 31	45	1,920	0	1,427,000,000	0.308	0.27
			1881-1882.			
November	0	0	0	0	--------	0.00
December	0	0	0	0	--------	0.00
January	0	0	0	0	--------	0.00
February	33	--------	--------	80,000,000	--------	*0.20
March	100	--------	--------	268,000,000	--------	*0.60
April	130	--------	--------	337,000,000	--------	*0.80
May	0	0	0	0	--------	*0.00
June	0	0	0	0	--------	*0.00
July	0	0	0	0	--------	*0.00
August	0	0	0	0	--------	*0.00
September	0	0	0	0	--------	*0.00
October	17	--------	0	46,000,000	--------	*0.10
I Per.: Nov.-Jan.	0	0	0	0	0.000	0.00
II Per.: Feb.-April	89	--------	--------	685,000,000	0.148	0.54
III Per.: May-July	0	0	0	0	0.000	0.00
IV Per.: Aug.-Oct.	6	--------	0	46,000,000	0.010	0.04
November 1 to October 31	23	--------	0	731,000,000	0.158	0.14

TABLE No. 9—Continued.

BEAR CREEK.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1882-1883.			
November	25	--------	--------	65,000,000	--------	*0.15
December	17	--------	--------	46,000,000	--------	*0.10
January	66	--------	--------	177,000,000	--------	*0.40
February	33	--------	--------	80,000,000	--------	*0.20
March	170	--------	--------	455,000,000	--------	*1.00
April	100	--------	--------	259,000,000	--------	*0.60
May	50	--------	--------	134,000,000	--------	*0.30
June	0	0	0	0	--------	*0.00
July	0	0	0	0	--------	*0.00
August	0	0	0	0	--------	*0.00
September	0	0	0	0	--------	*0.00
October	0	0	0	0	--------	*0.00
I Per.: Nov.-Jan.	36	--------	--------	288,000,000	0.062	0.22
II Per.: Feb.-April	103	--------	--------	794,000,000	0.172	0.61
III Per.: May-July	17	--------	--------	134,000,000	0.029	0.10
IV Per.: Aug.-Oct.	0	0	0	0	0.000	0.00
November 1 to October 31	39	--------	0	1,216,000,000	0.263	0.24
			1883-1884.			
November	0	0	0	0	--------	*0.00
December	0	0	0	0	--------	*0.00
January	17	--------	--------	46,000,000	--------	*0.10
February	660	--------	--------	1,654,000,000	--------	*4.00
March	910	--------	--------	2,437,000,000	--------	*5.50
April	660	--------	--------	1,711,000,000	--------	*4.00
May	330	--------	--------	884,000,000	--------	*2.00
June	170	--------	--------	441,000,000	--------	*1.00
July	66	--------	--------	177,000,000	--------	*0.40
August	0	0	0	0	--------	*0.00
September	0	0	0	0	--------	*0.00
October	0	0	0	0	--------	*0.00
I Per.: Nov.-Jan.	6	--------	--------	46,000,000	0.010	0.04
II Per.: Feb.-April	746	--------	--------	5,802,000,000	1.254	4.49
III Per.: May-July	189	--------	--------	1,502,000,000	0.324	1.14
IV Per.: Aug.-Oct.	0	0	0	0	0.000	0.00
November 1 to October 31	232	--------	0	7,350,000,000	1.588	1.40

Table No. 10.

MARIPOSA CREEK.

At Base of Foothills. *Drainage Area, 122 square miles.*

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1878–1879.			
November	0	0	0	0	....	*0.00
December	0	0	0	0	....	*0.00
January	0	0	0	0	....	*0.00
February	20	....	0	48,000,000	....	*0.16
March	45	....	....	121,000,000	....	*0.37
April	43	....	....	111,000,000	....	*0.35
May	4	....	0	11,000,000	....	*0.03
June	0	0	0	0	....	*0.00
July	0	0	0	0	....	*0.00
August	0	0	0	0	....	*0.00
September	0	0	0	0	....	*0.00
October	0	0	0	0	....	*0.00
I Per.: Nov.-Jan.	0	0	0	0	0.000	0.00
II Per.: Feb.-April	36	....	0	280,000,000	0.082	0.30
III Per.: May-July	1	....	0	11,000,000	0.003	0.01
IV Per.: Aug.-Oct.	0	0	0	0	0.000	0.00
November 1 to October 31	9	....	0	291,000,000	0.086	0.07
			1879–1880.			
November	0	0	0	0	....	*0.00
December	15	....	0	40,000,000	....	*0.12
January	20	....	....	54,000,000	....	*0.16
February	49	....	....	123,000,000	....	*0.40
March	24	....	....	64,000,000	....	*0.20
April	24	....	....	62,000,000	....	*0.20
May	18	....	....	48,000,000	....	*0.15
June	12	....	0	31,000,000	....	*0.10
July	0	0	0	0	....	*0.00
August	0	0	0	0	....	*0.00
September	0	0	0	0	....	*0.00
October	0	0	0	0	....	*0.00
I Per.: Nov.-Jan.	12	....	0	94,000,000	0.028	0.10
II Per.: Feb.-April	32	....	....	249,000,000	0.073	0.20
III Per.: May-July	10	....	0	79,000,000	0.023	0.08
IV Per.: Aug.-Oct.	0	0	0	0	0.000	0.00
November 1 to October 31	13	....	0	422,000,000	0.124	0.11

Table No. 10—Continued.

MARIPOSA CREEK.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1880–1881.			
November	0	0	0	0	....	*0.00
December	92	....	0	246,000,000	....	*0.75
January	134	....	....	359,000,000	....	*1.10
February	171	....	....	414,000,000	....	*1.40
March	38	....	....	102,000,000	....	*0.31
April	5	....	0	13,000,000	....	*0.04
May	0	0	0	0	....	*0.00
June	0	0	0	0	....	*0.00
July	0	0	0	0	....	*0.00
August	0	0	0	0	....	*0.00
September	0	0	0	0	....	*0.00
October	0	0	0	0	....	*0.00
I Per.: Nov.-Jan.	76	....	0	605,000,000	0.178	0.62
II Per.: Feb.-April	68	....	0	529,000,000	0.156	0.56
III Per.: May-July	0	0	0	0	0.000	0.00
IV Per.: Aug.-Oct.	0	0	0	0	0.000	0.00
November 1 to October 31	36	....	0	1,134,000,000	0.334	0.30
			1881–1882.			
November	0	0	0	0	....	*0.00
December	0	0	0	0	....	*0.00
January	0	0	0	0	....	*0.00
February	24	....	0	58,000,000	....	*0.20
March	74	....	....	198,000,000	....	*0.60
April	98	....	0	254,000,000	....	*0.80
May	0	0	0	0	....	*0.00
June	0	0	0	0	....	*0.00
July	0	0	0	0	....	*0.00
August	0	0	0	0	....	*0.00
September	0	0	0	0	....	*0.00
October	0	0	0	0	....	*0.10
I Per.: Nov.-Jan.	0	0	0	0	0.000	0.00
II Per.: Feb.-April	66	....	0	510,000,000	0.150	0.54
III Per.: May-July	0	0	0	0	0.000	0.00
IV Per.: Aug.-Oct.	0	0	0	0	0.000	0.00
November 1 to October 31	16	....	0	510,000,000	0.150	0.13

TABLE No. 10—Continued.

MARIPOSA CREEK.

PERIOD.	DISCHARGE IN CUBIC FEET PER SECOND. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1882–1883.			
November	18	....	0	47,000,000	....	*0.15
December	12	....	....	32,000,000	....	*0.10
January	49	....	....	131,000,000	....	*0.40
February	24	....	....	68,000,000	....	*0.20
March	122	....	....	327,000,000	....	*1.00
April	73	....	....	189,000,000	....	*0.60
May	37	....	0	99,000,000	....	*0.30
June	0	0	0	0	....	*0.00
July	0	0	0	0	....	*0.00
August	0	0	0	0	....	*0.00
September	0	0	0	0	....	*0.00
October	0	0	0	0	....	*0.00
I Per.: Nov.–Jan.	26	....	0	210,000,000	0.062	0.21
II Per.: Feb.–April	75	....	....	574,000,000	0.169	0.6[illegible]
III Per.: May–July	12	....	0	99,000,000	0.029	0.10
IV Per.: Aug.–Oct.	0	0	0	0	0.000	0.00
November 1 to October 31	28	....	0	883,000,000	0.260	0.2[illegible]
			1883–1884.			
November	0	0	0	0	....	*0.00
December	0	0	0	0	....	*0.00
January	12	....	0	32,000,000	....	*0.10
February	488	....	....	1,223,000,000	....	*4.0[illegible]
March	671	....	....	1,797,000,000	....	*5.5[illegible]
April	488	....	....	1,265,000,000	....	*4.0[illegible]
May	244	....	....	653,000,000	....	*2.0[illegible]
June	122	....	....	316,000,000	....	*1.0[illegible]
July	49	....	0	131,000,000	....	*0.[illegible]
August	0	0	0	0	....	*0.0[illegible]
September	0	0	0	0	....	*0.0[illegible]
October	0	0	0	0	....	*0.0[illegible]
I Per.: Nov.–Jan.	4	....	0	32,000,000	0.009	0.0[illegible]
II Per.: Feb.–April	551	....	....	4,285,000,000	1.260	[illegible]
III Per.: May–July	138	....	0	1,100,000,000	0.323	[illegible]
IV Per.: Aug.–Oct.	0	0	0	0	....	[illegible]
November 1 to October 31	171	....	0	5,417,000,000	1.593	[illegible]

TABLE No. 11.

CHOWCHILLA CREEK.

At Base of Foothills. *Drainage Area, 268 square miles.*

PERIOD.	DISCHARGE IN CUBIC FEET PER SECOND. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1878–1879.			
November	0	0	0	0	....	0.00
December	0	0	0	0	....	0.00
January	8	140	0	22,000,000	....	0.03
February	56	1,000	0	137,000,000	....	0.21
March	63	760	0	160,000,000	....	0.24
April	48	300	11	125,000,000	....	0.18
May	14	140	0	39,000,000	....	0.05
June	0	0	0	0	....	0.00
July	0	0	0	0	....	0.00
August	0	0	0	0	....	0.00
September	0	0	0	0	....	0.00
October	0	0	0	0	....	0.00
I Per.: Nov.–Jan.	3	140	0	22,000,000	0.003	0.01
II Per.: Feb.–April	55	1,000	0	422,000,000	0.056	0.21
III Per.: May–July	5	140	0	39,000,000	0.005	0.02
IV Per.: Aug.–Oct.	0	0	0	0	0.000	0.00
November 1 to October 31	16	1,000	0	483,000,000	0.064	0.06
			1879–1880.			
November	0	0	0	0	....	0.00
December	12	192	0	32,000,000	....	0.05
January	5	18	0	13,000,000	....	0.02
February	167	1,500	0	410,000,000	....	0.63
March	19	91	11	51,000,000	....	0.07
April	1,266	6,380	0	3,292,000,000	....	4.72
May	53	....	....	142,000,000	....	*0.20
June	27	....	0	70,000,000	....	*0.10
July	0	0	0	0	....	*0.00
August	0	0	0	0	....	*0.00
September	0	0	0	0	....	*0.00
October	0	0	0	0	....	*0.00
I Per.: Nov.–Jan.	6	192	0	45,000,000	0.006	0.02
II Per.: Feb.–April	483	6,380	0	3,753,000,000	0.502	1.80
III Per.: May–July	27	....	0	212,000,000	0.028	0.10
IV Per.: Aug.–Oct.	0	0	0	0	0.000	0.00
November 1 to October 31	127	6,380	0	4,010,000,000	0.537	0.47

TABLE No. 11—Continued.

CHOWCHILLA CREEK.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
1880–1881.						
November	0	0	0	0	....	*0.00
December	201	....	0	538,000,000	....	*0.75
January	295	....	....	790,000,000	....	*1.10
February	375	....	....	907,000,000	....	*1.[illegible]
March	83	....	....	222,000,000	....	*0.3[illegible]
April	11	....	0	29,000,000	....	*0.0[illegible]
May	0	0	0	0	....	*0.00
June	0	0	0	0	....	*0.00
July	0	0	0	0	....	*0.00
August	0	0	0	0	....	*0.00
September	0	0	0	0	....	*0.00
October	0	0	0	0	....	*0.00
I Per.: Nov.–Jan.	167	....	0	1,328,000,000	0.177	0.6[illegible]
II Per.: Feb.–April	150	....	0	1,158,000,000	0.154	0.5[illegible]
III Per.: May–July	0	0	0	0	0.000	0.0[illegible]
IV Per.: Aug.–Oct.	0	0	0	0	0.000	0.0[illegible]
November 1 to October 31	71	....	0	2,486,000,000	0.331	0.[illegible]
1881–1882.						
November	0	0	0	0	....	*0.00
December	27	....	0	72,000,000	....	*0.10
January	54	....	....	145,000,000	....	*0.20
February	164	1,120	0	397,000,000	....	0.61
March	1,168	10,770	0	3,120,000,000	....	4.8[illegible]
April	268	....	....	695,000,000	....	*1.00
May	54	....	0	145,000,000	....	*1.20
June	0	0	0	0	....	*0.00
July	0	0	0	0	....	*0.00
August	0	0	0	0	....	*0.00
September	0	0	0	0	....	*0.00
October	0	0	0	0	....	*0.10
I Per.: Nov.–Jan.	27	....	0	217,000,000	0.028	0.10
II Per.: Feb.–April	549	10,770	0	4,221,000,000	0.563	2.04
III Per.: May–July	18	....	0	145,000,000	0.019	0.07
IV Per.: Aug.–Oct.	0	0	0	0	0.000	0.00
November 1 to October 31	145	10,770	....	4,583,000,000	0.611	0.5[illegible]

TABLE No. 11—Continued.

CHOWCHILLA CREEK.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
1882–1883.						
November	53	....	0	157,000,000	....	*0.20
December	27	....	....	72,000,000	....	*0.10
January	80	....	....	214,000,000	....	*0.30
February	53	....	....	128,000,000	....	*0.20
March	268	....	....	718,000,000	....	*1.00
April	134	....	....	347,000,000	....	*0.50
May	107	....	0	287,000,000	....	*0.40
June	0	0	0	0	....	*0.00
July	0	0	0	0	....	*0.00
August	0	0	0	0	....	*0.00
September	0	0	0	0	....	*0.00
October	0	0	0	0	....	*0.00
I Per.: Nov.–Jan.	53	....	0	423,000,000	0.056	0.20
II Per.: Feb.–April	155	....	....	1,193,000,000	0.159	0.58
III Per.: May–July	36	....	0	287,000,000	0.038	0.14
IV Per.: Aug.–Oct.	0	0	0	0	0.000	0.00
November 1 to October 31	60	....	0	1,903,000,000	0.254	0.42
1883–1884.						
November	0	0	0	0	....	*0.00
December	0	0	0	0	....	*0.00
January	27	....	0	72,000,000	....	*0.10
February	1,340	....	....	3,358,000,000	....	*5.00
March	1,608	....	....	4,306,000,000	....	*6.00
April	1,072	....	....	2,779,000,000	....	*4.00
May	804	....	....	2,153,000,000	....	*3.00
June	804	....	....	2,084,000,000	....	*3.00
July	268	....	....	718,000,000	....	*1.00
August	27	....	0	72,000,000	....	*0.10
September	0	0	0	0	....	*0.00
October	0	0	0	0	....	*0.00
I Per.: Nov.–Jan.	9	....	0	72,000,000	0.010	0.03
II Per.: Feb.–April	1,343	....	....	10,443,000,000	1.399	5.01
III Per.: May–July	623	....	....	4,955,000,000	0.661	2.33
IV Per.: Aug.–Oct.	9	....	0	72,000,000	0.010	0.03
November 1 to October 31	492	....	....	15,542,000,000	2.080	1.84

TABLE No. 12.

FRESNO CREEK.

At Base of Foothills. *Drainage Area, 272 square* [illegible]

PERIOD.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge, Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1878-1879.			
November	0	....	....	0	....	[illegible]
December	0	....	....	0	....	[illegible]
January	27	80	0	73,000,000	....	[illegible]
February	80	117	66	193,000,000	....	[illegible]
March	118	202	66	316,000,000	....	[illegible]
April	156	202	124	404,000,000	....	[illegible]
May	79	102	66	209,000,000	....	[illegible]
June	15	54	0	38,000,000	....	[illegible]
July	0	0	0	0	....	[illegible]
August	0	0	0	0	....	[illegible]
September	0	0	0	0	....	[illegible]
October	0	0	0	0	....	[illegible]
I Per.: Nov.-Jan.	9	80	0	73,000,000	0.010	[illegible]
II Per.: Feb.-April	119	202	66	913,000,000	0.120	[illegible]
III Per.: May-July	31	102	0	247,000,000	0.032	[illegible]
IV Per.: Aug.-Oct.	0	0	0	0	0.000	[illegible]
November 1 to October 31	39	202	0	1,233,000,000	0.163	[illegible]
			1879-1880.			
November	0	....	....	0	....	[illegible]
December	109	....	....	292,000,000	....	*0.40
January	5	....	....	13,000,000	....	[illegible]
February	150	....	....	376,000,000	....	[illegible]
March	16	....	....	43,000,000	....	[illegible]
April	1,088	....	....	2,820,000,000	....	[illegible]
May	54	....	....	145,000,000	....	[illegible]
June	27	....	....	70,000,000	....	[illegible]
July	....	....	....	0	....	[illegible]
August	....	....	....	0	....	[illegible]
September	....	....	....	0	....	[illegible]
October	....	....	....	0	....	[illegible]
I Per.: Nov.-Jan.	38	....	....	305,000,000	0.040	[illegible]
II Per.: Feb.-April	418	....	....	3,249,000,000	0.429	[illegible]
III Per.: May-July	27	....	....	215,000,000	0.028	[illegible]
IV Per.: Aug.-Oct.	0	....	....	0	0.000	[illegible]
November 1 to October 31	119	....	....	3,769,000,000	0.497	[illegible]

TABLE No. 12—Continued.

FRESNO CREEK.

PERIOD.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge, Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1880-1881.			
November	0	....	....	0	....	*0.00
December	218	....	....	583,000,000	....	*0.80
January	544	....	....	1,457,000,000	....	*2.00
February	544	....	....	1,316,000,000	....	*2.00
March	272	....	....	728,000,000	....	*1.00
April	109	....	....	283,000,000	....	*0.40
May	54	....	....	14,000,000	....	*0.20
June	0	....	....	0	....	*0.00
July	0	....	....	0	....	*0.00
August	0	....	....	0	....	*0.00
September	0	....	....	0	....	*0.00
October	0	....	....	0	....	*0.00
I Per.: Nov.-Jan.	257	....	....	2,040,000,000	0.269	0.94
II Per.: Feb.-April	303	....	....	2,327,000,000	0.307	1.11
III Per.: May-July	18	....	....	14,000,000	0.002	0.07
IV Per.: Aug.-Oct.	0	....	....	0	0.000	0.00
November 1 to October 31	139	....	....	4,381,000,000	0.578	0.51
			1881-1882.			
November	0	....	....	0	....	*0.00
December	27	....	....	72,000,000	....	*0.10
January	54	....	....	145,000,000	....	*0.20
February	163	....	....	394,000,000	....	*0.60
March	1,088	....	....	2,914,000,000	....	*4.00
April	272	....	....	705,000,000	....	*1.00
May	54	....	....	145,000,000	....	*0.20
June	0	....	....	0	....	*0.00
July	0	....	....	0	....	*0.00
August	0	....	....	0	....	*0.00
September	0	....	....	0	....	*0.00
October	27	....	....	72,000,000	....	*0.10
I Per.: Nov.-Jan.	27	....	....	217,000,000	0.028	0.10
II Per.: Feb.-April	522	....	....	4,013,000,000	0.529	1.93
III Per.: May-July	18	....	....	145,000,000	0.019	0.07
IV Per.: Aug.-Oct.	9	....	....	72,000,000	0.010	0.03
November 1 to October 31	141	....	....	4,447,000,000	0.587	0.52

TABLE No. 12—Continued.

FRESNO CREEK.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1882–1883.			
November	54	....	....	140,000,000	....	*0.20
December	27	....	....	72,000,000	....	*0.10
January	82	....	....	220,000,000	....	*0.30
February	54	....	....	131,000,000	....	*0.20
March	272	....	....	728,000,000	....	*1.00
April	136	....	....	453,000,000	....	*0.50
May	109	....	....	292,000,000	....	*0.40
June	0	....	....	0	....	*0.00
July	0	....	....	0	....	*0.00
August	0	....	....	0	....	*0.00
September	0	....	....	0	....	*0.00
October	0	....	....	0	....	*0.00
I Per.: Nov.–Jan.	54	....	....	432,000,000	0.057	0.20
II Per.: Feb.–April	165	....	....	1,312,000,000	0.173	0.61
III Per.: May–July	37	....	....	292,000,000	0.038	0.14
IV Per.: Aug.–Oct.	0	....	....	0	0.000	0.00
November 1 to October 31	65	....	....	2,036,000,000	0.268	0.24
			1883–1884.			
November	0	....	....	0	....	*0.00
December	0	....	....	0	....	*0.00
January	27	....	....	72,000,000	....	*0.10
February	1,360	....	....	3,408,000,000	....	*5.00
March	1,632	....	....	4,370,000,000	....	*6.00
April	1,088	....	....	2,820,000,000	....	*4.00
May	816	....	....	2,185,000,000	....	*3.00
June	816	....	....	2,115,000,000	....	*3.00
July	272	....	....	728,000,000	....	*1.00
August	27	....	....	72,000,000	....	*0.10
September	0	....	....	0	....	*0.00
October	0	....	....	0	....	*0.00
I Per.: Nov.–Jan.	9	....	....	72,000,000	0.010	0.03
II Per.: Feb.–April	1,363	....	....	10,598,000,000	1.398	5.01
III Per.: May–July	633	....	....	5,028,000,000	0.663	2.33
IV Per.: Aug.–Oct.	9	....	....	72,000,000	0.010	0.03
November 1 to October 31	499	....	....	15,770,000,000	2.081	1.83

TABLE No. 13.

SAN JOAQUIN RIVER.

At Hamptonville. *Drainage Area, 1,637 square miles.*

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
			1878–1879.			
November	330	....	....	829,000,000	....	*0.20
December	410	....	....	1,098,000,000	....	*0.25
January	609	3,010	370	1,631,000,000	....	0.37
February	1,276	5,420	620	3,100,000,000	....	0.78
March	1,953	3,340	1,300	5,232,000,000	....	1.19
April	3,849	8,560	2,360	9,718,000,000	....	2.34
May	5,302	10,030	2,850	14,200,000,000	....	3.24
June	6,379	11,640	4,200	16,537,000,000	....	3.89
July	2,303	4,460	1,300	6,168,000,000	....	1.41
August	786	1,300	550	2,106,000,000	....	0.48
September	381	480	310	988,000,000	....	0.23
October	373	480	260	1,000,000,000	....	0.23
I Per.: Nov.–Jan.	448	3,010	....	3,558,000,000	0.078	0.27
II Per.: Feb.–April	2,348	8,560	620	18,050,000,000	0.394	1.43
III Per.: May–July	4,643	11,640	1,300	36,905,000,000	0.808	2.83
IV Per.: Aug.–Oct.	515	1,300	260	4,094,000,000	0.090	0.31
November 1 to October 31	1,985	11,640	....	62,607,000,000	1.371	1.21
			1879–1880.			
November	411	420	370	1,065,000,000	....	0.25
December	1,140	4,700	700	3,051,000,000	....	0.70
January	825	1,020	770	2,211,000,000	....	0.50
February	942	2,360	770	2,443,000,000	....	0.57
March	1,229	1,640	1,120	3,290,000,000	....	0.75
April	4,846	15,580	1,300	12,560,000,000	....	2.95
May	13,170	25,000	5,420	35,107,000,000	....	8.02
June	18,120	25,600	14,180	46,964,000,000	....	11.09
July	8,010	14,050	3,350	21,461,000,000	....	4.89
August	1,730	4,700	840	4,634,000,000	....	1.06
September	734	840	550	1,903,000,000	....	0.45
October	422	480	380	1,150,000,000	....	0.26
I Per.: Nov.–Jan.	796	4,700	370	6,327,000,000	0.138	0.49
II Per.: Feb.–April	2,352	15,580	770	18,293,000,000	0.401	1.44
III Per.: May–July	13,024	25,600	3,350	103,532,000,000	2.267	7.95
IV Per.: Aug.–Oct.	968	4,700	380	7,693,000,000	0.168	0.59
November 1 to October 31	4,296	25,600	370	135,845,000,000	2.975	2.62

TABLE No. 13—Continued.

SAN JOAQUIN RIVER.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
1880-1881.						
November	380	450	370	987,000,000	....	0.23
December	2,001	6,730	395	5,360,000,000	....	1.22
January	3,856	59,800	1,024	10,338,000,000	....	2.35
February	6,310	22,450	2,440	15,338,000,000	....	3.87
March	2,855	6,570	2,440	7,648,000,000	....	1.74
April	8,008	13,250	5,900	20,759,000,000	....	4.89
May	9,095	16,500	5,900	24,359,000,000	....	5.53
June	5,918	9,230	4,300	15,319,000,000	....	3.63
July	3,064	5,180	2,200	8,205,000,000	....	1.87
August	1,260	1,640	760	3,374,000,000	....	0.77
September	584	760	400	1,514,000,000	....	0.36
October	463	490	430	1,239,000,000	....	0.28
I Per.: Nov.-Jan.	2,090	59,800	370	16,685,000,000	0.365	1.28
II Per.: Feb.-April	5,688	22,450	2,440	43,745,000,000	0.958	3.46
III Per.: May-July	6,023	16,500	2,200	47,884,000,000	1.049	3.67
IV Per.: Aug.-Oct.	771	1,640	430	6,127,000,000	0.134	0.47
November 1 to October 31	3,620	59,800	370	114,441,000,000	2.506	2.22
1881-1882.						
November	461	530	380	1,196,000,000	....	0.28
December	632	2,740	340	1,693,000,000	....	0.39
January	303	330	290	810,000,000	....	0.19
February	330	520	280	741,000,000	....	0.20
March	1,522	3,800	340	4,076,000,000	....	0.93
April	3,409	7,360	2,540	8,835,000,000	....	2.08
May	8,850	12,860	7,360	23,703,000,000	....	5.40
June	7,867	13,980	4,280	20,391,000,000	....	4.79
July	2,918	6,900	700	7,818,000,000	....	1.78
August	591	1,630	450	1,584,000,000	....	0.38
September	240	....	....	622,000,000	....	0.15
October	564	....	....	1,511,000,000	....	0.34
I Per.: Nov.-Jan.	465	2,740	290	3,699,000,000	0.081	0.28
II Per.: Feb.-April	1,775	7,360	280	13,652,000,000	0.299	1.08
III Per.: May-July	6,531	13,980	700	51,912,000,000	1.137	3.98
IV Per.: Aug.-Oct.	479	....	....	3,717,000,000	0.081	0.29
November 1 to October 31	2,311	13,980	....	72,980,000,000	1.599	1.41

TABLE No. 13—Continued.

SAN JOAQUIN RIVER.

Period.	Discharge in Cubic Feet per Second. Mean.	Max.	Min.	Total Discharge. Cubic Feet.	Depth of Water Drained off. Feet.	Amount Drained off per sec. per sq. mile in cu. ft.
1882-1883.						
November	490	....	....	1,371,000,000	....	*0.30
December	320	....	....	857,000,000	....	*0.20
January	320	....	....	857,000,000	....	*0.20
February	320	....	....	774,000,000	....	*0.20
March	1,150	....	....	3,080,000,000	....	*0.70
April	2,130	....	....	5,521,000,000	....	*1.30
May	7,370	....	....	19,737,000,000	....	*4.50
June	6,220	....	....	16,122,000,000	....	*3.80
July	1,470	....	....	3,937,000,000	....	*0.90
August	490	....	....	1,312,000,000	....	*0.30
September	410	....	....	1,063,000,000	....	*0.25
October	330	....	....	884,000,000	....	*0.20
I Per.: Nov.-Jan.	388	....	....	3,085,000,000	0.068	0.24
II Per.: Feb.-April	1,219	....	....	9,375,000,000	0.205	0.74
III Per.: May-July	5,005	....	....	39,796,000,000	0.872	3.06
IV Per.: Aug.-Oct.	410	....	....	3,259,000,000	0.071	0.25
November 1 to October 31	1,760	....	....	55,515,000,000	1.216	1.08
1883-1884.						
November	250	....	....	648,000,000	....	*0.15
December	250	....	....	670,000,000	....	*0.15
January	410	....	....	1,098,000,000	....	*0.25
February	2,460	....	....	6,165,000,000	....	*1.50
March	4,090	....	....	10,953,000,000	....	*2.50
April	3,270	....	....	8,476,000,000	....	*2.00
May	8,190	....	....	21,933,000,000	....	*5.00
June	16,400	....	....	42,509,000,000	....	*10.00
July	13,100	....	....	35,082,000,000	....	*8.00
August	3,270	....	....	8,757,000,000	....	*2.00
September	980	....	....	2,540,000,000	....	*0.60
October	820	....	....	2,196,000,000	....	*0.50
I Per.: Nov.-Jan.	304	....	....	2,416,000,000	0.053	0.19
II Per.: Feb.-April	3,291	....	....	25,594,000,000	0.561	2.01
III Per.: May-July	12,520	....	....	99,524,000,000	2.179	7.65
IV Per.: Aug.-Oct.	1,697	....	....	13,493,000,000	0.295	1.04
November 1 to October 31	4,460	....	....	141,027,000,000	3.088	2.72

REPORT

OF THE

STATE ENGINEER

TO THE

Legislature of the State of California--Session of 1880.

Part II.

SACRAMENTO:
STATE OFFICE : : : : J. D. YOUNG, SUPT. STATE PRINTING.
1880.

ERRATA.

Page 10, paragraph 3, line 2, read "valley drains," for "valleys drained."
Page 11, paragraph 2, line 6, read "over," for "even."
Page 17, paragraph 4, line 2, read "As in the second division, there are not in this any tributaries."
Page 18, paragraph 4, line 4, read "to save elevation," for "to save the elevation."
Page 18, paragraph 5, line 5, read "acting," for "act."
Page 28, paragraph 3, line 2, read "clear-water," for "clear water."
Page 28, paragraph 7, line 3, read "stream," for "streams."
Page 29, paragraph 2, line 6, read "firmer," for "former."
Page 37, paragraph 8, line 4, read "floods," for "freshet floods."
Page 38, paragraph 1, line 12, read "Thence," for "Hence."
Page 41, paragraph 3, line 7, read "into," for "in."
Page 42, paragraph 2, line 2, read "rise," for "raise."
Page 58, paragraph 7, line 8, read "range," for "change."
Page 59, paragraph 6, line 3, read "land," for "low-land."
Page 68, paragraph 2, line 4, read "quantity," for "quality."
Page 68, paragraph 2, line 6, read "from above," for "from the above."
Page 68, paragraph 2, line 7, read "prevent," for "present."
Page 69, paragraph 6, line 3, read "where," for "when."
Page 69, paragraph 8, line 1, read "water," for "waters."
Page 71, paragraph 8, line 8, read "when," for "where."
Page 74, paragraph 7, line 1, read "prevention," for "preservation."
Page 89, paragraph 4, line 1, read "the," for "in."
Page 91, paragraph 4, line 9, read "currents," for "contents."
Page 30, read "RISING OF RIVER BEDS," for "*Raising of river beds.*"

LETTER OF TRANSMITTAL.

SACRAMENTO, California, January 21st, 1880.

Hon. John Mansfield, President of the Senate, State of California:

SIR: I herewith submit Parts I and II of my official report to the Legislature, being a report on the "History of operations" conducted under my charge, and a report on the "Drainage of the valleys, and relief of rivers when in flood," referring particularly to the Sacramento Valley drainage, with an incidental treatment of the debris problem, and also to the drainage of the San Joaquin Valley, and the improvement of the navigation of the San Joaquin River.

Accompanying you will find a letter introductory to the entire report, and addressed to the Legislature.

I also transmit a communication from Col. G. H. Mendell, consulting Engineer.

Very respectfully,
Your obedient servant,
WM. HAM. HALL,
State Engineer.

INDORSEMENT OF CONSULTING ENGINEER.

SACRAMENTO, California, January 21st, 1880.

To the Legislature of the State of California:

I have been, throughout the history of the State Engineer Department, familiar with the character and scope of its field operations. I have also read the report of the State Engineer, so far as it has been prepared, and have consulted and agreed with him in regard to its main propositions.

When the remaining chapters of the report shall be completed, I expect to submit my views upon the general subject.

I am, very respectfully,
Your obedient servant,
G. H. MENDELL,
Consulting Engineer.

REPORT.

INTRODUCTION.

OFFICE OF THE STATE ENGINEER,
SACRAMENTO, January 10th, 1880.

To the Honorable the Senate and the Assembly of the State of California:

INUNDATIONS IN CALIFORNIA.

The submersible lands.

There are two valleys in California whose low lands have been and still in a great measure are subject to annual inundation. These are the Valleys of the Sacramento and the San Joaquin, the combined area of whose submersible lands situated north of Tulare Lake, excluding Tulare and Kern Valleys, may be stated at 2,750 square miles—a territory much larger than the State of Delaware.

The main drainage ways.

The Sacramento and San Joaquin Rivers are the great natural main drains of these valleys, respectively.

The Sacramento.

The Sacramento River brings down a formidable flood volume almost every year, inundates a large area of country, and seriously threatens with devastation several hundred thousands of acres of lands, now in a measure protected by levees.

The San Joaquin.

The San Joaquin is in correspondingly high flood only about once in four years, so that, as to frequency of danger of destructive flooding, the low lands of its valley are at an advantage over those of the Sacramento.

Comparative floodings.

Moreover, owing to causes to be hereafter discussed, the condition of affairs, with respect to actual and threatened inundations, is annually becoming more alarming in the Sacramento Valley; whereas, in the San Joaquin no such tendency is apparent—at least to a degree which at all compares with that in the northern valley. Thus the Sacramento Valley drainage problems appear to be the most important of those pressing for attention.

The opportunities had.

Since this Department was created there has been one fairly good season for flood observations in the Sacramento Valley, and these have

DRAINAGE OF THE VALLEYS

AND

THE IMPROVEMENT OF THE NAVIGATION OF RIVERS

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been made as narrated in Part I of this report. The San Joaquin River has not presented an ordinary high flood since the work of this Department was commenced, so that, although the groundwork for the study of this subject of drainage has been, in a great measure, laid in the San Joaquin Valley, I have not been able to secure the data concerning flood phenomena which are necessary for the discussion of this particular subject in that valley.

Other scenes of inundation.

There are other important localities in the State which occasionally suffer from uncontrolled flood waters, and which, though less extended in area, are justly entitled to consideration and attention from this Department, in order that the data may be collected and formulated upon which some plans might be projected for their protection, but it has not been possible thus far for me to take up any but the most important subjects. Hence the report under this general heading now presented is devoted almost exclusively to the Sacramento Valley problems.

CHAPTER I.

THE SACRAMENTO VALLEY DRAINAGE.

TOPOGRAPHICAL DESCRIPTION.

The Great Valley.

The Valleys of the Sacramento, San Joaquin, Tulare, and Kern have been jointly called the Great Valley of California.

There is, in fact, but the one well-defined depression between the Sierra Nevada and Coast Ranges of mountains, so that it is difficult to draw the line of boundary between the adjacent portions severally named as above, and most of all is the line between the Sacramento and San Joaquin Valley hard to designate.

Boundary of the Sacramento Valley.

For the purposes of this report, the course of the Cosumnes River down to and as continued after joining the Mokelumne and the San Joaquin Rivers, to Suisun Bay, is adopted as a convenient and approximately correct boundary; and all of the territory lying northward therefrom, between the foothills of the Sierra Nevada on the east and those of the Coast Range of mountains on the west, is regarded as the Sacramento Valley.

Dimensions of the valley.

Its greatest dimensions on a straight line—that following nearly its longitudinal axis—is about 150 miles in a course S. 13° E. from the Iron Cañon to the mouth of the Mokelumne River, and its greatest width at right angles to this line is 50 miles. For 95 miles of its length, from the southern boundary, it maintains a width of 40 to 50 miles, and thence narrows down to a point at its northern extremity.

Area of the valley.

The region thus bounded is about 4,769 square miles in area. The lands may be classified as shown in the following table, wherein the areas given are of course only approximately correct, though compiled with care from the best topographical information to be had at this time:

Classification of the lands of the valley, as naturally constituted.

Designation.	Area in Square Miles.
High hill lands—Marysville Buttes	55.50
Low hill or rolling lands, adjacent to the foothills of the mountains	650.00
Dry plains, above reach of all overflow	2,321.45
Dry plains, subject to occasional temporary overflow from the tributary streams	450.00
Lands covered by debris and subject to flooding; river bottom or marginal lands naturally subject to temporary shallow annual overflow; low basin lands, not tule swamp, naturally subject to deep annual flooding; low basin lands, tule swamps, naturally subject to protracted deep annual flooding; island swamp lands and other tule swamps, naturally subject to flooding by high tides	1,254.00
River, slough, and channel surface of perennial streams	38.05
Total	4,769.00

Drainage of the plains.

Of the pluvial waters which fall in the valley of the Sacramento, it may be said that in all, except seasons of extraordinary heavy rainfall, such as have occurred about once every ten years since the settlement of the State, they are absorbed by the soil, and do not contribute materially to the swelling of the waves of flood in the main river and its tributaries.

Lands flooded in 1879.

During the high water of March, 1879, the low lands of the Sacramento Valley, to the extent of about 847 square miles, were covered with water; this area includes all flooded for a short period of time, as well as that upon which the water rested for several months. Above the mouth of Feather River, in what may be called the upper flood region, the area covered was about 483 square miles; and below that point, in what is called the lower flood region, the flooded area was about 364 square miles in extent.

Swamp and overflowed lands.

There has been listed to the State by the General Government about 549,540 acres of land in the Sacramento Valley as swamp and overflowed lands. It will be seen that although large areas of land were protected from flooding during the March freshet of 1879, yet the lands actually covered with water were greater in area than the total acreage listed by the General Government as swamp and overflowed lands.

THE MOUNTAIN WATERSHEDS.

Area and character.

The mountain watersheds whose drainage systems are tributary to the Sacramento, are in combined area more than two and one-half times the superficies of the valley itself. Subjected to violent rains during the winter and early spring, these mountain basins send down flood volumes of considerable magnitude at such times, and the melting of snows on the higher regions cause other waves of flood-water to flow down the principal streams during the later spring months.

The Sierra Nevada slope.

The eastern side of the Sacramento Valley is flanked by the Sierra Nevada Mountains, whose slope, drained by the American, Bear, Yuba, and Feather Rivers, Butte, Chico, Rock, Deer, Mill, and Antelope Creeks, with other smaller streams, has an area of 8,298 square miles: in elevation rises 7,000 to 11,000 feet above the sea, and receives, in seasons of ordinarily heavy rainfall, from 24 to 102 inches of the waters of precipitation in the form of rain and snow.

The Coast Range slope.

Upon the west the Coast Range slope, drained by Putah, Cache, Oat, Cortero, Willow, Stony, Thomes, Elder, Red Bank, and Reed's Creeks, with numerous smaller streams, into the valley of the Sacramento, is 3,075 square miles in area. This region is much less elevated than the face of the sierra east of the valley, is generally subjected to less downfall of waters, but receiving these for the most part in the form of rain upon surfaces from which it rapidly sheds, the volumes of flood are quickly accumulated and delivered upon the plain.

The Sacramento River mountain basin.

Northward, from the two great mountain slopes spoken of, extends the drainage basin of the main Sacramento, with those of the tributaries which enter before it comes out upon the plains, and is situated between the crest of the Sierra Nevada on the east and the summit of the ridge, which, with Mount Shasta for a central object, forms the divide just south of the Trinity River basin, whose waters find their way through the Coast Range to the sea.

Area and character of the basin.

This region, comprising the sub-basins of Cottonwood Creek, Clear Creek, McCloud River, Bear Creek, Canoe, Stillwater, Cow, Battle, and other creeks, includes the whole of Shasta and parts of Siskiyou Counties, and is 5,616 square miles in area. It is a mountainous and hilly region, with intervening comparatively small valleys and plains, and in elevation ranges from 1,000 to 14,000 feet above the sea. The rainfall is almost always in excess of that received in any portion of the great basin to the south of it, ranging from 30 to 110 inches per annum.

The Pit River basin.

In addition to this, the upper Pit River, above the boundary of Shasta and Lassen Counties—the principal tributary of the upper Sacramento coming through the mountains from the high plains and ridges of Lassen County and Siskiyou, east of the sierra—is a stream of considerable magnitude at times. The drainage area of this stream cannot be stated with any pretension to accuracy, but probably is about 2,950 square miles. This region is not subjected to such heavy rainfall as that previously described, and it is likely that flood-waters rarely come from the two at the same time.

THE STREAMS AND FLOOD-WATERS OF THE VALLEY.

The streams.

The streams which enter the Sacramento Valley are all torrential in character—that is to say, they are subject to sudden freshets of considerable magnitude, but generally of short duration, caused by the immediate and rapid drainage of a large portion of the waters of rainfall from their mountain watersheds.

Periods of full flow.

These freshets come at intervals generally of greater spaces of time than the duration of any one period of full flow. The occasions are exceedingly rare when all of the streams are in high flood at the same time, or even in consequence of the same storm; and, ordinarily, the waters of one freshet should be well out of the valley before those of another come into it.

Freshets in the sierra streams from the east.

The freshets of greatest magnitude in the Sierra Nevada streams, which enter the valley from the east (the Feather and the American), and which are the larger tributaries, succeed the falling of warm rains, after the mountains have become covered with snow, thus causing sudden thaws in the snow-fields. Such an event only happens after the main stream through the valley has already been moderately high several times during the season from the effects of rain storms brought down by some of its tributaries.

Freshets from the northern streams.

The freshets of greatest magnitude from the mountain basins of the Sacramento and the tributaries which also enter the valley near its northern extremity, are produced by violent and sudden storms of rain, which ordinarily pass over the region of the tributaries farther south, as cold rains of short duration and less violence.

The two sources of flood-water.

There are, then, in general terms, two sources of high water in the valleys drained, each composed of a group of streams which we must expect to be in high flood simultaneously; and at the same time we must look for a moderate flood flow, in each instance, from the streams of the other group.

The ordinary high flood of the valley.

This combination of events produces what we may call the ordinary high flood wave of the lower valley—such as passes through the channel and over the low lands once, and perhaps twice, each winter or spring, except in seasons of drouth, occurring once or twice every ten years.

The extraordinary high flood of the valley.

When, after several moderate storms during a season, there occurs a violent and somewhat prolonged storm, or succession of rain storms, immediately followed by a quiet and warm rain, the snows melt on the mountains, and great volumes of flood-waters enter the valley from all the surrounding watersheds at the same time, and thus are produced the extraordinary floods which have occurred periodically about once every ten years in the past.

The low land basins—Temporary reservoirs.

The river channels, and more particularly the Sacramento, as the main drain of the valley, being insufficient in capacity for the immediate passage to the bay of ordinary floods, these waters have, for ages past, poured over its banks and been temporarily lodged in the low basins by which it is flanked for miles of its course, to be drained off after the passage of the flood-water proper.

The Sacramento as a water-carrying channel.

The river has always been one of poor regimen—great variation of capacity to pass the waves of flood through its different divisions—and its channel has always had serious local defects which have acted as obstructions to the passage of flood-waters. Thus, for 106 miles and more above the head of Butte Slough, there is a channel of *greater grade and greater dimensions than there is below*, all the way to the mouth of the Feather River, a distance of 64½ miles. And, again, the very shallow bars known as "Six-mile," "Haycock," "Hog's-back," "Iron House," and "Newtown" shoals, do not permit the free passage of the flood waves, as do the deeper and better formed reaches of the channel above and below them.

The Feather and auxiliary main drain.

Besides the Sacramento, the Feather is the only other river channel which acts as a main drain, and is in that capacity auxiliary to the Sacramento throughout the middle portion of its valley course, receiving and leading down the valley the waters of the Yuba and Bear Rivers, as well as those of other smaller streams, to the Sacramento, of which it is the largest affluent.

THE CAUSES FOR RECENT CHANGES IN THE VALLEY RIVERS.

Mining debris in the rivers.

These streams, the Feather, and the Sacramento below the junction of the two, have been greatly reduced in flood-carrying capacity by the lodgment of sand in their channels which has come down the rivers from the mining regions during the past 25 years or more. The presence of this sand in the waters and in the beds of the upper rivers, constitutes the present cause of the changes in the channels of the lower streams spoken of; but its precipitation and retention in the last mentioned channels have been greatly increased by other causes, which are now to be mentioned.

A defective levee system.

The attempts which have been made to keep the flood-waters off the swamp and basin lands by the construction of levees, have not been conducted according to any uniform plan, or upon any system which could be generally successful. The result has been in a measure satisfactory to the projectors of these works at some points, or in some localities, at the expense, however, of others, and even a larger territory, where failure, partial or complete, is apparent. By this unequal treatment the natural order of things, with respect to the regimen of the stream, has been interfered with in a measure to still further impair the even capacity of the channel in the several succeeding divisions of its course, to pass the waters which are brought to it.

The Sacramento—Its natural condition.

In the natural state of the stream the waters of the Sacramento River, at times of ordinary flood, just overtopped the banks—thus spreading in small quantities in innumerable places along its course—and found vent into the basins (without that material sudden checking of the current which must happen when a large quantity of water is diverted at one place), and the banks were gradually and uniformly built up by the annual deposit of sediment thereon.

Effect of crevasses.

The construction of levees stopped the general escape of waters in the manner described, and they are now confined, for comparatively long distances, and then escape in large volume through crevasses or breaks which occur annually, or are left open from year to year. New divisions of the stream into two streams, as it were, are thus formed at many points, and, as a result of such division of waters, the regimen of the main channel is disturbed, and its flood-carrying capacity diminished by the shoaling which takes place below each point of division, while the increased scouring power which should be acquired by concentration of the water is nullified in effect by the irregularity of the flow caused by the considerable local losses of water through the crevasses.

Effect of faulty leveeing.

The faulty location of levees, with respect to the proper training of the current and to the shape or trend of the channel, as well as with regard to the width or space between those on the opposite banks of the river, has restricted the effectual water space unequally in succeeding reaches of the river, and, producing inequalities in the movement of the flood-waters, by causing eddies, whirls, and bars, has resulted in an elevation in the flood line, while the increased scouring capacity which should be acquired by the concentration of floods between banks has been locally nullified by this increased irregularity of flow.

Cut-offs in an upper division of the river.

Certain cut-offs which have occurred during late years in the upper portion of the middle division of the river, between Colusa and Chico Creek, while they have hastened the drainage of the river above them, have had a bad effect upon the general regimen of the river, by hurrying the waves of flood down upon the division below, which was already of comparatively small capacity.

No treatment of the river as a drain.

Thus, in reviewing the situation, we find that, while the works undertaken by individuals or combinations of individuals into districts—each striving for his or their own local interest—have tended to diminish the efficiency of the stream, nothing whatever has been done toward the general treatment of the river as a flood-carrying channel, a drain in the preservation and improvement of which all have a common interest.

MINING DETRITUS AND THE VALLEY RIVERS.

Intimate connection of the subjects.

The connection between these drainage questions and the "debris problem" is so intimate, and the satisfactory settlement of the former depends so much upon an engineering solution of the latter, that it may seem proper here to discuss this last mentioned subject, and elucidate whatever conclusions may be arrived at concerning it. But this would necessitate a long and not altogether relevant digression from the main object of this particular portion of my report. Moreover, it is a subject worthy of special consideration, and will be treated in a separate paper under the title of "The Debris Problem." Meantime, so far as this question affects the river problems, I now announce certain primary conclusions respecting it, and ask attention to Part III of this report, for a more detailed consideration, based upon such data as I have thus far been able to secure.

Improvement of the natural drainage lines.

Taking the streams through the valley in the condition in which their channels now are, it is within the scope of engineering work not only to restore them to their former comparatively good condition, but to make them capable of carrying away a very much greater, momentary volume of water than they have ever been able to provide for; and this end can be attained, and the improved channel maintained, it is believed, at an expenditure of money by no means out of proportion to the benefits which will result from it, and the dangers to be warded off.

The sand-flow from the mountains.

But this cannot be accomplished at reasonable cost on the lower rivers if the supply of sand, annually brought down from the cañons above by the eastern tributaries, and liable to be brought down upon the occurrence of one of the periodical extraordinary large floods, remains undiminished.

Reservoirs of sands.

The Feather River (below the mountains) and its main tributaries, as well as the American River, in their several courses through the valley itself, the main cañons of these larger streams (except the Feather) for considerable distances within the foothills and at points well up in the mountains, and many of the side ravines tributary to all these main cañons, are now vast reservoirs of detritus, whence will come for years in the future, with each wave of flood-water, a volume of sand calculated not only to maintain the lower Sacramento River in its present condition of deficient carrying capacity, but to further impair its efficiency in that respect.

Arrest the sand-flow where now reservoired.

It is within the range of engineering work to check the flow of sand from the upper rivers to a great extent, and to ward off the danger which exists from the presence of this material where it is in position to be brought down in large quantities from the mountains and foothill cañons, by the construction of dams and the placing of other obstructions in its way, and thus causing its lodgment and retention in the cañons; and this can be done in a rude, but effectual manner, gradually, as circumstances require, and, it is believed, at a cost not inconsistent with the dangers warded off and the measure of damages averted.

Prevent the sands from entering the cañons.

The more material that is put into the cañons, however, the more expensive will be the work of restraining the flow of sands into the valley rivers; and hence, it is most important that washings from the mines should be reservoired otherwise than in the main cañons, if possible. It is believed that this can be done with respect to the most injurious materials, the sands and a portion of the finer sediment, in a number of cases at least, by dumping only the gravel and stones into the cañons, and conveying the mud-laden waters, with the sands, to settling reservoirs. The possibility and cost of doing this can only be determined, in each case, by a special engineering examination of the property and the surrounding country. These examinations it has been beyond my power yet to make.

Divert low water-flow of streams at foothills.

More than this, further to do away with the evils which may arise from the continued running of mud-charged waters into the rivers, it is possible to divert the low water flow of the streams which come from the mining regions (except the Feather River) at or near the points where they emerge from the foothills, and to conduct their waters to settling reservoirs upon the rolling lands which border the foothills, whence they could be used for irrigation or returned to the natural channel after clearing; and this, it is believed, can be done at an expense not inconsistent with the direct benefits derived and the dangers averted.

Divert sands into the basins.

And still again, it is possible to divert a large portion of the water and sediment of several of the more heavily charged rivers, notably the American and the Bear, not only at low but at comparatively high stages also; into the low sinks or basins of swamp lands, and there cause the deposit of the material which injures the river channels. Without doubt this can be done very much to the benefit of the lower streams, and certainly to the advantage of the low lands covered in the future.

THE POSSIBILITIES IN THE DRAINAGE OF THE VALLEY.

Rapid drainage in the valleys, and the debris problem.

The success of these works assured, it becomes possible, as heretofore asserted, permanently to greatly improve the lower rivers; but this can only be accomplished, with any considerable degree of satisfaction, by an uniformly thorough treatment of them as water-carrying channels throughout their several courses, according to one broad design, executed in all and each of its parts when and in what manner the phenomena in nature developed make its prosecution necessary.

What may be expected from a successful system of works.

By a proper system of works and a wise government of them we may expect to reclaim the swamp and basin lands of the valley from overflow by the waters of ordinary floods, and to raise the lowest swamp depressions so as to render them susceptible of cultivation in the future, by the deposit thereon of a portion of the sediment which the rivers each year must bring down. We may expect, also, permanently to shelter the cities of the valley from inundation, and to render the main streams navigable in a greater degree than they ever have been.

Great inundations.

But let it also be remembered that these remarks apply, as heretofore described, to the case where we deal with the ordinary floods of the valley, for no limit can be assigned to the amount of water which may at some time in the future come down this valley: and, as in the past there have been phenomenal inundations, now spoken of as "the flood of '62," "the flood of '52," etc., so may there yet be others as great or greater than they, against the general spread of which no human foresight can provide, nor secure protection for the great body of the lands in the valley. Of course, limited tracts, such as the sites of cities and towns, can be raised to elevations or protected by embankments over which, in all probability, no flood-water will ever reach. Yet even these are safe only in comparison with other lands less elevated or less securely protected.

Great floods must spread.

Dupuit, a writer of repute on river phenomena and the science of hydraulics, has quaintly remarked that levees may be divided into two classes, to wit.: submersible and insubmersible levees. The first are those which have been overtopped by former floods; the latter differ from the former only in being less frequently submerged in the past, or are awaiting submergence by a larger flood yet to come in the future. And so it should be fully understood that floods will occasionally come which must be allowed to spread. But we may guard greatly against their ravages by a proper system of works; and, with prosperity and plenty for nineteen years, a rich and populous section should be able to afford to be submerged on the twentieth; and, moreover, should be prepared for it, so that the protective works would not be injured, and the lands overflowed would be benefited rather than otherwise.

THE PRESENT CONDITION OF THE SACRAMENTO RIVER.

The divisions of the river.

For the purpose of a preliminary consideration of the regimen of the Sacramento River, it may be set out in nine divisions, each of which embraces a portion of the channel commencing and ending at points where, when in flood, it naturally receives an important tributary, parts with a material portion of its waters through an outlet channel, divides distinctly into two streams, or again unites into one.

Relative capacity of the divisions.

Thus each represents a portion of the great drain subjected to a task somewhat uniform throughout its length, in carrying away the waves of flood-water; and each succeeding division in the series down the valley should be of capacity sufficient promptly to pass onward, or hold in reserve within itself, the waters brought to it.

A cursory review of the field.

I commence at once a cursory consideration of the field from the point of view of individual and relative capacity of the several and succeeding divisions of the river's channel.

FIRST DIVISION.

From the Iron Cañon to Stony Creek, a distance of 58 miles, the Sacramento receives many small tributaries. It is for the greater portion of the distance bordered by a narrow strip of bottom land, which at times of ordinary high flood flow, is covered with water.

Floods in the First Division.

The escape of water from the main channel in this division (until within five or six miles of its lower end) does not contribute to any wide spread inundations of lands below; for throughout the course (with the exception just mentioned) the bottom lands are bordered by plains or rolling lands lying above the elevation of flood-waters in the main stream.

Character of flood-waters in First Division.

Thus until below the mouth of Chico Creek on the east bank, where we have the exception mentioned above, all the waters escaping from the main channel within the first division return to that channel almost immediately, or are led along parallel with and near to it, through subsidiary channels and bottom land depressions, for short distances, without effecting great damage, or long depriving the proprietors of the use of their lands; for the duration of floods seldom exceeds two days in the upper part, and four days in the lower part of the region considered.

SECOND DIVISION.

From Stony Creek to Butte Slough—a distance of 53 miles—the Sacramento does not receive a single tributary, but is flanked on each side by lands depressed one to ten feet below the immediate banks; the line of lowest depression being from two to seven miles away from the river channel.

Floods in the Second Division.

The disastrous and wide-spreading overflow of the valley commences near the head of this division—just below Chico Creek on the east and Stony Creek on the west side of the river—so that the great work of handling the waters that come down must begin here for the protection of lands situated many miles below, as will be more fully explained hereafter.

Character of channel and banks.

The waters which enter the head of this division of the river, including those of Stony Creek, constitute all that are presented for passage onward to the head of the next division, there not being any tributaries below Stony Creek. The channel has not thus far shown itself of capacity sufficient to accommodate the ordinary high floods' waves, the waters of which were wont, in part, to leave the river and its fringes of bottom lands and escape into the basins heretofore referred to. The channel itself is exceedingly irregular in width and depth throughout this division—more so than in any other portion of its course. The banks generally are inclined to cave down, but on each side of the strip of bottom land, which is a mile or two in width and through which the main channel meanders, there is a line of hard bank land.

Alignment of channel cut-offs.

The alignment of the channel is exceedingly irregular, and at many places constantly changing; cut-offs occur sometimes naturally, and can be readily caused artificially. The channel, however, is already on much greater grade and of larger dimensions than that of the division below; the natural grade of the country is greater, and the soil, for the most part, admits of active scouring effect and the rapid formation of a larger cross section than already exists.

Leveeing in the Second Division.

The construction of levees, which are generally set back on the hard rim lands in this division, has for the most part prevented the overflow of waters into Colusa basin on the west, but the great line of escape into the head of the Butte basin on the east, near its upper end, and into the lower portion of the same basin from near the lower end of the division, is still open to the waters of ordinary high floods, although for many miles the direct overflow eastward is also prevented by levees throughout the middle portion of the division.

Butte Slough.

Butte Slough, at the lower end of this division, is a large escape channel for flood-waters into the lower end of the Butte basin above it, and the upper end of the Sutter basin below it, on the east side. Attempts have been made to close this slough and keep it closed by means of earthwork embankments and timber structures; but either from the flood force alone, or the action of persons opposed to the closure, who have on occasions destroyed the works, these efforts so far have failed.

Drainage from the east.

The waters from Butte and Table Mountain Creeks, streams from the mountains on the east, flow into the Butte basin, and are led through that and the Sutter basin to the river far below. These waters come so near entering the river in the lower portion of this division, that they may be regarded as of a right tributary thereto.

Drainage from the west.

The drainage from the Coast Range, brought down by numerous small creeks opposite this division of the river, spread into the Colusa basin, generally from 5 to 15 miles away, and gravitate towards the lower end of the next division below.

THIRD DIVISION.

From Butte Slough to Sycamore Slough, at Knight's Landing, a distance of 49.8 miles, as in the second division. There are not in this any tributaries, and low land basins flank the river on each side, generally three to seven miles away, and five to fifteen feet below the elevation of the banks.

Character of the channel.

Here we have a contracted, but deep channel, and for the most part an exceedingly crooked one, with banks generally very firm and not inclined to cave. The irregular and oftentimes grotesque alignment of the banks results in bad eddies, whirls, and water dams at time of flood, and thus seriously impedes the flow of the waters, so that what is termed "bend resistance" is in this division at a maximum.

Fall and shape of channels.

The longitudinal fall of the river and of the country is less throughout this division than in the one above; the channel is materially smaller in dimension, but more even in cross sectional form than in the preceding division, there being no shoalwater bars, except in one limited locality, between Grand Island Mills and Wilkins' Slough, where some comparatively wide and shallow places exist.

Slope back into basins.

Along this portion of the river the surface of the ground generally falls rapidly away from the banks back toward the low basins, the fall frequently being as much as 12 feet in 1,000 feet. This is particularly the case on the east bank, and at places opposite to the points or bends which extend toward the east.

Prospect of cut-offs.

Although the very crooked channel presents many points where cut-offs might be looked for from natural action, yet the firmness of the soil, consolidated and protected by plant growth along the banks, seems to have prevented any occurrence of the sort for a long time in the past, and there are no indications of material natural changes of this kind for the near future.

Deficient capacity.

Throughout this portion of its course the channel, as compared to that in the division above, is very deficient in capacity. It does not carry on the average more than half the water brought to it in time of ordinary high flood, the remainder escaping through Butte Slough and certain crevasses into the Sutter basin on the east, and occasionally rupturing the levee on the west, in its endeavor to flow into the Colusa basin.

Leveeing in the Third Division.

Levees have been pretty generally built throughout this division, and owing to the considerable fall in the ground's surface back from the river, they are located close to the banks, sometimes as close as they can be built, to save the elevation in construction. The levee on the west bank is generally a very good structure, and located with more judgment—further from the bank—than that on the east, which latter, with the exception of the upper four and five-tenths miles protecting Swamp Land District Number Seventy, is an irregular and weak embankment, often not over two to three feet high, and indeed near the lower end of the division it can be hardly said that there are any levees at all on the east side. It is understood, however, that these levees have been raised generally a foot since examination of them was made by this department. Two large outlet channels—Upper Sycamore and Wilkins' Sloughs—have been closed by the works connected with the system of levees on the west side.

Drainage from the east.

There are not any tributary streams which approach the Sacramento from the east in this division, all the mountain drainage from that direction being intercepted by the Feather River, and carried on down the valley to a lower point of joining. The Sutter basin lies between the two streams: each thus act for this portion of the valley as a main drain.

Sycamore Slough.

As in the next upper division, all drainage from the west is intercepted by the Colusa basin. The outfall of this basin is naturally Lower Sycamore Slough, into the river just above Knight's Landing. When the river is in ordinary flood there is no drainage way for this basin, for the flood elevation at the lower end of the drain is 13 feet

above the general elevation of the bottom of the basin, nine miles up the valley. The levee and works connected therewith now prevent this back flow of water, so that the creek waters from the Coast Range rest in the basin until the subsidence of the river flood, when they are drained away.

Drainage from the west.

But if the Colusa basin is to be kept entirely free from water, it will be necessary, in addition to keeping the waters out of it from the river, to intercept the flood flow of the Coast Range streams which now drain into it, and carry their waters to the river at some point at a sufficient elevation to give them free outfall into the river at all stages of the waters thereof. The Knight's Landing ridge is the natural site for the entrance of such a tributary; hence the commencement of a new division at this point.

FOURTH DIVISION.

From the mouth of Sycamore Slough, at Knight's Landing, to the mouth of Feather River, 14.8 miles in distance by the river, but only 5.5 miles in a straight line, there are no tributaries, and low land basins flank the river on either side—the lower end of Sutter basin being on the left and north, and the upper end of the Yolo basin on the right and south.

Character of the channel.

The channel here presents an aggravated case of the disease with which it is afflicted in the preceding division—an extreme contraction and contortion of its waterway. The cross sectional form is good and nearly uniform, there being but one shoal, which is at Knight's Landing, immediately at the head of the division. The banks are firm, and generally densely overgrown with trees and shrubbery, which prevents erosion and the formation of cut-offs, for the opportunities are so favorable for these that doubtless they would occur but for this protection to the narrow isthmuses which separate succeeding reaches of the channel. The slope in this division is reduced considerably by the filling that has taken place at the mouth of the Feather.

Leveeing in the Fourth Division.

The levees in this division are generally very poor, although some lands on the south side at the head of the Yolo basin are protected from immediate flooding by fairly good embankments. On this side, however, a large crevasse exists, through which the water pours each year, and other breaks occur almost annually; while on the opposite side the floods move at will over the bank, back and forth, out and into the Sutter basin.

FIFTH DIVISION.

From the mouth of the Feather River to the mouth of the American River, a distance of 19.7 miles, there are no tributaries, and the river is flanked by the Yolo basin on the west and the American on the east. In addition to the waters of the Sacramento proper, those of the Feather and its tributaries are presented at the head of this division.

Character of the channel.

The channel has a good width, an average of nearly three times that through the two preceding divisions, and previous to the general silting up which has occurred below the mouth of Feather River during recent years, it maintained a good depth and cross sectional form, except at one or two places, notably at the "Six Mile" Shoals, above Sacramento, where there has always existed, so far as is known, a wide and shallow reach. Now, notwithstanding the changes alluded to, the river is a better one to deal with in this division than in the two preceding, for with its considerable width it still maintains a fair depth, though its general capacity is, under present circumstances, greatly decreased from what it formerly must have been.

Alignment of the channel.

Through this division the river is not a crooked one, though two sudden changes of direction exist, to the detriment of its maintenance free from eddies and bars. The banks do not cave down, and are generally protected by a fringe of willows. There are no places where cut-offs are in the least likely to occur, for the channel does not double around upon itself, as it does above the mouth of Feather River; moreover, the slope in this division is already considerably greater than in the one preceding.

Leveeing in the Fifth Division.

The surface of the ground falls rapidly back toward the low land basins, from the river, hence we find levees, as in the third division, placed near the banks. With the exception of the division from Knight's Landing to the mouth of the Feather, the leveeing in the division now being considered is the most uneven in construction and effect of any along the river. For 6.5 miles from the upper end on the east bank the continuation of the Feather River levee is fairly good, and under present circumstances protects a strip of land behind it from overflow by the waters of any ordinary high flood. Thence on down there is no levee worthy of mention on the east bank, and flood-waters flow through deep cuts into the American basin. On the west bank the levee is very good at places for several miles; generally it is sufficient for three-fourths of the distance, under present circumstances; but a number of large crevasses exist, through which the flood-waters pour in large volume into the Yolo basin.

SIXTH DIVISION.

From the mouth of American River to the head of Grand Island, a distance of 27.7 miles, there are no tributaries, and the river is still flanked by two basins, the Yolo on the west, and the Sacramento and Mokelumne basins on the east. The waters of the American River are presented to this division at its head, in addition to those brought to the foot of the division above through the river channel itself, and through the American basin, which here empties into the river, the waters which escape from it on the east above, together with water drained from the mountains between the American and Bear Rivers, brought down by Auburn Ravine and other similar streams. These are the last waters tributary to the river on the east bank.

Character of the channel.

This division of the river closely resembles the fifth, but the channel for the upper portion of its course is somewhat more crooked and less even in width and depth. Local bars exist, as for instance the Haycock Shoal—a serious obstruction to the flood flow. There are no localities where cut-offs might occur, as the channel does not persue a tortuous course; and the banks, as a general thing, resist the undermining action of the current, so that considerable changes of alignment are not to be expected.

Flood capacity of the channel.

As in the preceding division, the general flood capacity of this portion of the river has been much diminished of late years by the deposit of sand therein, which has filled the deeper reaches in an astonishing degree, and raised the shoal places or bars, so that now there is not any more, if as much water, as there used to be on them, though the general plane of the water surface has been raised several feet.

Leveeing in the Sixth Division.

The surface of the ground generally falls away from the river, so that levees have been located near to the banks. Here are to be found some of the best levees along the river. That on the east bank is rarely breached, and is more nearly uniform in disposition and construction than any similar piece of levee of the same length in the valley, excepting, perhaps, that on the west side of the river above Knight's Landing to Colusa, and that around Grand Island. On the west bank, though fairly good levees exist at notable places, sometimes for several miles in length, the structure as a whole through this division is very defective, for there are long distances where it is slight and of uneven disposition and construction.

Flood slope.

At the upper end the flood slope in this division is somewhat greater than in that above next preceding, owing to the receipt of the tributary waters of the American River and basin, but towards the lower end this slope is materially decreased in approaching the point of bifurcation, in the next division at the head of Grand Island.

SEVENTH DIVISION.

From the head to the foot of Grand Island, a distance of 18.28 miles by one route, and 11.9 miles by the other, the river runs through two channels, called Steamboat Slough and Old River, respectively. A few years ago Steamboat Slough was the deepest and probably the most capacious of the two, seeing that it is 6.38 miles shorter than the other, and consequently has the greater grade, and its cross sectional dimensions were probably as considerable and more regular. Now, however, it is found much filled with sand, and its flood-carrying capacity in a great measure destroyed, for during the past season, at time of flood, it carried only half as much water as did Old River, which is not in much better condition than it was years ago.

Steamboat Slough.

Steamboat Slough is somewhat crooked for 4.5 miles of its course, at the upper end, but it is a well aligned channel thence on down. The entrance to it is very badly disposed, being narrow and sharply defined at right angles to the general course of the main stream. It gradually increases in width after the first 4.5 miles of its course, so that for the lower seven miles it is more than twice as wide as it is above. And so we find it shallow, and becoming more so, for the sands drawn in at the head are deposited, when the current slacks, in the wider reaches below, and a dam is thus formed against all material and water entering above. Other possible causes for this rapid shoaling will be adverted to elsewhere. The Hogs-back Shoal—a very shallow place—has always interfered with navigation and been an obstruction to flood flow in this channel, and it is now as bad or worse than ever. The south bank of Steamboat Slough is generally very good and firm, but that on the north is for the most part low and swampy. No caving, however, has ever occurred worthy of mention.

Old River.

The Old River channel has improved somewhat since the rapid silting up of Steamboat Slough commenced. Near its head is a channel of good form, but for the lower 6.5 miles of its course it is wide and shallow. Generally it is well aligned, though one or two bends exist, which are doubtless material obstructions to the flood flow; but these could not be cut off, even if it were desirable to do so. Georgiana Slough is an outlet from this channel into the Mokelumne and San Joaquin Rivers, and at time of flood carries a material portion of the Sacramento waters altogether out of the river. The banks of Old River are generally firm, but towards the lower end the first soft swamp banks are found. There has not been any caving, however, of moment, except at one limited point where protective works have been resorted to with success.

Leveeing in the Seventh Division.

Around Grand Island there is a good levee except on the Steamboat Slough face near the lower end, where it was badly damaged by the flood of 1878. On the north side of Steamboat Slough there is no levee worthy of mention. On the south and east side of Old River a fairly good levee, which has done good service, exists, particularly throughout the upper portion of the division. These levees are all as close to the river bank as they could be built; placed so, probably, because the highest and firmest land was there found, and consequently the cost of construction reduced, and because a saving was thereby effected in tillable land to the owners of the property.

Grade and capacity.

With respect to the river above, the Steamboat Slough has a much greater grade, and the grade of the Old River channel is somewhat greater, also, through the upper portion of its course. Hence we find, at the head of Grand Island, a hump in the flood profile of the river. The two channels, as they exist, are not of sufficient capacity to carry away the floods which could be brought to them from above by the main channel as it exists; but this main channel is shoaling for some distance above the point of division, so that it is being adjusted to the decreased capacity below, and this effect will, of course, gradually work on up the river. There can be no doubt that the levees in this division, particularly at the head of Grand Island, should have been

set further back to make way for ordinary floods, though their present position cannot be made altogether accountable for the shoaling which is going on above the point of bifurcation.

EIGHTH DIVISION.

From Grand Island to the point of junction with the San Joaquin River, opposite Collinsville, a distance of 15.8 miles, the river flows in one channel, except in the short distance opposite Rio Vista, where Wood Island makes a division of somewhat more than a mile. The waters brought down by the Old River and Steamboat Slough channels unite at this division, as also those brought down the Yolo basin, west of the river, from the overflow of the Sacramento on that side below Knight's Landing, and from the floods of Cache, Putah, and other creeks, which drain the Coast Range on the west. Thus, should the Cache Slough, which drains the Yolo basin, deliver as much water at its mouth as escapes from the Sacramento above at the time of maximum flood, the channel through this eighth division would be doing full duty, under present circumstances, in carrying it. These are the last waters tributary to the Sacramento.

Character of the channel.

The channel in this division is generally of good alignment; but it is very uneven in width and depth, with one notably narrow point, and another wide and shallow reach, both of which changes are material obstructions to the flood flow. The banks are for the most part low, and, comparatively speaking, swampy, with the exception of where the river sweeps close to the high and firm upland, which it does at several points on the northern side.

Leveeing in the Eighth Division.

On the south side of the river there is a levee throughout this division, which has been found generally efficient, where constructed high enough. It is still, comparatively speaking, a low levee, and has been overtopped on several occasions, to be referred to hereafter. On the north side there is no levee of importance, and the marsh land is quite low.

Capacity of the Eighth Division.

Generally, the river in this division is a very large one. Compared to the channel at any point above, it is more nearly proportioned to the duty it would have to perform were all the waters confined to one channel, and more easily improved in flood carrying capacity than any other division, for the obstructions here are purely local, and of a character easily removed.

NINTH DIVISION.

From Collinsville to Suisun Bay the Sacramento is in one channel with the San Joaquin River. This is a wide, open estuary, and it is difficult to say where the river ends and the bay begins. The shores are salt marsh; tidal action is here at its full, both at low and high water stages of the river. Shoals exist, one notably opposite Collinsville, just at the point of junction of the two streams; and this shoal is an obstruction to the escape of flood-waters from the Sacramento

River. Further than this the ninth division of the river has not been examined by this Department. It was in part re-sounded by the Coast Survey in 1879, but the results of this work have not been secured for study in time to be considered in this part of my report, and will be considered hereafter.

LEADING DEFECTS OF THE SACRAMENTO RIVER.

The river deficient in capacity.

After this examination of the river throughout its valley course, if we glance over the field we find a channel which, in its present condition, is not, in any one single division of its course, capable of affording passage to the maximum volume of the ordinary high floods of the valley as they would be presented to it if confined between banks with levees all brought to a height uniform with the average of those which now exist in the several divisions, and in most divisions, even if the levees were brought to a height uniform with the highest that exist.

Defective divisions.

We find, moreover, several divisions of small capacity, generally, throughout their length; as for instance the third and fourth, from Butte Slough to the mouth of Feather River, deficient in grade and width, and suffering from excessive bend resistance, thus diminishing the flood flow by reason of its tortuous course. And again, the upper end of the seventh and the lower end of the eighth division, where the river is restricted in capacity by the effect of the division of its waters at Grand Island, and the construction of levees close up to the banks of streams already too narrow. It should be understood that these remarks, although true to a certain extent as applicable to the past and present, are especially meant to apply should the attempt be made to run the channels up to their maximum capacity by an uniform system of leveeing.

Local obstructions.

And still again, we find serious local obstructions of long standing in certain divisions, as, for instance, the Six-mile Shoal in the fifth division; the Haycock Shoal in the sixth; the Hogs-back in the seventh; the Newport Shoal in the eighth; and the Collinsville Shoal in the ninth division.

The question of capacity.

Hence we are to conclude that before providing for that portion of the waters of ordinary floods which the river is not generally now in a condition to carry there are certain special defects of its channel to be rectified, in order that it may work as a drain up to an uniform standard of efficiency throughout its course, and then the question of disposal of surplus waters will come up on its merits. Shall this channel be made large enough to carry these waters, or shall it be supplemented by other lines of escape?

THE FLOODS OF THE VALLEY.

Designation of the flood region.

As there are in the Sacramento Valley two great sources of flood

waters, as heretofore explained, so are there two great seats of overflow, one above the mouth of Feather River, in which the Colusa, Butte, and Sutter basins are specially involved, and one below Feather River, in which the Yolo and American basins, and all lands bordering the river from Sacramento to the foot of Grand Island, are threatened. The first may be called the upper valley flood, and the second the lower valley flood.

The upper valley flood region.

The upper valley flood may be occasioned under existing circumstances altogether by waters from northern streams. It is due directly to an insufficient capacity of the river in the second and third divisions of its course, from Stony Creek to Knight's Landing, and, indirectly, of course, to insufficient capacity in the divisions below. Or a partial flood may be occasioned in this upper valley by high water in the Feather River alone, when the greater part of the Sutter basin would be submerged by back water, principally entering near the lower end. Such a flood would be due directly to an insufficient capacity in the Feather River, below the mouth of the Yuba, and in the Sacramento fifth division, from the mouth of Feather River to the mouth of the American, and indirectly to deficient capacity in the Sacramento division below.

The lower valley flood region.

The lower valley flood may be occasioned alone by the waters of Sierra streams—the Feather and its tributaries and the American River; that is to say, there may be more water presented to the Sacramento River by these streams when the upper Sacramento is only at its ordinary winter stages than it is now capable of carrying through its fifth, sixth, and seventh divisions, without submerging the American and Yolo basins, even if existing deep gaps in the levees and banks were closed and no water escape until it overtopped existing levees at some points; though, of course, the American basin would be partly submerged by backwater from its lower end, where there is no levee at all.

Interdependence of floods.

A lower valley flood may, then, be almost entirely independent of one in the upper valley, though, of course, this is not generally the case; and furthermore, an upper valley flood might occur if the general overflow was produced by the waters of the Sacramento, while the Feather remained low, without occasioning a flood in the lower valley, if existing gaps were closed, though, of course, as in the previous case, the American basin would be partly filled by backwater; for the channel below the mouth of Feather River is of sufficient capacity to carry the maximum quantity of water which would reach it, under these circumstances, from an ordinary upper river flood-wave.

The highest flood source.

Though, as things now are, the American and Yolo basins ordinarily receive large volumes of water through existing crevasses, before the greater volumes come from the upper valley, the ordinary high flood-waters, so called, in the river below the Feather, as well as above it, generally come from the northern streams—the Upper Sacramento and its tributaries—the most distant source of supply, whose maximum flow arrives at the head of the lower valley flood region from 30 to 40 hours later than those from the eastern streams.

The delta islands.

In addition to these two primary seats of inundation and threatened flooding, there are the low islands below the seventh division of the river, which might not be endangered, if evenly leveed throughout, though there were overflow in the flood regions up the valley. Particularly, under existing circumstances, in the seventh division of the river, might there be inundation of considerable magnitude in the upper flood region, involving also the American basin, and threatening all lands east and west of the river below the American, without precipitating a volume into the river below Grand Island, which it could not carry if the overflow into the Yolo basin was prevented. This will be more fully explained hereafter.

EFFECT OF LOW LAND BASINS.

Deceptive appearances of floods.

In the present condition of the river and adjacent country, the ordinary floods seem much more formidable than they really are. They spread over a wide area, and make a great appearance of water, but were it all confined to a channel, and made to pass off as rapidly as it came down—not allowed to accumulate in the low basins from one freshet to another—the aspect would be quite different.

Escape of waters from the channel.

These basins become partly filled by the first freshets of the season, whose waters escape through deep crevasses and sloughs into them.

Effect of the early freshets.

The early freshets bring down a vast amount of sediment—light sand and earth and clay—from the eastern rivers. Instead of carrying this material on through to the outfall of the river, a portion of their waters escape into the basins described, and the sands are deposited in the main river channel. Thus the first and moderate freshets, which could easily be carried away between the banks of the river as they exist (provided that the crevasses and sloughs were closed), and which might carry away not only their own sediment, but clear out the channel also, if they were confined to a channel of good regimen, serve to deposit more material in the main channel, and to fill with water the basins of relief.

The basins not the relief they appear to be.

When the later and higher freshets of the season come, their first waters also find vent in the basins, and spreading over those already there, raise still higher the wide expanse that looks so formidable. Thus when the highest flood wave comes—the only one, generally, which is in great excess over the general capacity of the river to transmit—the basins of relief are already filled to near the flood mark, and the waters running in every direction—into the river at some points and out of it at others—and driven about by the winds, make a great appearance of a big flood, which is not due to the real volume of water which should be passing down the valley at that time.

Deposit of the early freshets.

And furthermore, this highest flood wave of the season finds the channel bed in the lower rivers raised by the deposits of the earlier freshets, as before described, and is forced to cut up and take away material which should not be in its way. Thus in the higher freshets, generally the last of the season, the bottom of the lower rivers is swept out, but not in time to prevent this extra material which has been deposited by the earlier waters from causing the higher floods to rise still higher than they would have done if they had none but their own sediments to push along with them.

Condition of the drainage system.

Here, then, we have the picture of the abnormal condition of things which exist in the Sacramento Valley; a condition which is annually growing worse, instead of better. The deep cuts or crevasses out from the river are becoming more decided, thereby diverting more water, causing more uneven flow in the main channel, and a corresponding shoaling thereof at points which would not take place if the channel were forced to carry all that it could carry, and none were diverted at any one point, except in small quantity, where the channel was full and unable to carry all the water brought down.

FEATHER RIVER BEFORE THE ERA OF MINING.

The channel in 1848.

The channel of Feather River has been subjected to such considerable changes during the last 10 or 15 years, that a description of its present condition would not convey a just idea of the real character of the river. It was, in 1848, a clear-water river, with a well defined high bank channel. It left the mountains in a rocky bed, and ran alternately over short cobble-bottom rapids, where, at low water, but one (1) or two (2) feet of depth was found, and through pools of several miles in length, sometimes with water 10 to 25 feet in depth at the lowest stages. This character continued to near the point of entrance of the Yuba, from whence, on down, fine gravel and sandbars appeared in place of those coarser materials, with long reaches intervening where the water was from 8 to 15 feet deep, on the average, at its lowest stages, but becoming less deep, and sand only appearing on the bars, as it approached the Sacramento.

Bottom lands above the Yuba.

A bottom land of sandy alluvial soil, varied, particularly on the east bank, by a rich, light brown surface wash from the hills, brought down by the Honcut and other smaller streams, extends from a point about five miles below the foothills to within about the same distance of the mouth of the Yuba, and was generally, in the early years of settlement, above the reach of all ordinary flood waters.

High land plains above the Yuba—east side.

The plains from the foothills, on the east, slope rapidly toward the river, and there is not any outlying depression, except the Wyandotte Valley, tributary to the Honcut, which still has quite sufficient slope to the river for purposes of good drainage.

West side.

On the west a high, plain ridge extends parallel to the river's general course, and about one or two miles away from it, for about ten miles below the foothills. Thence on down the plain lands slope from the edge of the river bottom land away to the west and toward the basins which border the Sacramento River, for the most part 15 to 20 miles away.

Mouth of the Yuba—site of Yuba City.

The Yuba formerly entered the Feather River about at right angles to its course, a comparatively narrow clear water stream well down between banks, running over a gravelly bottom, and crowded the main stream over against the high plain land formation on the west, thus cutting off the bottom lands on that side. The bank was high above all floods, fifteen (15) feet above low water, and firm; and here the town known as Yuba City was built.

Sutter County Slough.

From the end of the bottom land above Yuba City a depression in the plain lands, away from the river, and extending close behind the town, takes the form of a shallow slough, 400 to 500 feet in width, pursues a course south and west across the plain, diagonally away from the river, to the low lands heretofore designated as Sutter basin. This slough was naturally an overflow channel to the river, and its presence now marks the appearance of direct connection between the hard plains on the west and the bank upon which Yuba City stands.

Site of Marysville.

On the east bank of the Feather River, just above the Yuba, a strip of bottom land, not over 200 or 300 yards in width, extended, and on the somewhat high plain which came down to the Yuba River just behind, the town of Marysville was built.

West bank, south of Yuba City.

The waters of the Feather, at times of flood, before the contraction of levees, always found passage through the slough behind Yuba City, and sometimes topped the banks and rim of plain land at low points above within the first ten miles, and coursed across the plains to the basin beyond. The higher banks were seldom, however, overflowed below the mouth of the Yuba on the west side; but the bottom lands on the east side have always been subject to flooding almost annually.

Mouth of Bear River.

The Bear River formerly entered the Feather in a contracted but well defined channel from the northeast, through a low bottom land several miles in width which here skirts the larger streams on the east. In the acute angle between the two streams, above the mouth

of Bear River, a depression in the bottom land, several miles in length, and lower than the bank of either stream, constitutes the first basin-like formation east of the Feather. It is referred to hereafter as the *Bear River Basin.*

East bank, from Yuba to Bear River.

Down to within several miles of the mouth of Bear River the line of demarkation between the higher plains and the bottom lands can be readily traced on each side of the Feather. Here the task becomes more difficult; and within a few miles below, as in a similar case on the Sacramento about Colusa, the bottoms are at points higher than the former plains behind.

Site of Nicolaus.

Just below the mouth of Bear River, the high land, without intervening depressions, extends from the plains to the river bank, and hereon the town of Nicolaus is situated. Except in seasons of most extraordinary floods, this point was formerly above highwater mark.

East bank, below Nicolaus—American Basin.

Immediately below here the river's banks, built up above the lands to the east, continue to become relatively higher; and thus is commenced that basin which extends almost uninterruptedly east of the Feather and Sacramento Rivers to the mouth of the American, and which has been called the *American River Basin.*

West bank, near the mouth of Feather.

Five or six miles from its mouth, it may be said that the last vestige of the high plain lands west of the Feather merge into the basin which skirts the Sacramento River on the east, from the Buttes southward; and thence to the junction of the rivers the banks of the Feather form but the rim to this, the *Sutter Basin.*

THE CHANGE IN CHARACTER OF FEATHER RIVER.

Near Oroville.

Of late years the channel of Feather River has been filled greatly, and the general character of its profile much changed. Where it comes out from the mountains, at the town of Oroville, there formerly existed an ordinary high-water channel but 400 feet in width, with pools 30 to 40 feet in depth at low water, alternated by rapids where, at this low stage, the stream poured only a foot or two deep over cobbles and boulders. These deep holes are now filled with cobblestones, sand, and gravel; the plane of low water has been raised about six feet, and the general slope of its surface, which was formerly very irregular, as heretofore described, has been rendered more even and steeper for the first five miles of its course below, where the greater irregularities formerly existed.

Mouth of the Yuba, and above.

Below the mouth of the Yuba the whole river bed has been raised, until now there are no more long reaches of deep water and the alternate shoal bars, but a wide, uncertain channel in a sandy bed, of almost even rate of inclination down to the Sacramento, with a general slope much increased over what it formerly was, and other changes, as hereafter more fully described.

Effect on the adjacent lands.

The bottom lands all along the Feather River are now naturally more subject to overflow than they were, and, of course, the river is more than ever inclined to flow over its western banks into the Sutter and American basins.

PRESENT CONDITION OF FEATHER RIVER.

As we now find it, the Feather River may be described as follows:

First division.

From Oroville to Burt's Ferry: A moderately well aligned stream, with good banks, underlaid by gravel, and not inclined to cave. This distance is 12.8 miles.

Second division.

From Burt's Ferry to the Yuba: A crooked stream; numerous small, round bends; banks less stable than above, but still good; coarse sand bottom; the channel flanked by bottom land, subject to overflow, particularly on the east side. This distance is 24.2 miles.

Third division.

From the mouth of Yuba to Nicolaus, near the old mouth of Bear River: A very well aligned stream, but with two remarkable exceptions, where the channel makes a right angle set-off for half a mile or more each time, and then as suddenly resumes its former course. The length of this part of the channel is 19.6 miles.

Through this portion of its course, the Feather River has comparatively low banks; indeed, these are at points almost indeterminate; its width is quite irregular, and its channel through a shifting sand bed. The adjacent bottom lands, though raised by sand and sediment deposits, are subject to overflow by each ordinary high water. The banks are inclined to cave, and generally covered by willows and other bottom land growth. Just above Nicolaus, a considerable portion of the flood-waters of the river annually flows over its western bank into the Sutter basin.

Fourth division.

From Nicolaus to the Sacramento: A remarkably well aligned channel, with but one exception—a sudden turn to the right, and back again. The length of this division is 10.4 miles.

Through this portion of its course, the banks of the river are lower, and the waters frequently break over them into the Sutter basin on the west. The channel is even more irregular in width and shifting in its sandy bed than in the division above.

The grades and dimensions of the Feather River channel will be found in tabular form in a subsequent portion of this report.

Raising of the river beds.

It is quite certain that the bed of Feather River, and that of the Sacramento below the point of junction with the Feather River, has been greatly raised during the past 30 years, and that since 1862, when sands were brought from the upper cañons in great volume, the rate of filling has been more rapid than prior to that time. The raising of a bed of a river is first made apparent by the increase in elevation by its lower water plane or level, the movement of which is a fair indication of the average filling on the shoals of the channel. Thus the Sacramento may have reaches of 5 to 10 miles in length, of water 15 to 40 feet in depth at its low stage, alternating with short shoals where the water will only average 5 to 10 feet in depth; and the low water plane will be held in position by the shoals, which act as partial dams. There is abundant evidence to show that this was the character of the channel below the mouth of Feather River in the early days of its navigation. Now we find these deep reaches in great measure filled up and the shoals raised, as evidenced by the increased elevation of the low water plane. Feather River, though less decided in its character formerly as a deep channel, has nevertheless been greatly filled, particularly at and below the mouth of the Yuba.

The low water plane of these rivers has been raised about as follows: Sacramento River—Head of Grand Island, 1½ to 2½ feet; Sacramento, 5 to 5½ feet; mouth of Feather, 3 to 4 feet; Knight's Landing, 1 to 1½ feet. Feather River—Nicolaus, 3 to 4 feet; mouth of Yuba, 13 to 15 feet; Oroville, 5 to 6 feet.

From what has been said it will be understood that these figures do not represent the full depth of filling in the beds of the rivers. It is difficult to determine just what this has been, for there were so few surveys made in early years with the results of which the present channel may be compared. It is known, however, that in front of the City of Sacramento, and for near two miles of the length of the channel, the average filling has been to a depth of 15.2 feet, and the maximum about 25 feet since 1854, when a survey was made under the direction of the Town Council by the City Surveyor. A copy of a map showing soundings made at that time has been secured. The condition of the river is found noted thereon, and the reading of the guage for that low water stage is known; so that the data are good, and the results of comparison the most reliable at my command. This subject will be more fully discussed in Part III of this report.

TABLES OF CHANNEL DIMENSIONS AND GRADES.

The following tables show the relative dimensions, grades, etc., of the several divisions of the Sacramento and Feather Rivers:

SACRAMENTO RIVER.

Divisions of the Channel.

Number of the Divisions	Location of the Divisions.	General Direction of the Divisions	Distance in an air line, Miles.	Length of channel, Miles
I	Iron Cañon to Stony Creek	S. 18° 00′ E.	40	58
II	Stony Creek to Butte Slough	South	33	53
III	Butte Slough to Knight's Landing	S. 24° 30′ E.	29	49.9
IV	Knight's Landing to Feather River	S. 78° 00′ E.	5.5	14.8
V	Feather River to American River	S. 24° 45′ E.	14.3	19.7
VI	American River to Grand Island	S. 9° 30′ W.	20.3	27.7
VII	Old River Channel } Steamboat Slough }	S. 30° 00′ W.	10.0	18.2 / 11.9
VIII	Grand Island to Collinsville	S. 55° 00′ W.	12.3	15.8
IX	Collinsville to Initial Point	S. 52° 00′ W.	2.75	2.8

Total length of the river through the valley:
By way of Old River channel .... 249.2 miles.
By way of Steamboat Slough channel .... 255.6 miles.

FEATHER RIVER.

Divisions of the Channel.

Number of the Divisions	Location of the Divisions.	General direction	Distance	Length of the channel
I	Oroville to Burt's Ferry	S. 21° 00′ W.	9.4	12.8
II	Burt's Ferry to Yuba River	S. 4° 00′ E.	18.0	24.2
III	Yuba River to Nicolaus	S. 5° 00′ E.	15.9	19.6
IV	Nicolaus to Sacramento River	S. 16° 00′ W.	8.4	10.4

Total length of the river channel through the valley .... 67.0 miles.

SACRAMENTO RIVER.

Channel dimensions and grades in the several divisions.

Designation.	First Division—Iron Cañon to Chico Creek. Low Water	First Division High Water	Second Division—Chico Creek to Butte Slough. Low Water	Second Division High Water	Third Division—Butte Slough to Knight's Landing. Low Water	Third Division High Water	Fourth Division—Knight's Landing to Feather River. Low Water	Fourth Division High Water	Fifth Division—Feather River to American River. Low Water	Fifth Division High Water
Elevation of water at upper station, in feet	258.5	284.3	110.4	130.5	40.95	62.96	19.97	36.12	16.03	33.81
Elevation of water at lower station, in feet	110.4	130.5	40.9	62.9	19.97	36.12	16.03	33.81	9.83	28.00
Difference of elevation between stations, in feet	148.1	153.8	69.4	67.5	20.98	26.84	3.94	2.31	6.20	5.81
Average grade per mile, in feet	2.55	2.65	1.31	1.27	0.42	0.50	0.27	0.16	0.31	0.29
Maximum grade of any five miles, in feet	4.4	4.6	1.7	1.7	0.54	0.66	0.36	0.19	0.40	0.47
Minimum grade of any five miles, in feet	1.4	1.6	0.4	0.6	0.29	0.42	0.22	0.05	0.19	0.17
Maximum grade of any one mile, in feet	5.5	4.7	1.7	1.7	0.55	0.80	0.45	0.30	0.70	0.55
Minimum grade of any one mile, in feet	1.1	1.5	0.3	0.5	0.27	0.25	0.10	0.00	0.13	0.06
Average width of channel, in feet	500.	580.	450.	500.	249.4	281.2	286.	320.0	517.	683.
Widest average for any one mile, in feet	700.	800.	620.	650.	343.4	383.4	300.6	332.8	709.	770.
Narrowest average for any one mile, in feet	300.	375.	300.	320.	192.5	216.0	245.6	286.2	427.	502.

SACRAMENTO RIVER—Continued.

DESIGNATION.	Sixth Division—American River to Grand Island.		Seventh Division—Old River.		Seventh Division—Steamboat Slough.		Eighth Division—Grand Island to Collinsville.		Ninth Division—Collinsville to Initial Point.	
	Low Water.	High Water.	Low Water.	High Water.	Low Water.	High Water.	Low Water.	High Water.	Low Water.	High Water.
Elevation of water at upper station, in feet	9.83	28.00	4.66	16.15	4.66	16.15	1.13	9.42	----------	----------
Elevation of water at lower station, in feet	4.66	16.15	1.13	9.42	1.13	9.42	0.15	2.58	----------	----------
Difference of elevation between stations, in feet	5.17	11.85	3.53	6.73	3.53	6.73	0.98	6.84	----------	----------
Average grade per mile, in feet	0.19	0.43	0.19	0.37	0.30	0.57	0.06	0.43	----------	----------
Maximum grade of any five miles, in feet	0.30	0.58	0.30	0.43	0.39	0.75	0.07	0.54	----------	----------
Minimum grade of any five miles, in feet	0.06	0.28	0.17	0.27	0.21	0.33	0.06	0.32	----------	----------
Maximum grade of any one mile, in feet	0.43	0.60	0.40	0.45	0.45	0.85	0.07	0.60	----------	----------
Minimum grade of any one mile, in feet	0.05	0.20	0.17	0.20	0.20	0.08	0.05	0.30	----------	----------
Average width of channel, in feet	531.	627.	381.	417.	407.	468.	1.163.	1,297.	----------	----------
Widest average for any one mile, in feet	740.	850.	610.	626.	580.	597.	2.084.	2,100.	----------	----------
Narrowest average for any one mile, in feet	442.	480.	274.	282.	215.	259.	687.	704.	----------	----------

FEATHER RIVER.

Channel dimensions and grades in the several divisions.

DESIGNATION.	First Division—Oroville to Burt's Ferry.		Second Division—Burt's Ferry to Yuba River.		Third Division—Yuba River to Nicolaus.		Fourth Division—Nicolaus to Sacramento River.	
	Low Water.	High Water.	Low Water.	High Water.	Low Water.	High Water.	Low Water.	High Water.
Elevation of water at upper station (above low tide on the Bay)	----------	160.5	84.8	106.0	49.4	65.7	25.6	41.7
Elevation of water at lower station (above low tide on the Bay)	----------	106.0	49.4	65.7	25.6	41.7	16.0	33.7
Difference of elevation at lower and upper station	----------	54.5	35.4	40.3	23.8	24.0	9.6	8.0
Average grade per mile	----------	4.26	1.46	1.67	1.21	1.22	0.92	0.76
Maximum grade of any five miles	----------	4.58	2.06	2.64	1.80	1.82	1.36	1.07
Minimum grade of any five miles	----------	3.80	0.06	1.18	0.74	0.68	0.49	0.50
Maximum grade of any one mile	----------	5.20	2.50	2.80	1.83	2.15	1.86	1.10
Minimum grade of any one mile	----------	3.20	0.05	1.00	0.60	0.80	0.35	0.50
Average width of channel	200.	260.	280.	340.	330.	620.	340.	510.
Widest average of any one mile	470.	520.	320.	400.	410.	820.	370.	580.
Narrowest average of any one mile	150.	180.	200.	300.	240.	510.	250.	460.

REMARKS ON THE TABLES OF CHANNEL DIMENSIONS AND GRADES.

SACRAMENTO RIVER.

The data available.

The data from which this table is prepared is complete and reliable for the third, fourth, fifth, sixth, seventh, and eighth divisions, and about two-thirds of the second. For the remainder of the second (above Butte City), and for the first division, the data are good, but not being so much in detail, small errors in the averages may exist.

The water line given.

A part of the sixth and all of the seventh, eighth, and ninth divisions are within the range of tidal influence; and the water elevations given within these divisions are those for the low tide planes during both the low water and flood stages of the river.

Effect of defect at Grand Island.

It should be remarked here that what is said elsewhere in this report concerning the break in the flood line at the head of Grand Island may not be so apparent from this table, for the reason that the grade above, as here represented, is the average throughout the sixth division, while that taken in the discussion referred to only extends to Freeport from the head of the island. Haycock shoal and the action of the American River make the grade in the flood plane steeper above Freeport; hence the effect of the Grand Island defect in regimen is taken as extending only to Freeport in the extreme flood stages. Furthermore, the half tide slopes are considered in the discussion, whereas the slopes here given are for extreme low tides only, which at times of high water are felt a small part of the way up Steamboat Slough and Old River Channel.

To obtain a fair idea of the break in the profile at the head of Grand Island, look at the minimum grade for five miles of channel in the Sixth Division, which occurs first above Grand Island, and the maximum grade of five miles in the Seventh Division, which occurs just below the head of Grand Island. Thus, at flood stage, for five miles above the head of Grand Island, the grade of the water line is 0.28 feet per mile, while below the same point at the same stage, in Steamboat Slough, the grade is 0.75 feet per mile, and in Old River 0.43 feet per mile, showing the effect of the defective capacity past Grand Island in holding the water back above.

THE INITIAL POINT.

The initial point of the surveys of this Department, from which all distances on the rivers are reckoned, is situated in mid-channel, in the main stream—the San Joaquin and Sacramento combined—on range between the lower points of New York Slough and Spoonbill Creek, which join the main channel opposite to each other. This point is opposite New York Landing, where tidal observations were made for determining a low water plane of reference. Above this plane elevations are given in feet.

The Ninth Division of the channel is made to end at the initial point, because there are no observations and data to give dimensions and slopes below it.

EFFECT OF THE SUTTER BASIN WATERS.

The effect of the Sutter Basin waters and channel defects of the Sacramento is seen in the flood grade line of the Fourth Division, where at the very highest water there was no perceptible fall in the river just above the mouth of Feather. The floods from Feather River sometimes produce the same effect.

FEATHER RIVER.

Effect of the Yuba.

The grade line of Feather River is exceedingly irregular. The filling at the mouth of the Yuba makes almost a still-water pond of the Feather above for 6 to 8 miles during low water stage, and produces a rapid descent for a corresponding or greater distance below. This effect is apparent, though in a less marked degree, during the flood stage also.

Effect of the Sutter basin waters.

The Sutter basin supply of water seriously disturbs the Feather River flood slope at times, by affording a greater quantity of water than the Sacramento can carry below the mouth of Feather; the Feather itself is backed up and forced to run over into the basin at a point above, and where it has yet the elevation to do so.

THE THREE DRAINAGE PROBLEMS OF THE VALLEY.

From what has been said, it will be seen that there are three main problems in the drainage of this valley:

First—To insure a sufficient outfall from the foot of the lower valley flood region, that it may be drained without flooding the delta islands.

Second—To insure a sufficient water-carrying capacity from the foot of the upper valley through the lower valley flood region, in order that the former may be promptly drained without causing damage below. And,

Third—To provide drainage way sufficient to bring the waters of ordinary flood volume, from the upper Sacramento, near Stony Creek, through to the head of the lower region, without overflowing the upper region of freshet floods.

Certain circumstances complicate the first two problems, and make it necessary to consider them for a moment as one. For instance, if by diverting water from the river near the head of or at points in the lower flood region, that is, at or below Knight's Landing—we might conduct it by a separate channel to the Bay, and in such volume as to effectually relieve the river below the point of diversion and Feather River mouth without causing inundation of the low lands, then the first and second problems would apparently be solved at once. I consider this mode of possible relief first.

FIRST AND SECOND PROBLEMS.

The Yolo basin.

The Yolo basin lies west of the Sacramento, and extends, parallel to the general course of the river, from near the mouth of Feather to the eastern foot-slope of that high land known as the Montezuma Hills, against and near to whose southern base the main river channel is situated for nearly the entire division of its course from Grand Island to Collinsville. The line of lowest depression in this Yolo basin, near its upper end, is about one mile from the river; thirty-two miles below, opposite Courtland; it is about two miles from the river; while opposite Sacramento, nearly midway between the extreme points, it is five miles away. In the middle 20 miles of this distance the bottom of the depression falls 15 feet, giving an average grade of nine inches per mile. Hence the surface of the ground, in the bottom of the basin, is about level to near its lower end, ten miles further, where it raises to the hills on the west and south, and to the bank of the Steamboat Slough channel of the river on the east and south.

Comparison of river and basin grades—Cache Slough.

The average grade of the bed of the river opposite the portion of this basin, whose bottom line has a fall of nine inches per mile, is about three inches per mile. At its extreme southern end the basin is drained by Cache Slough, which joins the Steamboat Slough channel of the river about half a mile above the lower end of Grand Island. This drainage slough extends across the low level portion of the basin, and comes to the river at right angles to its general direction. From the fact that there is no sand brought into it, Cache Slough is a deep and commodious channel—more so than the river immediately above it; and it is kept open by the swell and ebb of the tides, which have free action in it, especially at times of low water.

The waters of the basin.

This basin receives the drainage from the Coast Range on the west, brought down by Cache and Putah Creeks principally, and also the overflow waters from the Sacramento, which escape over its west bank and through the crevasses below Knight's Landing. These waters, for the most part, enter the basin near its head. When not in very large volume, they are held back by the growth of tules, and do not find their way rapidly down the steep grade of the basin; but, after filling the deeper depressions thereof, they are delivered gradually through Cache Slough, to be drained away by the river below Grand Island.

The floods of the Yolo basin.

When, on the contrary, after the basin has been partially filled, there is a large accession of water from the creeks or the river suddenly precipitated therein, it delivers at its lower end through Cache Slough, and over its rim into Steamboat Slough, a large flood volume in advance of the rise which comes regularly down the river, and thus temporarily gorging the river below Grand Island, creates a perfect water-dam in the Steamboat Slough channel, and causes an elevation of the flood up-stream as far as Sacramento. If this occurs when the river above is already at flood level, it is likely to produce disastrous results.

The flood of 1878.

This state of affairs occurred on the 20th and 21st days of February, 1878, and resulted in the overflow of the Grand Island levee on the Steamboat Slough face, at several points near the lower end, where the waters came across the river, struck the levee at right angles, and ran up stream as well as down in this channel for a short time. The same flood-wave made several breaches in the levee south of the main river, below Grand Island.

Proposed relief through Montezuma Hills.

To guard against such inundations, and to relieve the river from its surplus waters below the mouth of Feather River—through the lower flood region and the delta islands—it has been proposed to construct a canal which shall carry a portion of the waters of the river, and the waters from the creeks of the Coast Range, into Suisun Bay by way of a new outfall, to be made opposite the lower end of the Yolo basin, through the Montezuma Hills.

A relief canal.

This project takes two forms:

First—To tap the river, and draw from it into a canal, to be carried on grade around the west side of the basin, such waters as may be surplus in the main channel, and intercepting the flood waters of the creeks from the west, conduct all, by a comparatively shallow cut, through the hills to the new outfall.

A drainage canal.

Second—To tap the river at one or more points, permit its surplus waters, with those of the creek, to enter a drainage canal constructed along the bottom of the basin to near its lower end, and thence pass, by a comparatively deep cut, through the Montezuma Hills to the new outfall.

The first arrangement would properly be called a *canal of relief* to the river, and an *intercepting canal* to the creek. The second arrangement might claim, in addition to the performance of the duties above named, to effect the complete drainage of the low basin.

Diversion of creek waters.

Aside from these phases of this proposition—because not so intimately connected with the river problem—is the proposition to conduct the waters of Cache and Putah Creeks alone to a new point of outfall, over the Montezuma Hills, without tapping the river at all. The work would be simply *an intercepting canal*, or an extension of these creeks to a new mouth. It is the simplest proposition connected with this entire problem, and therefore will be spoken of first.

THE INTERCEPTING CANAL.

A high grade canal.

The summit of the lowest depression in the crest of the Montezuma Hills is 37 feet above low tide in the bay. Putah Creek, on an approximate grade contour, with a rise of one and a half feet per mile, is 25 miles distant from this point, and the line continued, on a grade of two feet to the mile, would reach Cache Creek in 18 miles of distance, additional. A cut of 13 feet deep through the Montezuma Hills would afford a grade of two feet per mile also in the first division—to Putah Creek. By this disposition the initial grade elevation at the summit of the hills would be 24 feet; at Junction with Putah Creek, 74 feet; at Cache Creek, 110 feet above low tide in the bay.

Depth of cutting, and grades.

Lowering the whole line ten feet would bring the grade elevation to 14 feet at the summit of the hills. The distance thence to Montezuma Slough is about six miles, and thence out into the bay by the shortest route, six miles further. For this distance of 12 miles, the 14 feet yet to spare of grade would afford a fall of three inches for each of the six miles through the slough, and nearly two feet, respectively, for the first and each succeeding mile thence to grade in the summit of the hills. To pass the waters of Cache Creek (supposing 34,000 cubic feet per second represents the maximum) on to Putah, the canal, on a grade of two feet per mile, would have to be 240 feet wide on an average depth of flow of 20 feet.

Required dimensions.

To pass the flood-waters of Putah Creek (supposing 76,000 cubic feet per second to represent the maximum) on through the hills, the canal, on a grade of two feet per mile, would have to be 535 feet wide, on an average depth of flow of 20 feet. To pass the combined waters of the two streams (taken at a maximum of 100,000 cubic feet per second) the width would have to be 704 feet. It is, however, not at all probable that the flow from both streams would ever be in the same part of the canal at the same time, even to an aggregate quantity represented by the figure adopted; for they are both highly intermittent in character, and their floods are of very short duration each.

Importance of diverting the creeks.

The importance of diverting these streams is not to be measured alone by the increased value of property in the Yolo basin, which might thus be relieved from annual overflow, for circumstances may readily occur when the whole river and island property below Sacramento would be at the mercy of their uncontrolled floods.

Effect of creek flood.

As in 1878, so may these waters at any time contribute largely to the inundation of Grand Island and other island property below, beyond the immediate basin into which they pour, and otherwise comparatively safe from overflow.

A deep channel required for diversion.

If these streams can be turned permanently, it can only be accomplished by creating a *deep* channel for the purpose—one resembling the form and approximating the slope of those in which they run above where they commence to deposit their sediment. Any other disposition would only result in the destruction of the new waterway and damage to property now safe from flooding.

Manner of construction.

To estimate upon the cost of such a canal, at any fixed price per cubic yard of all the material to be moved, would not be doing the subject justice, for the waters themselves should be made to perform by far the greater portion of the labor. Thus a canal at first constructed 10 feet deep, 10 feet wide at the bottom, and 30 feet wide at top, for the entire distance over the plains above the hills, would necessitate the removal of 1,643,000 cubic yards of material. The cut through the hills at the same width on the bottom and down to the grade with the portion excavated to half depth above, would involve a maximum cut of 13 feet in depth and the removal of 93,000 cubic yards of material.

An estimate of cost.

The earth from the canal on the plains should be put in an embankment on the lower side of the canal, at least 100 feet away; the material from the hill-cut could for the most part be moved out lengthwise of the work by means of cars on a tramway, and used to make embankments for the continuation of the canal across the low plains to the slough below. Then,

1,643,000 cubic yards from canal on plains, @ 10 cents per cubic yard	$164,300
93,000 cubic yards from cut through hills, @ 20 cents per cubic yard	19,600
Total cost of construction	$183,900

Other expenses necessary.

In addition to the above, there must necessarily be a leading channel two or three miles long for Putah Creek; a set of regulating gates in the canal just below where it taps each creek; and also a movable dam in each creek, below where tapped by the canal. The process of enlargement would then be each year to plow and otherwise loosen the material in the bottom and on the upper side of the canal, and each wet season to admit as much water in the new canal as it could be made to carry, and no more, flushing out the excavated soil, and effecting the enlargement without great cost.

Levees should not be necessary.

In the course of a few years, the new channel for the creeks would, under favorable circumstances, be excavated below the surface of the plain; no embankments would be necessary; the movable dams in the old channels of the creeks would be replaced by solid earthen embankments (unless it might be desired still to draw water through for irrigation) and the turning of the stream would be effected.

Right of way, etc.

There would, of course, be other expenses attendant upon this work than those alluded to here, as, for instance, property damages, and cost of right of way, and cost of attendance upon the works during the process of enlargement. It is believed, however, that the whole work could be completed at a cost far within the limits of immediate returns from benefits to lands in the Yolo Basin and immunity from danger of flooding the islands below. More particularly would this be the case if the waters of the Sacramento were also not permitted to enter the Yolo Basin, as they do now, through the crevasses above Sacramento.

Examinations necessary.

Whether or not the material to be removed would admit of the inexpensive manner of construction here spoken of, can only be determined by a careful examination of the route, with borings to test the sub-soils.

Conditions to be looked into.

If the streams are now raising their channels at the points where it is necessary to divert them, we might expect the canal-bed to raise also; and this would be an unfavorable circumstance. If, on the contrary, the water can be taken out on suitable grades, where the natural disposition is now to cut down, and carried in grades approximating thereto, then the outlook would be hopeful. This can only be ascertained by watching the streams through at least two seasons.

RESERVOIRS FOR THE CREEK FLOODS.

To reduce the maximum flow of these creeks, and thereby effect a saving in the size of the canal, it may be thought the plan of holding back a portion of their flood by open dams in the cañons might be adopted to advantage. What is said in an appendix to this report on the general subject of this method of dealing with floods, however, should be remembered in this connection.

Cache Creek now regulated.

Cache Creek would be the tributary to this new channel, most distant from its mouth. This stream is made up by two principal tributaries, one of which drains Clear Lake. This lake is already a regulator upon the flood volume in its stream, the time of delivery is set back, and amount of maximum flow is doubtless decreased. As it is now, the freshets from the other branch of the creek come down rapidly, and are led away before there is any large contribution to the main stream from the Clear Lake branch, which follows afterwards. Suppose, now, a reservoir dam were put in at some suitable point on the northern branch, and its waters held back like those of the Clear Lake branch, we may readily understand how the uniting of the two flood volumes, from the two streams, in that event made to come down at the same time, instead of in succession, would form a freshet of greater momentary magnitude than would otherwise occur if the additional reservoir had not been built, even though each of these waves were reduced in volume itself by the effect of its particular reservoir.

Danger in holding back floods.

This same argument would apply in considering a proposition to hold back the floods in Putah Creek, if the two creeks were to be led away in the same canal; for by preventing the rapid escape of Putah Creek freshets we might hold them so that their maximum volumes would be presented to the main channel at the same time that the greatest flood flow arrived from Cache Creek, which, of course, would not only be bad economy, but might result in disaster.

Diversion of the creek waters recommended.

On the whole, the proposition to lead the waters of Cache and Putah Creeks into Suisun Bay, by means of a high-grade canal over the Montezuma Hills to Montezuma Slough, may be looked to as the groundwork of a probable solution of one of the most difficult problems on the drainage of the valley, but its efficacy will depend largely upon what course of treatment other features of the case receive, as will hereafter appear more fully, and its possibility and cost can only be determined after a fuller examination than the time thus far elapsed could permit of being made.

Storage of the creek waters not recommended.

But the plan of holding back a portion of the flood-waters of these creeks, or of either of them, by means of dams—either open or closed—constructed in the cañons, is one of very doubtful policy, though further investigation may show it to be, in this particular case, free from the grave objections which there are generally to such works. It is hoped the opportunity may be afforded of reporting definitely on this whole subject, when the lapse of another season has given opportunity to judge of the present action of the streams in question, with respect to the movement of their beds.

THE RELIEF CANAL.

A project to divert a portion of the waters of the river at Gray's Bend or Knight's Landing—the head of the lower region of floods—and conduct them to the bay, on the route heretofore described, has already been reported on by the Engineer to the Sacramento River Drainage Commission, under date of November 28th, 1879.

The conclusions put forth in that report are here summarized and enlarged upon.

Conclusion of the District Drainage Engineer.

First—In the present condition of the drainage lines of the valley, the waters which are regarded as surplus below the proposed point of diversion cannot be put into the projected relief canal, because they enter the main channel below that point. The point of diversion selected is itself the lowest down the valley whence such a canal could be taken out from the stream and maintained, for the reason that thence to tide water the river is flanked by low basins, across which banks of the canal would have to be too high for safety; and hence, the projected work would not serve to relieve the districts below from danger of flooding.

The effect of the creek sediment.

Second—On the grade upon which it is possible to construct the canal—four inches to the mile—its waters would not carry on to the Bay the materials which would be brought into it by Putah and Cache Creeks, which have grades of four feet and over to the mile; and hence the main canal would be filled up and destroyed. It was also shown in this report that the cost of the proposed work would be excessive; but with that point for the present I have nothing to do.

The second conclusion is reasonable, and, to say the least, calculated to weigh heavily against this particular proposition, under whatever form it may be considered. It should be remarked here, however, that the same argument does not apply against the proposition heretofore considered, to divert the creek waters above through a high grade canal, for the reason that the channel for this latter purpose could be put on a grade sufficiently great to keep itself clear, while that which has to tap the river cannot.

Creek sediments might be held back.

The materials brought down by these streams possibly could be held back to a great extent, for a considerable time, at least, by dams constructed in the cañons and ravines above. Whether this could be effected in a degree so far to relieve the waters from sediment as to render their introduction into the low grade canal safe, is very doubtful. If this were done we might expect great erosion of material would take place in the beds of the creeks themselves, where their waters would be confined by levees in their courses across the plains (and there must be comparatively very heavy grades), which material would be deposited when the velocity of the waters was checked in the canal of high grade.

A high and low grade canal, too.

Cache and Putah Creek waters might be taken in a high grade channel, as heretofore explained, to the cut through the hills, and there joined with waters brought forward in a low grade canal from the Sacramento River, from which place of joining the combined volumes could be conducted through the hills in the same cut on a sufficient grade to keep the channel clear.

Construction of the cut.

By this arrangement the high grade canal and the cut through the hills could be constructed on the inexpensive plan heretofore spoken of; and it is probable that the cost of the combined works—high grade and low grade canal—would not exceed the cost of the low grade canal alone by the original plan wherein the creeks were to be taken directly into it opposite their points of debouchment from the hills. More particularly would this be the case if it were necessary, as it certainly appears to be under such arrangement, to build dams to hold back the solid materials which would otherwise fill the low grade canal. Thus disposing of the objection to the relief canal, based on the ground that the creek water sediments would destroy it, the proposition comes up on its merits as a relief to the river.

The river in its present condition cannot be relieved.

The first conclusion of the Engineer to the Drainage Commission heretofore cited, is based upon the present condition of affairs in the river system, viz: That sufficient water now enters the river channel below the point of proposed diversion at time of ordinary high floods to cause the flooding of Yolo and American basins, even with the crevasses now existing in the levees closed; and hence, the canal would not so far relieve the river below as to warrant its construction.

The lower valley floods.

It has been hereinbefore asserted that the eastern tributaries, the Feather and the American, might readily present sufficient water to the Sacramento below the proposed point of diversion to overtop much of the existing levees, when the upper Sacramento River was only at ordinary winter stage. This condition of affairs would probably occur but very seldom; but under present circumstances a large accession to the waters in the Sacramento River below the mouth of Feather, at times of ordinary high flood, is received from the Sutter basin, between the Sacramento and Feather Rivers. This water comes principally from the upper Sacramento River, and enters this basin, at its head, as well as at points below, through crevasses in the levees, which heretofore have occurred almost annually.

Why the river cannot be relieved under present circumstances.

Coming down the valley by this short cut, after the basin has been filled by the earlier freshets of the season, the waters of the higher floods are precipitately presented to the channel at the head of its fifth division, the mouth of Feather River, and thence on down there may be a large surplus in the river as it now exists, without its being possible to decrease the amount by diversion where a canal can be constructed, namely: at Knight's Landing, which is above where the great supply of water comes in. For, let it be remembered that this supply is drawn, as it were, from an immense lake with a free outlet, and if all of the water coming down the upper river channel were diverted into a canal at Knight's Landing at such a time, the supply to the river below the mouth of Feather would be just as great, for more would come down out of the lake if not kept back by the river water crowding past, only the supply would probably not last quite so long.

Diversion at Knight's Landing.

Thus, under present circumstances, diversion at Knight's Landing would not be a relief to the river below the mouth of the Feather. Supposing, however, that the waters of the Sacramento were confined to a channel or channels, and that thereby the amount of maximum flow past Knight's Landing were greatly increased, then it would appear that an abstraction of some certain quantity at Knight's Landing would make that much less for the river to carry below. Here, then, are the circumstances under which this project would come up on the merits of the diversion question. Would the diversion of as much water as could be safely taken through an artificial canal from this point be a real and lasting relief to the river below?

Always danger of harm from diversion of waters.

The question, in the abstract, of diverting water from a stream as a means of immunity from floods therein, is discussed in an appendix to this report. All of the objections to this mode of relief would apply in the present instance with full force.

The Sacramento River sediments.

The Sacramento River, below the mouth of the Feather, is at all times heavily charged with sediment. When at times of high water it has a less percentage of solid material in suspension than at other times, its waters are busily engaged in picking up and carrying forward the material deposited at the bottom by former freshets which had more material than they could carry. And, under any circumstances, this will be the case for years to come; for, keep as much material out of the upper rivers as we may, there will still be much come down to the Sacramento, below the mouth of Feather, from the stream-beds above. And then, too, whatever treatment may be adopted for the drainage of the valley, the scouring out of the present channels, to a considerable extent, must form a leading feature of it, and the waters may have enough to do to accomplish this work and maintain its results. Hence the diversion of the *clear* waters of the upper Sacramento River would have a peculiarly bad effect upon the action in the channel below. Your attention is asked to a portion of this report where this subject of diverting flood-waters is more fully considered. (See Appendix.)

The relief canal project ill-advised.

As the case stands at present, this project is an ill-advised one, for it certainly would not relieve the river below nor the country above. When it is *known* that the lower river cannot be brought to a capacity to pass the waters of ordinary floods, and when a plan is definitely settled upon and in operation for the prevention of overflow in the region above the mouth of Feather, then the question of relief at the point proposed may come up under more favorable conditions, and with necessities made more apparent and definite. Now, that time cannot arrive for some years in the future—pending a treatment of the natural drains—hence the subject does not seem worthy of more extended discussion at this time.

THE DRAINAGE CANAL.

It has been proposed to drain the waters which now collect in the Yolo basin through a deep cut in the Montezuma Hills into Suisun Bay, taking the water direct from the bottom of the basin after it has there collected. This is one feature of the second phase of the general problem of preventing overflow in the lower flood region heretofore explained. But, as reported upon by the engineer to the Drainage Commission, it was not in contemplation to make the work a means of relief to the river above, but only to carry away the waters of Cache, Putah, and other streams which drain into the basin from the Coast Range. As already shown, these creek waters can probably be taken through a high grade canal by tapping the channels where they come out of the mountains. But the very essence of this proposition is to keep on a steep gradient, so that the velocity of the current attained would insure the performance of the work required, namely —the transportation of its material and excavation of its channel.

What waters are surplus.

Such arrangement would keep the waters of the Coast Range streams out of the basin altogether. Then if, as the Engineer of the Drainage Commission assumes must be the case, the waters are kept out of the upper portion of the basin from the river by means of levees, and if the water is kept out of the lower end of the basin by means of levees and embankments across Cache Slough, etc., there would not be any water in the basin to drain out except that which would rain down upon it or percolate through the swamp soil from the river, and consequently the deep cut would not be necessary.

Relief for the Yolo Basin and the river.

Suppose, however, that it were necessary to relieve the river of a part of its flood waters, either by diverting from some points at or near the mouth of Feather and American Rivers, or permitting the back water to come into the basin at its lower end from the river through Cache Slough, were the high-grade canal constructed for the Coast Range waters, it would not be possible to make use of the same cut in which to conduct the water from the basin through the hills, because, in lowering the cut to an elevation that would accomplish the drainage of waters from the basin, its necessary grade through the hills would be destroyed, and the creek waters coming in on a great slope, as they must at the commencement of the cut, will simply back up the waters in the basin and prevent its drainage, for the lands of the basin proper are four feet below the high tide at the point of outfall. Furthermore, the creek waters would no longer have the grade and velocity upon which to carry their sediments forward to the bay, and would deposit them in the cut.

The bottom of the basin cannot be drained by the cut.

Then, again, supposing for a moment that this difficulty were overcome, and the waters of the creeks were dispersed so that they could not interfere with drainage of the basin through a deep cut if it were made; still, this could not effectually drain the basin, even though the waters of the river were kept out at the mouth of Cache Slough, for the reason that the surface of the ground over a large area of this basin is only four feet above low tide in Montezuma Slough, into which the waters could go, and the tide rises eight feet in that slough, or four feet above the level of the lands of the basin. Or, in other words, the land to be drained is at the height of mean tide at the outfall—seven miles distant.

Comparative efficiency of the river and deep cut.

By keeping the waters of the river out from the lower end of the basin, and by diversion, as heretofore suggested, of the creek waters through a high grade canal, it would seem that the only use of the deep cut would be to afford rapid drainage for flood-waters which might be diverted from or escape from the Sacramento River into the upper portion of the basin. Admitting, for the moment, the necessity for diverting water from the river above, either into this basin or into a canal therein, the efficiency of a cut for this purpose over the possible efficiency of the river channel itself from the mouth of Cache Slough to the bay, may well be questioned; and herein lies the most important fact with respect to the whole matter.

The proposed new outfall not an open one.

It may be supposed that this cut would end at a point of free outfall into the bay. Such is not the case. At best, it would only be carried to Montezuma Slough, at about a middle point on its course. Now, this slough extends from the mouth of the river, at Collinsville, in a great arc, around the north of Suisun Bay, a distance of 15 miles, and joins the open water again near the lower end of the bay. The land thus inclosed is known as Grizzly Island (with some small islets at the southern end. Montezuma Slough is generally a very shallow channel—at points almost dry at low tide—and quite a narrow one, not more than 300 to 500 feet in width for a considerable distance of its length, and with low marshy banks. Grizzly Island is for the most part surrounded by embankments which are now sufficiently high above high-tide level to effect its reclamation.

The waters of Montezuma Slough would have to be raised.

In order to put any such volume of flood-water through Montezuma Slough as would afford a material relief to the basin above the hills, it would be necessary to raise the water at the junction of the canal-cut to afford a fall through the slough channel sufficient to carry away the waters into the bay. When this is done we, of course, diminish the efficiency of the canal to draw down the waters of the basin. The whole water plane would be held at a higher level throughout the basin, the cut, and the slough than it would be if the lower end of the cut were at a point of free outfall. The result might well be an inundation of Grizzly Island, and other land already embanked and safe from overflow under present circumstances.

The mouths of Montezuma Slough.

Then, too, where would this water go? As before said, the slough has a mouth which joins the river immediately at its mouth or point of juncture with the San Joaquin River. The waters taken through the hills from the basin would then, in part, at least, return to the river by this roundabout channel and check the free outflow past Collinsville into the bay. This might be a more unfavorable condition of affairs for the low island property below the mouth of Cache Slough, than to have the water from the basin come into the river through Cache Slough.

The proposed outlet longer than the present one.

For the same reason the deep cut through the hills would not act as a relief to the river if the communication were left open between it, the river, and the basin at the mouth of Cache Slough; the waters would not find a point of free outflow by going through the cut; on the contrary, the distance to such a point of free outfall would be longer than by way of the main river channel. Montezuma Slough would not carry any such great volume of water as would be put into it from the deep cut, without a considerable elevation of its water-plane at the point of junction of the cut with it; and a portion of these waters would find their way back into the river at Collinsville, to the detriment of the carrying capacity of the main channel for the entire distance below Grand Island. These points are all so simple that it is not deemed necessary to encumber this report with any further elucidation of them.

Conclusion concerning the deep cut.

Hence, it appears that there is much of fallacy in the idea that such a cut would relieve any considerable portion of the lands of the basin from overflow, or lessen the danger of inundation to the islands below Grand Island.

Disastrous consequences might result from the deep cut.

Further than this, the creation of this new mouth, as it were, for the river, is a measure of extremely doubtful policy for the future welfare of the whole delta plain and safety of the commercial interests of the State.

Experience concerning the mouths of rivers.

If we are to have any faith whatever in the result of scientific and practical observation and experience, the fewer mouths there are to a sediment-bearing river the better. *The greater the volume of water, the lower the grade it can be carried on*, is the accepted rule derived from engineering experience in such matters.

Application to the case in hand.

As the practical object to be obtained, with respect to the river, is to lower its elevation at the foot of Grand Island, the working of this rule in the flow of the flood volume would defeat this end, if we divide such flow between two channels, instead of keeping it in one, even if the new channel was to be a shorter one, instead of a longer one, to a point of free outfall, and even if it had an entirely independent outlet, and did not pour a portion of its waters back into the river in the face of its outward flow at Collinsville. Then, too, the diversion of these waters from the river at the foot of Grand Island, as in all cases of diversion where the water is heavily charged with sediment, is a matter of doubtful policy on another score.

Division of the tidal scour.

By this diversion a very strong influence, which now acts in keeping the comparatively fine and commodious channel below Grand Island open, would be lost. Not only would the scouring power of the full winter flow be diminished, but the conservative action of the tides, elsewhere explained, would be divided between two channels, instead of being confined to one, and, as the tidal basin would not be materially increased, the tendency would be to make the two channels, combined, only as commodious as the one had been. There are already two serious obstructions to the flood-flow below Cache Slough—two bars, which should be removed ; and one of them is immediately opposite where the Montezuma Slough would return a portion of the diverted floods and cause a still worse bar. Practical observation and study of these questions by the most distinguished and successful engineers of late years, has led to the conclusion, in somewhat similar cases, that such diversion would result in serious injury to the navigable qualities of the river below the point of diversion.

The Mississippi mouths.

It has been shown that if the Mississippi River did not divide into three arms, or passes, as they are called, leading to as many mouths, but continued on in one channel, its waters would escape on so much less grade in the one channel than in the three; that the flood elevation would be lowered at the head of the passes 1.6 feet, and so on up to New Orleans, and beyond. Now, the advantage which the Mississippi gains in dividing, as it does, is to secure a wider field on which to deposit its sediment, and thus it does not build out any one of its mouths as fast as it would a single one, if all in one; and this is a slight advantage as compared to the disadvantages coupled with it.

The Sacramento mouths.

But the Sacramento would gain even no such advantage as this by a division of its waters in the manner proposed, for it has not a wide sea, like the Gulf of Mexico, to dump into, but, as shown, a portion of the diverted waters return to the main channel, and the other portion would be led by a circuitous route through a shallow slough, and be dumped out upon a mud flat, already, for the most part, bare at low tide. Under these circumstances, if this line of reasoning is sound, it is questionable whether the low cut through the Montezuma Hills would be permitted by the general government, having the interest of navigation in view. And it is more than questionable whether it would relieve the river in an appreciable degree at times of ordinary floods if it were made.

A cut through Grizzly Island.

There might be an entirely new mouth made to the river by cutting through the hills and through Grizzly Island, out into the bay; this would bring the channel to a great mud flat, four miles in width, necessitating jetties to keep it clear, and the effect would still be, as before explained, to hasten the arrival of the time when jetties will be necessary to keep the main channel free and open for navigation below Collinsville. Aside from this, the first cost of the work would necessarily be greatly in excess of that by the plan of making use of Montezuma Slough as a continuation of the new channel, and the damage to property would be greater also.

The deep cut a flood-gate only.

Now, it may be said that this deep cut would be used only to let the top of a sudden flood-wave out, and that the water would not be permitted to go that way, except in event of the channel below Grand Island being gorged.

A better flood outlet to be had.

If this is the only object in view, then it may be shown that a much better outfall exists, into which relief may be had at far less expense, namely: across Brannan Island, from the foot of Grand Island, into the San Joaquin River. This plan will be spoken of in the next article.

Final conclusions concerning the deep cut.

On the whole, it appears that the project for a deep cut through the Montezuma Hills, to drain the Yolo basin and afford relief to the river, is attended with many questionable points as to expediency and utility, aside from the fact that it must be a very expensive operation, for the cut alone might by no means constitute the greater portion of the cost, if it were undertaken. But of this more at some future time, when different plans of relief are considered on the economic basis.

Effect of leading the creek waters into Montezuma Slough.

In this connection it may be remarked, that the diversion of the waters of the Cache and Putah Creeks into Montezuma Slough would not have anything like the effect in raising the level of the water in that slough, that the admission of floods from the Yolo basin and Sacramento River would have. In the first place, the floods of the creeks mentioned are of very short duration up to their maximum limit; secondly, conducting these floods through the long channel they must run through, would greatly reduce their momentary volume, and increase their duration; thirdly, their volume is not so

great as that of the flood which would have to be poured through the hills in the deep cut, to make it worth while cutting; and, fourthly, the high grade canal would be carried to a point on the slough several miles nearer its lower outlet into the bay, and would enter it in such a manner as to send its waters, for the most part, out that way, and not back to the river at Collinsville.

Effect of diverting the creek waters from Yolo basin.

It should also be remembered that the diversion of these creeks would remove the chief cause of choking the river in Steamboat Slough, such as occurred in 1878, afford a greater capacity to the river above the point of choking, and leave more room for water in the river below; so that the relief sought for the island property by the cut through the hills would be in a great measure secured by removing this one great cause of the *sudden* accession of waters in the channel below the head of Grand Island.

RELIEF OF THE RIVER INTO THE SAN JOAQUIN.

The propositions for relief already discussed, have all related to some work designed to dispose of the waters of the Coast Range creeks, and the overflow or surplus waters from the Sacramento, which find their way into the Yolo basin, by carrying them to a new outfall through the Montezuma Hills.

Alternative plans of relief.

Should it be deemed advisable to attempt to turn the creek waters over the Montezuma Hills, it would then become necessary, in order to reap the full benefit from the work, to keep the Sacramento waters out of the basin, at least at its upper end. If the Sacramento, from the mouth of Feather River to the head of Grand Island, is to be relieved of a portion of its flood waters by means of a supplementary channel, undoubtedly the most favorable location for that channel is to the west, in or alongside of the Yolo basin, because the American river would interfere with the diversion on the east side.

A possible relief into the San Joaquin.

Below the head of Grand Island, however, as a measure probably calculated to afford a better outfall for a portion of the flood-waters which are so suddenly presented through the Yolo basin than the river presents, there is the alternative of opening an escape-way southerly into the San Joaquin river.

Floods of the San Joaquin.

This river is rarely in flood at the same time as the Sacramento. Its periods of full flow occur during the late spring months—May and June—when the snows melt in the high and distant Sierras, while full flow in the Sacramento is not to be looked for after March. It does not bring down anything like the amount of sediment that the Sacramento does, so that its shores are comparatively low and marshy. In its lower portion it has much less grade than the Sacramento, and having a more open mouth, the tidal action is greater. Indeed, it resembles an estuary or arm of the bay more than a river, below a point opposite the foot of Grand Island.

The San Joaquin channel a good point of outfall.

By diverting a portion of the flood waters of the Sacramento River into the San Joaquin, they would there find a much better outfall than in Montezuma Slough.

Past relief into the San Joaquin.

There are strong indications existing on Brannan Island, in the shape of the old channels which are there to be found, that at times in the past this has been the line of escape for the sudden eruption of floods from the Yolo basin into the lower Sacramento. Indeed, there was formerly an open channel, known as Jackson's Slough, which extended from Old River, near the foot of Grand Island, through to the San Joaquin. But this slough has been closed for some years, and other channels leading to the San Joaquin from near the Sacramento are still to be traced. If an outfall is to be made in this direction to take the top off the flood from the Yolo basin, its opening must be below the head of Grand Island; otherwise this property would be flooded.

Proposed point of relief into the San Joaquin.

The distance through from the Sacramento to the San Joaquin, opposite the foot of Grand Island, is five and one-half miles. During the flood of 1878, which has hereinbefore been described, the water stood in the Sacramento, at the point mentioned, thirteen feet above low tide in the bay.

The San Joaquin was in its normal winter condition at that time. There was not any flood there, I am told. If this was the case, and I have every reason to believe it was, then the tide was ebbing and flowing freely in that river, and at the point opposite the foot of Grand Island the low-tide level was two feet, and the high-tide six feet above low tide in the bay; or, in other words, the flood-water in the Sacramento, at the foot of Grand Island, was nine feet above half tide in the San Joaquin at a point only five and one-half miles distant. Suppose there had been a connecting channel through, the grade of the water surface would have been nearly two feet to the mile; or, rather, it would not have risen so high in the Sacramento, for the grade of the river flood-line itself was only 0.29 feet per mile.

A great relief might have been had.

Here, in much less distance than through the Montezuma Hills, might have been a free line of escape for that flood. The route lies through a low, swampy island. The cost of construction, as compared to that of the hill cut, would be insignificant, indeed, and the property damage no greater, if as great.

If, then, we are to anticipate the recurrence of the rush of waters from the lower end of the Yolo basin which occurred in 1878, it seems a wise measure to make a wide over-fall escape through the south bank of the Sacramento into a channel to be cut into the San Joaquin.

Effect of the proposed diversion.

It should be remarked that the objection urged heretofore against diversion of waters, on the ground of its causing deposit in the main channel below, does not apply with force as against the proposition

just considered, because it is thus far alluded to only as a channel of escape for a portion of sudden eruptions or waves of flood-water in the river, and would only act for a short time; and because, in the part of the river now under consideration, as will be hereafter shown, the conservative action of the tides will, under proper management, keep it clear.

Conclusion concerning the relief into the San Joaquin.

As a means of relief to be looked forward to with some degree of confidence, this measure is suggested, but its efficiency would depend greatly upon the line of treatment adopted for the river, thence to the mouth of Feather, as well as upon the treatment of the Coast Range creek drainage.

Such relief might not be necessary.

For instance, if the Coast Range creeks were turned over the hills into Montezuma Slough, and the Sacramento were not allowed to overflow into the Yolo basin, at its upper end, then there would be no sudden eruption of waters from Cache Slough and the Yolo basin to provide for at the lower end of Grand Island; and it would simply become a question of enlarging the capacity of the river. In this event, it would be necessary to afford all the relief possible past Grand Island, and then, as an auxiliary measure, Jackson Slough might be used to relieve the Old River channel. To effect a material benefit it would have to be opened and enlarged, probably. But more will be said of this plan hereafter, in speaking of the general treatment of the river.

In any event, the utility of this latter work would only appear after the flood-carrying capacity of the main river from the mouth of Feather River downwards had so far been increased that the volume of flood-waters brought to the point of diversion was such as to threaten overtaxing of the channel below, or if, by making the diversion, a greater capacity could be induced in the river above by affording a more open outlet than would be had otherwise.

The Old River channel to be attended to.

The Old River channel below this proposed point of diversion from it is already wider than it is above, so much so that the water is quite shallow, while above it is comparatively deep. To keep this channel well open, and at the same time to profit by the new outfall gained by the partial diversion into the San Joaquin, it would be necessary to provide for the passage of more water down the Old River channel to the point of diversion than can now pass, or else narrow it below the point of partial diversion, so that it would maintain a better depth.

Advantages and disadvantages.

There would also possibly be urged against a proposition to turn any considerable portion of the flood-waters of the Sacramento into the San Joaquin, the objection that the floods of the latter river might thereby be made to rise higher than they do now, to the detriment of lands now partially reclaimed but already so low and swampy as to be difficult to levee securely.

At present it cannot be said that the effect would be sufficient to lay a ground for such complaint. In view of the great size of the San Joaquin River below the point where the accession of waters would be had, and in view of the fact that the rivers are so seldom in flood at the same time (indeed never except at times of general extraordinary floods, when there can be no guarantee against overflow of any of the low lands), the probability is that no material effect of this kind would result; and the decided benefit which would accrue from having the very muddy waters of the Sacramento brought in to consolidate the river banks, and in time afford the material wherewith to build good levees, would be an argument in favor of the work.

Present relief through Three-mile Slough.

A considerable portion of the flood-waters of the Sacramento River now find their way into the San Joaquin River through "Three-mile Slough," which joins the two rivers at a point about six miles below the locality just under consideration. This junction is made at a point where the Sacramento has lost so much of its elevation above the San Joaquin, however, that no great amount of relief is effected, for the river above, during flood periods; though the 1878 flood was drawn down by that outlet, so that the surface slope from the foot of Grand Island to it was much greater thence to the mouth of the river.

INCREASING THE CAPACITY OF THE LOWER RIVER.

I have now indicated and set forth in general terms the merits and demerits, as they appear to me, of such plans of relief for the Sacramento River through the lower flood regions, by diversions of waters from their present channels, as seem at all feasible and worthy of consideration.

It yet remains to discuss the improvements of the channel of the river itself to insure the greatest flood-carrying capacity therein.

The groundwork for present opinions.

Preliminarily, I desire to state that the figures given in this discussion are partial results of laborious and extended computations made in this office. These computations are based upon the results of the surveys, examinations, and observations of this department, made during the past year and a half, and more particularly during the flood season when the cross sectional size and the slope of the river was constantly known throughout its valley course, and its discharge was being measured frequently at points between Colusa and the head of Grand Island (below which the operation of the tides interfered with current observations). And this work was supplemented by surveys or reconnoisances of all tributaries from Stony Creek, around the head of the valley, to the American River, together with observations for discharge during the flood flow in some of the largest of these streams as well as smaller ones of the number.

Deductions concerning the flood volumes.

From the data thus obtained, the rate of discharge for each tributary throughout the flood period has been approximately determined (knowing the character and drainage area of all), and tables of discharge made, from which it can be told, approximately, what amount

of water entered the valley during each hour of freshet. These flood volumes being traced down the stream and combined according to their time and place of presentation to the main channel by the rule that the toe of the flood-wave moves with the maximum velocity of the current, and the crest somewhat behind the mean velocity (varying according to the amount of reservoir space outside the channel itself to be filled, and assuming the channel to be of good regimen and sufficient in capacity throughout), it has been determined what would have been the maximum discharge at the head of each division had all the waters been confined within banks.

The results of this work will be submitted more in detail in a separate paper; meanwhile, for brevity's sake, certain extracts only will be herein used.

The ordinary and extraordinary floods.

The difference between the ordinary and the extraordinary floods of the valley have been heretofore explained in this report, and it has been intimated that the immediate object should be to plan for the rapid transmittal of the waters of ordinary floods, and only for the mitigation of the evils from extraordinary floods—such as that of 1862, for instance, which probably must be allowed to spread.

Types of the ordinary floods.

Now, the floods of February, 1878, and of March, 1879, may be taken as types of the ordinary floods of the valley, and as more is known of them than of others, they only are discussed herein.

CHANNEL IMPROVEMENT—GRAND ISLAND TO THE SAN JOAQUIN.

Actual discharge during flood of 1879.

During the highest water of March, 1879, the largest freshet of the season, and observed by this Department throughout its course down the valley, the channel below Grand Island passed about 87,000 cubic feet of water per second, as the largest average for 24 hours of flow.

Discharge really due to the lower river in 1879.

Supposing the channel of the river to have been of good regimen, and of sufficient capacity throughout—had the freshets last mentioned been confined between banks and carried forward to the portion of this river below Grand Island—the greatest volume here presented (leaving Putah and Cache Creeks out, as being diverted over the Montezuma Hills) would have been about 100,000 cubic feet per second.

Actual discharge in 1878.

By a comparison of elevations, slopes, and cross sectional dimensions, I am enabled to estimate that during the high water of 1878, when the large flood-volume came from the Yolo basin, the river channel below Grand Island afforded passage to about 135,000 cubic feet of water per second on an average through the tidal day. True, the levees on the south side were overtopped, for there was more water presented than was transmitted; but then the channel would carry the same volume at a lower level if its defects were removed, as elsewhere spoken of.

Discharge really due to the lower river in 1878.

Not having the data, it is difficult to say what would have been the greatest amount brought to the same part of the river had this freshet been confined. But, from some knowledge of the facts, and comparison of elevations at points where the discharging capacity of the river is known, I am led to believe that, had the creek waters been diverted, it would have been less than actually presented and transmitted under the circumstances of the rush of waters from the Yolo basin, as heretofore described.

The river below Grand Island.

In short, the Sacramento River below Grand Island can be rendered amply capable of carrying the maximum volume of ordinary floods, if that flow is presented to it in due order—as it would be if the whole river above were brought to a proper condition. And the islands south of the Sacramento, below Grand Island, can be protected from inundation during such ordinary flood-flow in the river, by levees but little higher than they now have, if the river is put in good condition past them, and at its mouth; *provided*, the waters are brought regularly down the river, and not through the Yolo basin.

The channel corrections necessary below Grand Island are three in number, as follows:

Proposed channel corrections.

First—Removal of the bar at the point of junction with the San Joaquin, opposite Collinsville; to be effected through the medium of the scouring action of the waters confined to a channel of proper width by jetties.

Second—Removal of the bar just above Rio Vista, opposite Newport, and the enlargement of the Rio Vista channel past Wood Island; to be effected in the same manner—by the construction of jetties from the mouth of Old River channel to the head of Wood Island.

Third—Widening of the channel and protection of Sherman Island shore in the Horseshoe Bend, just above Emmaton: to be effected by placing a series of spur-dikes in the concave side of the bend, to throw the current off and cause cuttings in the other shore, which is a low marsh island, not reclaimed.

The first two of these corrections are of the class sometimes undertaken by the General Government for the improvement of navigation in similar cases, and probably if any considerable appropriation were made for the Sacramento River, these works would be carried forward in that way, for the necessity for them is now being felt by the shipping interests of the river.

CHANNEL IMPROVEMENT—HEAD TO FOOT OF GRAND ISLAND.

Deficient capacity at Grand Island.

In a description heretofore given of the present condition of the river, it has been stated that the channels on either side of Grand Island are now large enough to pass the waters which could be brought to them by the one main channel above; that is, if its levees were maintained at a height uniform with and otherwise up to the standard of those on Grand Island, and along the east side of the river, generally, below Sacramento. As the effect of this deficient capacity, we

find a banking-up of the stream at the head of Grand Island, and an increased grade in the flood-slope down the channels on each side of it. Steamboat Slough is the shortest of these channels, and hence has the most grade.

The changes in Steamboat Slough.

Owing, however, to its exceedingly uneven cross-sectional form, to the unfavorable disposition of its head to receive the currents, and probably to other causes connected with the flood-flow from the Yolo Basin into and across its channel near the lower end, as well as to diminished tidal action, as hereafter explained, this slough has been shoaling rapidly of late years. It is really a *cut-off* in the channel; but these circumstances will not permit it to be effective.

Effect of cut-offs.

Cut-offs have the effect of lowering the flood-height above them, and unless they lead into a place of free outfall they also raise it below them; that is to say, in shortening the stream between two points—which a cut-off does—a certain amount of fall in its surface is saved; and this is distributed partly above by drawing down the water line, and partly below by raising it. Experience and observation have shown that, owing to bend-resistance being done away with, cut-offs generally draw down the level at their heads about twice as much as they raise it at their lower ends.

The river below Grand Island a free outfall.

The Sacramento River below Grand Island, when rectified as heretofore described, may be regarded as a free outfall of the streams above. First, because it will be of ample capacity to pass ordinary flood-waters; and, second, because its flood elevation heretofore at the foot of Grand Island, has been controlled by the waters which have entered it through Cache Slough and otherwise from the Yolo basin, and not by the waters which have gone down the river. So, as the amount which would reach it at any one time of ordinary flood through the channel, if all were forced to run in it, would not be as much as it was called on to transmit during the rush of waters in 1878, the flood-line would not be raised by sending the flood-waters into it on the route of Steamboat Slough.

To make Steamboat Slough the main channel.

Now, in view of the foregoing, and on the principle elsewhere spoken of, that the greater the volumes concentrated, the less the grades necessary in the streams, it may be readily understood that by making Steamboat Slough the principal flood-carrying channel of the river, we would lower the grade.

If, then, in diminishing the slope, we do not raise the lower end—as already shown would not be the case—the upper end would be lowered. This is the desired result—a relief of the river at the head of Grand Island, to induce a greater slope, scouring power, and capacity above.

Result of the observations of the Department.

For instance, the observations made by this Department during the last flood season have shown that the flood-slope at half-tide through the lower division of the river proper—from Collinsville to the head of Grand Island (15.78 miles)—was 0.2933 feet per mile, and above the head of the island for 13.83 miles of distance—to Freeport—the flood-slope was 0.3304 feet per mile.

If the river were one of good regimen, the slope of the middle division considered—that past Grand Island—would approximate very closely to a mean between the two adjacent to it—above and below. But we find it to be in Old River channel 0.3447 feet per mile, and in the Steamboat Slough channel 0.5305, in both instances greater than that above and that below; and the reasonable deduction is that something is wrong about the channel.

Without stopping here to consider the theoretical explanation of the phenomena, which will be attempted hereafter, I at once proceed to the practical consideration of the facts as they exist.

The distance from the foot to the head of Grand Island, via Steamboat Slough, is 11.88 miles. For this distance the elevation produced at the head of this division by the grade found to exist, is 6.30 feet above that at the foot, and the elevation which would be produced by applying a grade equivalent to a mean (0.3118) between that point in the division above and below, as just spoken of, would be 3.70 feet, or 2.60 feet lower than the flood-line observed. This would constitute the direct relief referred to.

Conclusions from these observations.

If the results of the one season's observations made by this Department are correct, it appears that here is an opportunity for greatly improving the river, namely, by making Steamboat Slough the principal carrying channel thereof.

The effect of relieving the river at Grand Island.

The beneficial effect of relieving the river through this seventh division would, of course, extend up the channel, and would be felt immediately in lowering the actual elevation as far as Sacramento. The tendency of the stream would then be to lower its bed through this sixth division and re-adjust its parts to the new conditions; and so the fifth division, in turn, would be relieved also.

Result of this relief.

Then, if the waters were relieved from the burden they now have to carry from above, if the sand-waves were arrested, we might treat the channel with the view of generally enlarging its capacity by forcing the scouring action of the currents, and which cannot be done to advantage until the defect in regimen at Grand Island is removed. This correction would necessitate the opening of a new head for the channel several hundred yards higher up stream, into which the current would change properly. And it would also necessitate widening its water-way, and straightening it also at the upper end for about 4.03 miles of its course, below which it is of ample width and only needs scouring out and some dredging, perhaps, at the Hog's-back bar.

Studies of this work.

Studies for this correction of the river are being made in this office on the detailed maps which have just been completed, and it is hoped that opportunity will be had to observe the flood phenomena

still further, in order that the results thus far obtained may be verified. Indeed, it is anticipated that further observations will give this matter even a more favorable aspect.

I now come to a consideration of the means whereby the general condition of the stream may be improved.

CHANNEL IMPROVEMENT—LOWER RIVER—INFLUENCE OF THE TIDES.

Land drainage waters.

The cross-section of the upper river (meaning by this term the portion above the Feather River) has for ages past, perhaps, been determined by the flow of the waters of land drainage only, together with local physical conditions whose mode of action is not so apparent.

The normal section of the river channel.

The character of the soil of the river bed, the quantity and kind of material transported by the waters, the presence or absence of reservoirs, relieving the height or prolonging the duration of high water, are elements helping to determine the normal section of the channel.

Determination of the normal section.

Leaving out what is merely local, and which may change from one part to another, the great general fact which governs the size of the river is the quantity of water it is called upon to carry, not spasmodically in great waves of flood of short duration, but habitually for great portions of the year.

Tidal wave in the lower river.

It will be observed, both in respect to the quantity of water carried and to the sources from which this water is derived, that there is a characteristic difference between the lower and the upper river. The latter derives its waters exclusively from land drainage. The former carries not only the land drainage, but also receives from and returns to the sea daily, two very considerable waves of tidal water. While the land drainage is spasmodic in its features—sending down for a month or two in the winter a great contribution, and then slacking down first to a moderate, and then to a smaller flow—the tidal supply remains sensibly uniform throughout the year.

Tidal action during floods in the river.

During the very high stages of the river, the tidal action upon the waters above the division nearest the bay becomes relatively insignificant, but during the low stages of the river, when the flow of low land drainage is reduced to five or six thousand cubic feet per second, the tidal supply becomes much the more important, and this is the condition of the river for some entire years, and for a great part of every year.

Importance of tidal action.

The proposition is well illustrated in the lower San Joaquin, which is a wide, deep, and imposing stream. That it is so is due almost entirely to the daily ebb and flow of a considerable tide in its lower divisions. If this tide were absent, or even if it were inconsiderable, rising only a foot, as it does at the mouth of the Mississippi, the section of the lower San Joaquin would be determined mainly by its land drainage above, and it must be plain, that under these circumstances, the river would be entirely different in character, and quite insignificant in dimensions.

Volume of tidal flow.

It is, then, not only the daily regularity of the tide, but its actual volume passing a given point, which goes so far to determine its channel section. Now, the quantity of tidal water which ebbs and flows through any given section during the tidal period of six or seven hours must depend upon the storage volume above; and it must also be said that the volume that can pass up a river is as much dependent on a favorable section and slope of channel as it is upon the rise of the tide itself.

Volume to be increased.

These two elements are in a sense complements of each other. If you can, by straightening a channel, or by guiding the greater velocity of tidal propagation up stream, and pass a greater volume, this same water on its return, being concentrated in its action, will not only conserve but will act to increase the depth of the channel.

Progress of the tidal wave.

The velocity of the transmission of the tidal wave is proportional to the square root of the mean depth. If, therefore, the mean depth is reduced by any cause, the velocity is lessened, the rise above becomes less, the quantity of water passing is reduced, the conservative action is diminished, and the useful qualities of the channel are in every way impaired.

Former tidal action in the Sacramento.

It is understood to be true, that 30 years ago the effect of the tide was noticeable at the mouth of Feather, and was as much as two feet at Sacramento. To-day, owing to the increase of slope, the tidal action is not felt above Haycock Shoal, which is about 31 miles below the mouth of the Feather River.

Increase in slope in the Sacramento River.

The increase of slope during the last 30 years below Sacramento is illustrated by the following facts: The low water of 1849 at Sacramento City was 3.85 feet above low water at New York Landing. The high tide mark at New York was then several feet higher than the low stage of the river at Sacramento. Now the average low water stage of the river at Sacramento is more than nine feet above low water at New York Landing, showing an increase of slope of more than five feet in 50 miles during 30 years.

Change in the mean depth in the water of the channel.

While the minimum depth of the channel below Sacramento has not greatly changed, except through Steamboat Slough, and on the Newtown Shoal, it is known that the mean depth has been much reduced. The deep pools have been greatly filled. In these facts we have the explanation of the reduction of tidal influence within recent years, as we ascend the river.

Conservative action of the tides.

If then, we admit the conservative action of the tide—and of this there can be no doubt—we must next inquire whether it is possible to extend the range of ascent of the tide to points higher on the river, and increase its height all along the range. From what has been said it will be understood that this question is only another form of inquiry whether the mean depth of the lower river can be increased and its slope diminished.

Difficulty of increasing the tidal action of the river.

The first answer to this question must, I think now, under present circumstances, be in the negative, for the reason that the volume of sand coming down the stream is as great as ever. The causes which have produced the increased slope, and have encumbered the channels, are still in existence. Not only are the channels now more or less encumbered with sand, but there remains an unmeasured reserve of great extent in the river beds above and in the cañons of the hills, to add influence to these unfavorable tendencies.

Restrain the sand flow.

If these bad influences cannot be restrained, or substantially modified and mitigated, we must continue to give a negative answer to the question. The opinion has been expressed in this report that such modification is possible. If this hope should, by proper action, become a positive fact, the character of the engineering problem would be entirely changed. The Sacramento would then become what we might term a natural river—subject to such influences only, for good or evil, as natural processes produce.

The tidal action can be increased in the river.

Under such conditions, the problem of extending the influence of the tide could be attempted with every confidence of success. It becomes, then, no longer an untried experiment. It is merely a repetition of operations that have been successful in many European rivers, notably the Clyde and the Thames.

It can hardly be necessary to do more here than sketch a general outline of the means of accomplishing these results. This has been really indicated in what precedes, but it may be well to point out here how it will be possible to detect the places where special constructions will be necessary in order to promote the object in view.

To discover the defects of a tidal channel.

A defective condition of a tidal channel may be recognized in one or both of two ways: Either by the abnormal shape of the diurnal tidal curve, which is recorded by an ordinary clockwork tide-gauge, or it may be shown by a sudden change in the slope of the co-tidal line, as shown on the profile of the water surface in the channel.

The defect being evidenced in this way, the cause is sought for in the local section or local slope; the section may be too wide, or too narrow, or ill shaped, an adjacent bar may exercise an injurious influence, or the slope may be too great, or a secondary channel may interfere. In some such way, the cause being clearly established, and the case diagnosed, the remedy is usually not difficult.

Diagnosis of river phenomena.

In river treatment the diagnosis of the case is really the essence of the matter. The facts are so various, and so obscure, that in ascertaining them and disposing them in their proper relation, lies the main difficulty, and in the inability to ascertain and formulate the facts, is the explanation of the failures that have sometimes occurred.

Scouring power of the waters.

These local defects being cured, the natural forces, which are the land drainage and the tidal currents, will then have a fair opportunity to do their work, and the influence of the tide being favored, it will return the service partially in the flood—by disposing the material which it carries on the borders of the channel—and in the ebb wearing a deeper channel in carrying the sands to lower points.

Observations of the past season.

Now, the observations of the past season, conducted in the manner described through the agency of clock-work gauges and connecting level lines, have shown not only the serious defects in the river above, heretofore spoken of, but that the channel bars at the mouth of the river exercise a most pernicious influence on the tidal wave in its passage up the river—prevents its free propagation, and hence diminishes the conservative action just outlined. A striking illustration of this is found in the fact that the high tide level below the bar is a foot higher at the low stage of the river than it is at Rio Vista, 13.8 miles up stream, along a deep, open channel. Thus the bar prevents the filling of this basin by the tides, and their beneficial action in scouring the channel above is limited; hence, for this reason also, as well as that it is an obstruction to the flood escape, this bar should be removed, as heretofore recommended.

Time required to improve a tidal channel.

This sketch of operations is not for those of a day or a year. The engineering devices will bring about no violent or sudden change in the river. They must first arrest or modify the destructive agencies, and then they must aid the force of nature in restoring the channels and further improve them.

To improve the Sacramento River channel.

It has required the expenditure of vast amounts of time, ingenuity, money, and physical force to put in operation and to bring to their present condition the agencies which have wrought and still are working injury to these channels, and of which I have spoken. To counteract these the State must recognize that at least some considerable proportion of the same elements must be applied.

The tidal flow and the floods in the river.

Now, it may be asked, supposing that these results are obtained after some years of effort and expense, in what respect, other perhaps than in navigation, will the river community be benefited—*will the flood line be lowered?* If we admit the tide again to the upper reaches, will not the tide add to the height of the flood within reach of its influence? Does not the increased slope now existing promote rapid drainage of flood? To this may be answered, that the increase of slope

does add something to the velocity of drainage, but that is much more than offset by the filling of the stream.

The river section and slopes.

The increase of section in the rivers, the cleanness and smoothness of the channels promoted by the daily action of the tides, and the lowering of the slope, are all favorable to a low flood-line.

This is well illustrated in the lower section of the river, where the flood-slope is much less than in the section about Sacramento, as shown on the longitudinal river profile in this office. If this slope could be carried to Sacramento, the flood-line of 1879 would have been seven feet lower than it actually was at Sacramento.

Low slope of tidal rivers.

This low slope is found in the parts of the river least impaired by deposits, and preserved from these deposits by tidal action. In the ratio that the lower channel is blocked by deposits, so will the flood-slope be increased, and the floods above be heightened.

Importance of the conservative action of the tides.

The tide is, then, according to the view of this report, the salvation of the lower divisions of the river; and the extension of its influence, either by raising its level at any given point, or by extending its flow up the river, is so much gained in this general interest.

CHANNEL IMPROVEMENT—LOWER RIVER SCOURING ACTION OF THE CURRENT.

In the improvement of the Sacramento River channel, the most potent influence for general good must ever be the transporting power of the current in the stream itself, produced by the outflow of land drainage waters; for the beneficial effect of the tides will be confined to the lower division of the river, while this scouring force of the drainage waters gravitating to the sea is present throughout the length of the river, and only needs to be guided and concentrated to work industriously for the desired result.

Transporting power of currents.

Without entering here upon any discussion of the transporting power of running water, which is very generally recognized but very little understood, it is well to say that the observations made by this Department in the transportation of sediment and sands by the waters of the Feather and Sacramento Rivers show conclusively that, though at the lower stages of the streams, with the presence of a small mean velocity of current, there may be a greater percentage of solid matter held in suspension, yet, when the streams are high, the sediments carried are of a heavier character, more sandy in their nature. And, furthermore, it has been observed that during the full stages of the streams the bottom is one moving mass of sand.

Observations of the past season.

At Freeport, 14 miles below Sacramento, where the river was sounded and resounded 14 times in one cross section, carefully, over the same spots, during the highest freshet of the season, changes in mean depth of 1.5 feet in 24 hours were frequent, and the rule; while on one occasion the mean depth in one cross section varied 2.64 feet, with a maximum variation for about 100 of the width of 6.5 feet in depth. And from the cross-sectional measurements of the streams, it has been found that where the waters, which are now confined below the mouth of American and above Grand Island in one channel, pass between banks about 450 feet apart, their mean depth is 12 feet below the low water line of 1878, as against a depth of 4.8 feet in widths of 900 feet; and that during floods the tendency is to raise the bottom in the wide reaches and scour it out in those of average width and in the narrow places, when scouring is going on at all.

Here is the evidence of the ability of the current to restore the channel and make it better than ever, if it had the opportunity—were freed from the load of sands constantly coming from above, and had its channel bars removed by proper treatment. It were useless to prolong this report by the citation of many facts as to the nature and extent of this class of phenomena observed during the past season; suffice it to say, that certain primary practical conclusions of fact are had, as follows:

Results of the observations made by this Department.

Where the channel is at a width duly proportioned to the amount of water it now habitually carries, we find depths of water which produce a well-formed cross-section; and furthermore, at such places the sands are carried up in the body of the current more than in the wider reaches, where they are rolled along the bottom.

Conclusions from these results.

These facts appear to show that confining the water to a channel of width bearing such a proportion to its volume as to cause a scour to the greatest depth possible, produces conditions in the filaments of the current favorable to the transportation of the heavier sediments.

Now, if these observations are not in error, and if the deductions are sound, then we have a key to the measure of scouring power we may expect should the river be run as full as could be carried between embankments of a safe height.

General treatment of the river channel.

It were idle at this time, however, to enter upon a discussion of just what this effect would be, even if the observations had extended over a sufficient length of time to be certain of our results (which they have not); for so long as there remains the constant supply of sand from above, the increase of scour in the lower river would only accelerate the advance of this injurious silt from the upper source. Of this we may be certain, however, that if the supply of sand could be stopped, these river channels could be very much improved within a few years, chiefly through the agency just discussed.

Process of channel improvements.

The process would be somewhat as follows—for the river below the mouth of Feather: We must suppose the water delivered at this point through channels from the Upper Sacramento and from the Feather, and not from the great Sutter basin, as much of it now comes. Why this must be, and how it may be accomplished, will be spoken of later.

With the corrections in the channel below, heretofore noticed, and

a similar treatment for several other shoals at points above the head of Grand Island, the stream would be of fairly good regimen; it would be in a condition to levee, and by raising the water surface force the scouring action without danger of washing out the material at one place in the channel only to deposit it at another, and thereby making a worse obstruction than there would be if it had been deposited more evenly down the bed.

Uniform system of leveeing.

Thus, were the levees of even disposition, uniform heighth, properly adjusted width apart, according to the flood volume to be carried, we would have a channel balanced in all its parts.

With these embankments five feet above the flood plane of 1879, 3.3 feet above that of 1878, from Feather River to the head of Grand Island, in the average their mean elevation would be 7.0 feet, or 3.0 feet higher than the average of the levee now existing on the east side of the Sacramento below that city to the lower point named.

Relief of the channel.

During the first years of the flushing of the channel such a levee would be liable to overflow by the waters of ordinary floods; but this must not be permitted, neither should considerable volumes of water be diverted at one point as a relief, for the conditions in the current favorable to the transportation of sediment would thereby be disturbed, and deposit would occur. But at many points, say every four miles along the way, located according to circumstances, to be studied attentively, there should be an escape weir capable of passing a maximum volume of 2,000 to 5,000 cubic feet per second, each opening into a channel between embankments leading back into Yolo basin.

Forcing the scouring action.

Now, so long as the river channel could pass all the water presented for transmission during any freshet, none should be allowed to escape; but the scouring power should be preserved at a maximum degree for the greatest period possible; but when there came danger of rupture or overthrow of any portion of the levee, the floodgates should be permitted to act sufficiently to ward of the evil.

The result to be expected.

It cannot be doubted that the result would be made manifest in a great increase in the capacity of the stream. The narrowest places would be widened, the bottom all along taken out, and if per chance a hard bar should be exposed that would not yield to the scouring action, it must be dredged out; if a bank cave so as to endanger the levee, it must be protected, and promptly, too.

Such is an outline of what is thought to be a proper treatment for the lower Sacramento. Further details at this time would add nothing to the practical value of this report. The principle involved is broad; river improvement, the "promotion of rapid drainage, the reclamation of swamp and overflowed lands" of this valley, requires organization, government of works, subservience of individual interest to public good.... . ....

TO PROMOTE RAPID DRAINAGE—LOWER FLOOD REGIONS—RECAPITULATION.

Works advisable on the lower river.

With the lights before me at present, it appears that much good can be effected, and great harm prevented by—

First—Turning Putah and Cache Creeks over the Montezuma Hills to a new outfall, through the Montezuma Slough.

Second—Removing the channel bars between Grand Island and widening the channel in the Horseshoe Bend.

Third—Opening a new head to Steamboat Slough, and making it the main flood-carrying channel of the river.

Fourth—Constructing an uniform system of levees higher than those now existing, with waste or flood escape weirs at short intervals of space, leading into the Yolo basin.

The sand flow must be stopped.

Always provided, however, that the sand flow from the upper streams be checked, that the whole drainage system is properly managed after the works are built, and that the upper valley drainage is regulated as hereinafter described.

Results from this treatment.

With this accomplished, very much of the Yolo basin would be exempt from flooding in all ordinary winters; for a comparatively narrow strip through the upper part would lead away all the flood that would get into it after a very few years, to the great sink at its lower end; and as the floods would always run down much sooner than they do now, such lands would dry out earlier in the season, for there would be no escape upon them except at the top of the flood flow.

The American basin would be exempt from overflow from the rivers, but would still receive the drainage waters brought down by Auburn Ravine and other creeks from the east. In the course of time this could be remedied by conducting these waters to the river, some around the head of basin, and some into the American at the lower end.

Grand Island, and others below it, would be no longer endangered by sudden eruptions of water from the Yolo basin upon them; for unless there should come such a great inundation as was presented in eighteen hundred and sixty-two, there would never be enough water got into the basin to produce anything more than a gentle flow from Cache Slough.

The river bank property, including the City of Sacramento, would be much more secure than it would be otherwise, for the river, though kept at a high stage, would have a regulator, so to speak, upon it, and with judicious management the danger of overflow would be reduced to a minimum.

The character of the relief to the channels.

It will be seen that the project involves the diversion of water from the river channel at time of flood, but it should be distinctly understood that the manner of diversion is entirely different from that, where 20,000 to 30,000 cubic feet per second are taken out in a low grade canal at one point. And furthermore, it should be remembered

that the diversion is only proposed for the top of the flood; that it would only be a temporary mode of relief during the first years of the process of improvements; and that the whole aim and object of the work would be to make the river in the course of time carry all the waters of ordinary floods, in its own channel.

A final report impossible.

I regret that I am not enabled at this time to give an unqualified opinion that this plan will afford a speedy and complete relief from overflow. All that can be said now is that it will greatly better the existing state of affairs; that instead of becoming worse, there will follow a gradual but certain improvement in the drainage of the valley, and that in any event, if present tendencies are to be stopped, and the drainage ever to be perfected, very much if not all of what has been suggested must be done. In this connection I call your attention to the concluding paragraphs of this part of my report.

THE UPPER VALLEY DRAINAGE PROBLEM.

This problem has been stated as follows: To provide drainage-way sufficient to bring the waters of ordinary flood volume from the Upper Sacramento, near Stony Creek, through to the head of the lower region without overflowing or threatening the upper region of present floods.

By reference to the description already given of the river, it may be seen that above Butte Slough we find a channel of greater slope, dimensions, and capacity than below it.

The waters advance rapidly to the point spoken of, gorge the channel below, are thus backed up to high flood level, and cause inundations. True, they also overtop the banks or break existing levees between Princeton and Chico Creek, before the gorge, 25 to 50 miles below, is consummated; but then, as compared to the leveeing on the lower Sacramento River, there has never been anything done, except at limited localities, to prevent this.

Suppose even greater embankments would be required for the purpose than on the lower rivers, certainly if levees must be higher and stronger in one locality than another, it seems reasonable that when the greatest flood wave is presented, it should be dealt with by means proportioned to the necessities of the case, if such are practicable, unless relief may be had without increasing the burden to be borne elsewhere.

This latter exception is seldom the case; for in conducting flood waters down the valley, any acceleration in rapidity of drainage in its upper divisions, by precipitating the flood below, increases the momentary volume there, and necessitates more drainage way for its accommodation, else inundation will follow. This is particularly the case where, as in the Sacramento Valley, there are large tributaries joining the main stream, whose freshets arrive at the point of junction before the waters from the upper valleys get there. The first flood wave thus presenting itself to the main channel, should have all the time possible in which to move away before another is brought down upon it.

The only exception to the general rule discountenancing increase in rapidity of drainage from the head of an alluvial plain when the stream below is deficient in capacity, is to be found where its waters can be conducted to a separate outfall; that is, not brought down to meet other floods. I have not been enabled to see how this can be accomplished from the Upper Sacramento, and hence conclude that the wise and just plan to follow will be to do all that can be done—construct works at least up to the standard reached elsewhere in the valley—to prevent the spread of the waters which cause so much injury below. When this is accomplished the floods will appear less formidable. I hope to have an opportunity hereafter of presenting much detail of fact concerning this problem, which would unnecessarily prolong this already lengthy report; for the present, the subject will be considered only upon the principles involved in dealing with the flood-waters and the river.

CHANNEL IMPROVEMENT ABOVE COLUSA.

From what has been said concerning the relative capacity of the river above Butte Slough or Colusa, and below those points, the importance of limiting the discharge from the upper divisions into that below, to as small a maximum quality as possible, will be readily recognized; the capacity below is already deficient; it will take time to increase it, therefore the waters from the above must not be unduly presented if possible to present it. The greater the storage room in the stream itself, above the point of least capacity, the less the maximum outflow from the upper divisions need be to prevent disaster to levees there. Hence above Colusa it is necessary that the levees should be far apart. Fortunately other circumstances contribute another argument for this disposition. The immediate banks of the river in this region generally do not afford a safe foundation for levees, for they are continually caving down, but a favorable locality is found in the hard plain lands which extend on either side of the river, at the distance of a mile or more from rim to rim. By placing the levees back on these hard rim lands, one great object of the work will have been accomplished; a large reservoir capacity attained above a portion of the river where the capacity to pass the water is comparatively small.

It has been stated that another object of work in this division above Colusa should be to prevent the too rapid passage of the waters to the division below.

The natural tendency of the river is continually to shorten its course by cutting across the long sinuous bends at time of high water, and then when it falls within banks, to increase its tortuous course by caving down the banks in the concave side of the bends, and so add to its length again. Thus at any one of the many different points a cut-off may at any time occur, which would shorten the route of the main volume of water from half a mile to two or three miles. The rate of fall is thus increased by shortening the distance between points; the resistance to onward flow presented by the sinuous course of the river is done away with at that locality, and a more rapid advance of the flood-wave is the result.

This result is just what is not wanted in the division under consideration, for the general good sought by a drainage system for the valley, hence it seems reasonable that cut-offs above Colusa should be prevented, and the river should be encouraged to increase the

sinuosities of its course, up to the point wherein the reservoir capacity in this division is brought to the highest figure in volume it can be put to without overtopping levees of safe and reasonable elevation and cost. Were the channel more crooked than it now is, it would be longer, and the storage capacity greater in it, the slope would be less, and hence it could be the more readily made navigable and kept so all the year round.

Upon this general plan the principal works essential above Colusa to Stony and Chico Creeks, will be:

First—A levee from eight to fourteen feet in height, on each side of the river; the two as far apart as the topography of the country and the character of the soil will admit, up to a maximum limit of two miles, with an average of about 1¼ miles.

Second—Protection of banks to prevent caving where the river manifests a disposition to make cut-offs.

Third—Encouragement of caving at points where it is desirable to increase the length or give a better trend to the channelway, and so prevent the formation of bars.

Fourth—Training the current to cut channels of moderate depth through the very shoal places, and so increase the navigability of the stream, and preserve its stability when desired.

Fifth—Production of a growth of timber and underwood on a large portion of the country between the levees, to hold back the flood waters, when above the natural surface of the ground, and so prevent a downward rush thereof by the short route across points, and the formation of cut-offs which would thus occur.

It may be thought well to divert waters from this channel, near the head of the division under consideration, and conduct it by a canal through the Butte basin or alongside of it to some other point on the stream below, and thus diminish the necessity for extended work along the river in this upper division.

After what has been said, a moment's reflection should lead us to recognize the fact that this would constitute one big cut-off—a cutting off of all the bends at once—for a part of the waters at least. If the principle is wrong in the one instance under existing circumstances, it is wrong in the other.

If the waters from the Upper Sacramento are brought to the river below sooner and in greater volume than they would come down through a natural channel of good regimen—even capacity to hold or pass the water as it is presented to it—the problem of drainage is rendered more difficult. The lower regions would be flooded for the relief of those above. And it seems reasonable, first, at least, to do all that can be done to prevent this result before it is deliberately sought after.

CHANNEL IMPROVEMENTS—COLUSA TO FEATHER RIVER.

While above Colusa, an object to be held in view under existing circumstances, is to prevent unnecessary rapidity of movement in the flood-wave, below that place the point of balance is passed, and thenceforward to the mouth of Feather, and, indeed, to the bay, it is necessary to assist in every way the carrying capacity of the channel in order that the waters may be conducted onward as promptly as they will be presented from above.

In the division below Colusa, or Butte Slough, rather, the channel is extremely crooked and narrow. The fall is small compared to that above, as will be seen by the description given elsewhere.

In the 64.6 miles of the route from Butte Slough to the mouth of Feather, the fall in the flood line of 1879 was 29.15 feet. Of this fall about thirty to thirty-five per cent. was consumed in bend resistance. That is, if the channel were a straight one, or one of moderate and gradual curvature, the same amount of water would run through it with thirty-five per cent. less fall.

The importance of cutting off some of the worst bends in this region is here made apparent.

Aside from this line of treatment, to increase the flood slope and diminish bend resistance in this portion of the river, we may apply the expedient proposed for generally enlarging the capacity of the stream below the mouth of Feather, namely, thorough levying and working the channel up to its full capacity, without allowing the levees to be breached, for as long a time each season as the river will furnish the supply.

But above the mouth of the Feather greater obstacles are to be overcome in the scouring process than below, in the form of a harder bottom and banks more firm. So it is possible that the power in the running waters would have to be assisted by artificial excavations to a much greater extent than below.

Perhaps this channel would not at first carry all of the waters presented to it during the passage of the crest of the flood waves down the valley.

Admitting this, the period of time when it might not thus pass all presented would be short—three or four days at most—and for that time all in excess of the maximum capacity may be taken through the levees by means of suitable weirs, or flood-gates, and conducted in embanked channels to the low basins from whence it could be drawn out again so soon as the river would fall.

The Sutter basin, for instance, is now annually flooded. The water enters it from both ends, commencing with the first rise of the river each season, probably in November, and it is not drained until as late as July.

Quite frequently there is not more water presented to the river past these basins than it could readily carry until the end of January or middle of February, if treated as heretofore described.

This was the case in the season last past, the floods of which were observed by this department.

Yet the Sutter basin received water in December, 1878, was well filled in January following—six weeks before the highest freshet came.

And on only one occasion during the season—for seven days, from the 5th to the 12th of March—was there more water presented than this channel would carry in its present condition, if evenly leveed and the river below presented a good outfall, as it would if the system of works outlined for it were carried out.

Thus during the season of 1878-79 the real surplus waters of this upper river, had it been under treatment by the progressive system proposed, would not have filled the Sutter basin alone to more than about half the depth it was filled. The river would have run down much earlier in the season, and the water that would have been put into the basin could have been drawn down earlier in the season than it was under the order of things now existing.

It is respectfully submitted that even this would be a vast improvement to the present condition of affairs.

It would be an improvement for the basins themselves, because it would keep them free from water for a longer period each year, and because a larger portion of their lands could be cultivated during each such year as the past has been.

And it can not be doubted that the river would annually become more and more capable of carrying the waters brought to it, so that a complete immunity from flood during ordinary years might be looked forward to for all the low lands of the upper region.

Not only would this arrangement produce at once a great improvement over the present condition of affairs for the lands now annually flooded in the upper valley, but it would render possible a proper treatment of the river below the mouth of Feather, which could not now be undertaken, even with all other pernicious influences removed, if the Sutter basin remains open.

INFLUENCE OF THE UPPER VALLEY FLOOD-WATERS.

In the discussion heretofore entered upon concerning the relief canal, and again in considering a treatment of the lower river for its general improvement, I have spoken of how the water now flows at will into and out of this Sutter basin at its lower end. As it is now, the elevation of water in this basin governs the flood line in the Sacramento at the mouth of Feather River where the basin comes to an end.

Should the attempt be made to improve the lower river by a uniform system of leveeing and the treatment heretofore outlined, the flood line must be raised, temporarily at least, at this point. Were the Sutter basin open it of course must fill before this elevation could be obtained, and possibly to a higher level than ever before in ordinary years.

We would, under such circumstances, have a state of affairs about as follows:

A large portion of the waters of the earliest freshets of the seasons would be taken up in filling this reservoir, and meanwhile the river below could not be run full and the benefit of the scouring action obtained. Later would come a heavier freshet; much of the storage capacity of the basin would be by that time taken up; this new water—the first of the heavier freshets—would fill still higher the wide expanse in the basin, by entering as it does now from points above on the upper river, as well as at the lower end, and where the maximum volume of the flood—that only which the upper river could not pass readily to the mouth of the Feather—presented itself, the waters must rise still higher to give it room. Meanwhile the river below, until this highest point in the flood above should be reached, would not have been performing its full duty—for there would not be *head enough to force it* as long as the waters had the opportunities to spread.

Now, this vast volume of water, resting unrestrained immediately at the head of the lower river, and in open communication therewith, would be a continual menace to the region below, an impending evil which might at any time overthrow the best laid plans; for, were the levees up to a standard as to elevation and weight never so perfect, and amply sufficient for all ordinary flood contingencies in the river proper, yet might a strong north wind, sweeping over the twenty-seven miles of this lake surface down to the head of the leveed portion of the river, pile up there such a volume of water to be carried away as would bring disaster to works and lands far below.

Something similar to this occurred in 1878. A large portion of the great flood-wave which overthrew the levees of Grand Island was blown out of the Sutter basin 59 miles above. Entering the head of the lower Sacramento from this basin, the flood line was raised at the point of junction about five feet in a few hours. This wave went down the river, caused breaches in the levees, and swept into the head of the Yolo basin, diagonally across which it coursed, running well up on the west rim, and making higher water there than on the east side at opposite points; thence, turning, it again crossed the basin and was projected out into the Steamboat Slough and the division of the river below, where it overthrew portions of all levees in its way, and destroyed property valued at hundreds of thousands, almost millions of dollars.

The primary cause of this mishap, of course, was the deficient capacity in the river at many parts of its course; but, setting natural causes aside, there is an important cause in the defective system of works in the upper flood region. Thus does the safety of property, the good condition of the river, and the welfare of the lower valley, depend upon efficient works in the upper valley. Unless the waters are kept from spreading from the river at will into the head of the Butte basin, and thence on down into the Sutter basin, there can be no thoroughly efficient treatment of the lower river, and no permanent security for works and property far removed from the seat of primary flooding.

I hope to have the opportunity of presenting facts in this and similar cases in a more definite form at some future time. At present the most important and the fundamental principles are sufficiently illustrated.

The present condition of affairs can be greatly improved. Very much land now annually inundated can be protected from overflow during any ordinary flood, through a proper treatment of the drains made by nature to carry away the waters, provided the whole system of works be under proper control, and authority be lodged in the right place to adopt such measures as may be necessary to construct and maintain the works everywhere in the valley to an equal degree of efficiency. When this is done a long step will have been taken towards the complete and rapid drainage of the valley, and this much wished for consummation will neither seem nor be so far in the distance.

SUMMARY OF CONCLUSIONS.

In closing this part of my report, for the purpose of bringing together what appear to be the important points in the whole matter of promoting the rapid drainage of the Sacramento Valley, I now summarize certain deductions already made, and add thereto others which will be more fully substantiated in what will be said hereafter under the head of "The Flow of Mining Detritus."

The channels deteriorating.

First—The valley rivers, already much deficient in capacity to carry the waters of ordinary floods, are annually, in the most important divisions, becoming less capable of performing this duty.

The sands the primary cause.

Second—The great primary cause of this deterioration of the channels is the flow of sands from the cañons into which the mining detritus is dumped.

A bad levee system.

Third—The carrying capacity of the streams and their efficiency as drains has been greatly injured, and the problems of regulating the drainage of the valley have been much complicated by the injudicious location of embankments and uneven results of leveeing along the rivers.

The channels never large enough.

Fourth—The river channels never were capable of passing the water of ordinary floods through some of their divisions without material rectification thereof, and the attempt to confine flood-waters by the simple construction of levees without systemization and the aid of other devices to improve the channels themselves, could not have succeeded generally, even though the sand-flow had not come down the rivers.

Destruction of Steamboat Slough.

Fifth—The very existence of Steamboat Slough, an important branch of the river, as a navigable and flood-carrying channel, is threatened, as evidenced by its rapid filling within recent years.

The future of the lower rivers.

Sixth—In the natural order of things we may look for the serious impairment of the navigable qualities of the lower portion of the main river in the near future; the flow of sands from the supply already in the beds of the Feather, Yuba, Bear, and American Rivers will bring about this effect unless the lower river itself is treated to improve its regimen; and, in any event, this result would follow before the general good effect of the scouring action could be fel below the mouth of the American River, unless the river channel below that point were rectified.

Importance of restraining the sand-flow.

Seventh—The presence of sand in the upper rivers, whence it is liable to be brought down in quantities, impairs the confidence which ought to exist in the success of whatever plans may be projected to regulate and facilitate the drainage of the valley; and hence, it is doubly important to ward off the danger.

The sands now in the cañons.

Eighth—If the deposit of detritus in the streams were to cease at once, yet would it be necessary to restrain in the cañons, and in the tributary streams below the cañons, that which is already there, and stop the flow of the sands therefrom, in order that we may count, with any considerable degree of certainty, upon the efficiency and permanence of drainage works in the valley.

A remedy possible.

Ninth—This danger can be warded off, in a great degree, at least, without radical interference with existing interests.

Danger of delay.

Tenth—The restraint of the sands in the cañons, and in the deposits along and in the tributary streams below their cañons, admits of no delay. It is the first objective point in the restoration and improvement of the carrying capacity of the valley streams.

Natural tendency of the stream.

Eleventh—If this desirable result were measurably secured—if the flow of sands into the Feather and Sacramento Rivers was stopped—the natural action of the rivers, relieved in a great degree from the load they now have to carry, would be to excavate their beds, and gradually to work back to the regimen of twenty years ago.

The river channel.

Twelfth—The accomplishment of this latter result can be greatly hastened by engineering devices and works, and subsequent management thereof; and, under any plan, this treatment of the natural drains must form the chief feature of the scheme for providing rapid passage for the waters.

Extent of possible improvement.

Thirteenth—As it would have been eminently practicable to have improved the carrying capacity of the streams to a very great extent before they became injured by the sand-flow, so, as they are brought back to their former regimen, may their rectification and enlargement of capacity be carried far beyond that point.

Raising of the river channel.

Fourteenth—This filling of the main channels, though confined to the Feather River and the Sacramento below the Feather, does, by raising the flood lines at the junction of the two streams, reduce the slope and capacity of the Sacramento above the point of junction, causing greater overflow, and seriously complicating the problem of drainage in the upper valley.

Interdependence of works.

Fifteenth—The interdependence of works for the preservation of overflow throughout the valley has been so completely demonstrated by the mishaps and disasters of the past, that the solution of the problem of drainage here presented can only be hoped for when the work is carried forward with the one object of disposing of the waters as a whole, and not, as heretofore, for purposes of reclamation of separate parcels or districts of land, and therefore it is essential that those operations should be under one head.

Injury to valley lands.

Sixteenth—The direct injury to valley lands, caused by the flow of sand and "slickens" over certain large tracts thereof does not represent the measure of harm thus far done to the agricultural interest, for other lands are in danger of similar submersion; still others have been rendered less fit for cultivation by having the flood lines raised in the adjacent streams so as to make them swampy in character, and the great body of the low valley lands has become less valuable, because more difficult of permanent reclamation, by reason of the injury to the flood-carrying capacity of the rivers.

Benefit to valley lands.

Seventeenth—On the other hand, however, there are lands in large bodies which, as they stand now, are more valuable than before the stream beds were raised; for, having been dry lands of poor soil, they have been rendered moist and tillable in a high degree by the raising of the sub-surface waters in them, which has followed as a consequence of the raising of the streams.

Keeping sands out of the cañons.

Eighteenth—Without doubt much of the mining detritus can be kept out of the main cañons, thus largely diminishing the quantity to be there reservoired, but how far this remedy, or preventive, rather, may be applied, can only be determined by special examinations of the various mining properties.*

Scope of the subject.

Nineteenth—This is a subject of great scope and importance directly, affecting the welfare and prosperity of a large portion of the people of the State, and the problems involved are of the gravest character, so that their solution cannot be arrived at, if fully worked out, even in a year.

Gradual treatment.

Twentieth—Remedial works can only be carried out by degrees, and the detail of treatment which the subject must receive can only be determined upon finally, as the partial results attained point out the way, and by such policy a satisfactory issue may be looked forward to.

RECOMMENDATION.

The State control of river works.

The study of this subject having brought me to a sense of the absolute necessity for organized effort in these matters, I can only recommend that the State take charge of the drainage ways and all drainage works, and exercise such control over them as will regulate their use, promote their improvement, and systematize the construction and management of all works designed to promote rapid drainage and prevent inundations.

Financial outlook.

As to who is to pay for the necessary constructions, it does not appear that any suggestions find a proper place in this report. I may remark, however, that nothing which has been said is to be interpreted as meaning that I see no way of accomplishing the desired end except by State work; on the contrary, while some of the devices necessary are certainly such as the State might with propriety, in my opinion, contribute towards, the great bulk of the work is

* The last conclusions will be illustrated in the report on Mining Detritus.

such as should be paid for by the property in the drainage district where waters are to be purified and conducted away. And it would seem strange, in view of the immense amount of property affected, if the necessary funds could not be secured by organized effort.

CONCLUSION.

In conclusion, I respectfully call attention to the circumstances under which this report is made. But little over a year has passed since the work of investigation was begun. The field of operations has reached from Shasta to San Bernardino, and extended over a third part of the State in area. Necessarily the results accomplished are largely preliminary in character.

I hope that the foundation is laid for an intelligent and thorough study of the great drainage problems which sooner or later must here be solved; that the steps taken in the matter of inquiry into the problems of irrigation—the results of which are to be submitted to you in a separate report—have been in the right direction to effect a solution of that problem, in a manner that will insure the greatest good to the greatest number, from the use of the waters.

The data so far obtained is now barely brought into form for study. The systemization of observations, the training of assistants in special duties, is but just accomplished, and the knowledge of localities and present conditions barely acquired.

With respect to the river phenomena of low and high water, the observations of one season have shown where it is necessary to observe more, and how to conduct the work so as to catch the items of knowledge necessary.

The condition of the rivers noted during one season must be overlooked the next, to ascertain what is going on and study the tendency of present influences. The general drift of influence may be ascertained in one season; but the measure of effect can only be appreciated by comparing the result of several seasons' work.

That which has been done is the most expensive part of the work on the field gone over; the practical results can be duplicated at half the expense, and the valuation of deductions quadrupled by the continuance of the work.

Thus it would be an act of vanity on my part, and certainly a responsibility which I am not prepared to take, to assume to report after so limited an examination, what purported to be final conclusions and recommendations as to details, or even general plans; more particularly, seeing that the law under which I have been called upon to act anticipates at this time only "'a statement of the condition of the inquiry, a history of operations up to date, the important facts that have been ascertained, either accurately or approximately, and the deductions or recommendations which have been justified by the inquiry in regard to the principles which ought to govern in the irrigation of lands and the relief of the rivers when in flood, with such practical recommendations as the State Engineer may see fit."

CHAPTER II.

THE SAN JOAQUIN VALLEY DRAINAGE.

In what was said concerning the San Joaquin and Sacramento Val-
ley floods, by way of introduction to this second part of my report, I
have spoken of the very limited opportunity I have had to study the
river problems of the San Joaquin.

No flood observations on the San Joaquin.

There really has been no opportunity at all of observing a high
water in the San Joaquin—there has been none to observe—nor has
there been any means at hand to fully collect the data of flood phe-
nomena, though an effort was made, as explained in part one, to
conduct some observations in June, 1879, which failed, however,
because the waters did not rise.

Hence, though I would much like to do otherwise, I am forced to
give the subject a very superficial treatment at this time.

Examinations and surveys on the San Joaquin.

Surveys and examinations have been extended up the San Joaquin
and all its subsidiary channels, as far as the mouth of the Stanislaus,
and no further. For this reason the data available will not admit of
a full description of the field of overflow, as has been given in the
case of the Sacramento Valley flood regions, and hence, no general
description will be attempted. There are, though, some points of
especial interest which are sufficiently understood to make possible a
discussion of them, and, as they are important and of great local
interest, I feel justified in undertaking it, at the same time reiterating
the fact that it has not been possible to obtain the information neces-
sary upon which to make definite statements. It is my intention,
however, should I have the opportunity, to make this a special object
of study during the approaching spring.

THE SAN JOAQUIN RIVER PROBLEM.

The river flood problem proper commences far above the region
surveyed, for we have here very much such a case as is presented in
the upper Sacramento Valley: a case where an upper division of the
channel is larger and on a greater grade than that below, which
habitually loses a large portion of its waters and has become con-
tracted. Hence, for the relief of the lower division from flood, it is
essential that the river above it be not treated so as to precipitate the
floods upon the channel where it is of deficient capacity. It may be
said that the San Joaquin River flood problem necessitates a study of
the river as high up on its course as the point where its waters first
escape from their channels in time of ordinary flood, and this point is
above the mouth of Fresno Slough, and not far below the crossing of
the Valley Railroad; for it is only there, for the first time in ascending,
that a good gauging of volume in one channel can be made at time
of flood.

The river problem in the Sacramento Valley.

In dealing with the drainage problems presented in the Sacramento Valley, but little has been said concerning the improvement of the rivers for purposes of navigation. The prevention of overflow, the preservation and enlargement of the channels to enable them to carry away the flood waters is, there, a pressing necessity, and in considering this subject it becomes apparent that the interests of internal navigation will be subserved by a treatment of the rivers to accomplish the prime purpose.

Moreover, the large volume of water habitually carried by the Sacramento renders its navigation, for freighting purposes, by the use of barges, comparatively a safe and certain highway.

The river problem in the San Joaquin Valley.

The San Joaquin, on the contrary, drains a larger extent of country, wherein the traffic is of a character which demands cheap water transportation, yet the river itself is of small volume (as compared to the Sacramento), and its channel presents many serious obstructions and inconveniences to the movement of boats. Furthermore, while this deficiency in navigation facilities is an ever present inconvenience, and a serious drawback to the welfare of the valley, inundations occur but seldom; the flood volumes are small for about nine years out of every ten; and when we view the situation in the two valleys, though it may prove to be comparatively an easy work to conduct away these San Joaquin floods without overflow, it must always remain a delicate work to establish and maintain the best possible conditions in the channels of this river for purposes of navigation, for the volume of water habitually carried by it is barely sufficient to admit of its successful treatment as a navigable stream.

Navigation the ruling consideration.

Hence, while we may treat the Sacramento altogether as a flood-carrying channel, and be assured of securing results favorable to navigation, the latter interest must be more carefully looked to in dealing with the San Joaquin, lest, in planning for flood relief, we seriously retard low water navigation and inconvenience that interest at all times.

Discussions in the preceding chapter.

The principles which should govern in the treatment of a river as a flood-carrying channel, are sufficiently discussed in other parts of this report, and in the preceding chapter I have spoken of the conservative action of the tides in the lower rivers. To avoid repetition I refer to these paragraphs, and here only make such applications of the principles brought out as appear to me necessary.

FLOODS FROM THE SAN JOAQUIN.

Causes of the ordinary flood disasters in the San Joaquin Valley.

With respect to inundations of leveed lands, it appears there are two immediate causes why these occur on the San Joaquin:

First—At the upper portion of the leveed region the floods rise and overtop the embankments before the waters can escape through the river channels.

Second—Towards the lower end of the leveed region the levees, or

the foundations upon which they stand, yield to the pressure of the water before the embankments are overtopped.

The cause of the first class of disaster is either that the flood volumes are presented with undue velocity and momentary amount at some points, or the channels are generally deficient in capacity between the embankments to pass the waters presented.

More data necessary.

To properly discuss this matter of flood volumes and channel capacities would necessitate much more data than are at my command, but enough is known to enable me to point out where and how both these last mentioned causes contribute to produce the overtopping of the levees which occurs at the upper end of the large leveed islands.

The following tables exhibit certain data obtained by the surveys of the river channels made under my direction, and, as far as it goes, the information is good of its kind. But it must be supplemented by flood observations before these problems can be discussed definitely.

SAN JOAQUIN RIVER.

Channel dimensions and grades in the several divisions.

Designation.	First Division—San Joaquin City to Paradise Cut.		Second Division—Paradise Cut to Old River.		Third Division—Old River to head of Burns' Cut-off.		Fourth Division—Head to foot of Burns' Cut-off.		Fifth Division—Foot of Burns' Cut-off to Twenty-one-Mile Slough.	
	Low Water, 1878	High Water, 1878	Low Water, 1878	High Water, 1878	Low Water, 1878	High Water, 1878	Low Water, 1878	High Water, 1878	Low Water, 1878	High Water, 1878
Distance from upper to lower station	13.8 miles.		5.8 miles.		13.2 miles.		4.7 miles.		7.5 miles.	
Elevation of upper station (above low water in the Bay)	19.00	29.25	9.00	23.35	5.60	20.15	3.35	12.15	2.50	10.0
Elevation of lower station (above low water in the Bay)	9.00	23.35	5.60	20.15	3.35	12.15	2.50	10.00	1.75	8.35
Difference of elevation between upper and lower station	10.00	5.90	3.40	3.20	2.25	8.00	0.85	2.15	0.75	1.65
Average slope per mile	0.72	0.43	0.57	0.53	0.17	0.61	0.18	0.46	0.10	0.22
Maximum slope for any five miles	----	----	----	----	0.19	0.65	----	----	----	0.31
Minimum slope for any five miles	----	----	----	----	0.15	0.56	----	----	----	0.04
Maximum slope for any one mile	----	----	0.80	0.65	0.20	0.67	0.20	0.49	0.14	0.60
Minimum slope for any one mile	----	----	0.15	0.47	0.14	0.53	0.16	0.44	0.07	0.03
Average width of channel	----	420.	----	340.	----	180.	----	150	300.	310.
Greatest average width for any one mile	----	550.	----	390.	----	210.	----	190.	----	340.
Narrowest average width for any one mile	----	260.	----	310.	----	160.	----	100.	----	280.

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San Joaquin River—Continued.

Designation.	Sixth Division—Twenty-one-Mile Slough to Middle River.		Seventh Division—Middle River to Old River.		Eighth Division — Old River to the Mokelumne.		Ninth Divisien—Mokelumne River to Three-Mile Slough.	
	Low Water, 1878	High Water, 1878	Low Water, 1878	High Water, 1878	Low Water, 1878	High Water, 1878	Low Water, 1878	High Water, 1878
Distance from upper to lower station	10.2 miles.		4.8 miles.		1.6 miles.		6.6 miles.	
Elevation of upper station (above low water on the Bay)	1.75	8.35	1.00	8.22	0.960	8.200	0.947	8.193
Elevation of lower station (above low water on the Bay)	1.00	8.22	0.96	8.20	0.947	8.193	0.550	8.080
Difference of elevation between upper and lower stations	0.75	0.13	0.04	0.02	0.013	0.007	0.397	0.113
Average slope per mile	0.07	0.01	0.008	0.004	0.008	0.004	0.060	0.017
Maximum slope for any five miles	----	----	----	----	----	----	----	----
Minimum slope for any five miles	----	----	----	----	----	----	----	----
Maximum slope for any one mile	----	----	----	----	----	----	----	----
Minimum slope for any one mile	----	----	----	----	----	----	----	----
Average width of channel	----	410.	----	1,600.	----	1,800.	----	----
Greatest average width for any one mile	----	510.	----	1,900.	----	----	----	----
Narrowest average width for any one mile	----	300.	----	1,200.	----	----	----	----

OLD SAN JOAQUIN RIVER.

Channel dimensions and grades in the several divisions.

Designation.	First Division—San Joaquin to Middle River.		Second Division—Middle River to Tom Paine Slough.		Third Division — Tom Paine Slough to Mohr's Landing.	
	Low Water, 1878	High Water, 1878	Low Water, 1878	High Water, 1878	Low Water, 1878	High Water, 1878
Distance from upper to lower station	4.2 miles.		3.9 miles.		9.3 miles.	
Elevation of upper station (above low water on the Bay)	5.50	20.15	4.95	18.00	4.20	16.20
Elevation of lower station (above low water on the Bay)	4.95	18.00	4.20	16.20	2.97	11.60
Difference of elevation between upper and lower station	0.55	2.15	0.75	1.80	1.23	4.60
Average slope per mile	0.15	0.51	0.19	0.46	0.13	0.50
Maximum slope for any five miles	----	----	----	----	0.15	0.60
Minimum slope for any five miles	----	----	----	----	0.07	0.35
Maximum slope for any one mile	----	----	----	----	0.23	0.75
Minimum slope for any one mile	----	----	----	----	0.05	0.32
Average width of channel	----	180.	----	100.	----	120.
Greatest average width for any one mile	----	200.	----	105.	----	150.
Narrowest average width for any one mile	----	150.	----	90.	----	90.

Old San Joaquin River—Continued.

Designation.	Fourth Division—Mohr's Landing to Italian Slough.		Fifth Division—Italian Slough to Connection Slough.		Sixth Division—Connection Slough to main river.	
	Low Water, 1878	High Water, 1878	Low Water, 1878	High Water, 1878	Low Water, 1878	High Water, 1878
Distance from upper to lower station	11.3 miles.		15.4 miles.		10.0 miles.	
Elevation of upper station (above low water on the Bay)	2.97	11.60	2.30	9.45	1.42	8.00
Elevation of lower station (above low water on the Bay)	2.30	9.45	1.42	8.00	0.90	----
Difference of elevation between upper and lower station	0.67	2.15	0.88	1.45	0.52	----
Average slope per mile	0.06	0.19	0.06	0.09	0.05	----
Maximum slope for any five miles	----	0.25	----	----	----	----
Minimum slope for any five miles	----	0.12	----	----	----	----
Maximum slope for any one mile	----	0.27	----	----	----	----
Minimum slope for any one mile	----	0.10	----	----	----	----
Average width of channel	----	100.	----	300.	----	780.
Greatest average width of channel	----	110.	----	410.	----	820.
Narrowest average width of channel	----	95.	----	200.	----	625.

The main flood region of the valley.

The Stanislaus River enters the San Joaquin from the east, at the head of what may be called the main flood region of the valley.

Above this point there have been, almost annually, inundations of a region of country generally a mile or two in width, and in exceptional flood seasons the waters spread over a much greater area.

But a few miles below the mouth of the Stanislaus, the greatest expanse of what has been known in the State as swamp and overflowed land commences, and extends to the Sacramento Valley delta islands heretofore described.

The large islands.

Roberts and Union Islands are the two principal tracts of this great body of swamp. They lie alongside of each other, in the midst of the wide expanse, being formed by the division of the San Joaquin River into three branches, called Old River, Middle River, and Main River, respectively.

These two islands are partially reclaimed, having levees entirely around them. They spread out across the body of swamp sixteen miles in combined width, and stand in the way, as it were, of the movement of the floods down the valley, for, before they were leveed, the waters moved over their surface in broad sheets, and were drained away by sloughs which join the river at or near the lower end of the islands. Since the leveeing of these islands, however, and of the main lands east and west of them, it has been found that the flood waters rise higher in the channels than they did formerly, and they have frequently overtopped and breached the embankments along the head of Union Island, as well as at other points. It is proposed to inquire somewhat into the causes of these floods.

Observations at San Joaquin City.

A point called San Joaquin City is situated on the river, one mile west from the mouth of the Stanislaus in a straight line, and two miles below it by the course of the channel. There was a river gauge rod at this point, and some flood marks were ascertained, so that the slopes, etc., will be given from it.

San Joaquin City to Old River.

From San Joaquin City to the head of Roberts Island the river pursues an exceedingly tortuous course; the distance by the channel being 19.6 miles, while in a line following the general direction, from point to point—bearing north 19° west—the distance is 10 miles. Thence the main channel runs northerly.

Old River.

The head of Roberts Island lies in the forks of the Main River and Old River. The last mentioned channel leaves the Main River about at right angles to its general direction, and pursues a very winding way across the heads of Roberts and Union Islands. From this place of leaving the main channel to Mohr's Landing, a point on Old River, the distance is 10.6 miles in a straight line, on a course S. 85° 30′ W., and the channel is 17.4 miles in length.

Old and Middle Rivers.

Near Mohr's Landing, Old River turns northerly along the west side of Union Island. Middle River leaves the Old River channel about 4.2 miles from the head, and runs for about four miles northerly between Union and Roberts Islands, and thence pursues a westerly and northerly course to the main river, 15 miles below.

The region above Old River.

From this it will be seen that the main river above the head of the islands, and the Old River across the head of the islands, lie on the two sides of a great body of country, triangular in shape. The hypothenusal line across any portion of this triangle is, of course, shorter than the distance round by the two sides, following the general direction of the river, and when it is considered that the river itself is exceedingly crooked, it will be appreciated at once that the straight line across is very much shorter than the crooked channels around.

Adjustment of bank elevation.

Previous to the occupation of the country and leveeing along the rivers the bank elevations were built up and adjusted to grades made principally by the flow of water in the channels, and its spread each way therefrom; for the waters generally were retained in the channels above the head of Old River, except as they ran in thin sheets over the banks.

Effect of the crevasses.

Of late years certain large crevasses have occurred on the west bank of the main river, at points between San Joaquin City and the head of Old River, and large volumes of flood-water now escape by them each season, and pursuing the short route on the diagonal line, of comparatively heavy grade, across the great triangular shaped body of land before referred to, are precipitated into the Old River channel at about a right angle to the general direction of its course. There, finding a channel insignificant in size, exceedingly tortuous in alignment, and of small grade compared to the route by which they have come across the country, these waters are checked; they form a wide lake, with the Union Island and Roberts Island levees for the northern shore thereof, and the high plain lands bordering them on the south and west, for the shore on that side.

Overtopping of the levees.

Under these circumstances disaster is almost inevitable. Not having a line of escape equal in capacity to that of supply, the waters continue to rise against the levees, and ultimately overtop them. This result is sometimes hastened by the occurrence of a strong south wind, which, sweeping across the shallow lake for several miles, causes a surf to beat upon the levees or raises the water over them.

The large crevasses.

Three principal crevasses in the left bank of the San Joaquin, between San Joaquin City and the head of Old River, allow the escape of its flood-waters into the basin. The first, at Kassons' Cut, 3.1 miles below San Joaquin City; the second, just below Kassons' Landing, 7.1 miles; and the third, at Paradise Cut, 13.8 miles below San Joaquin City.

Flood-flow through the crevasses.

From the opening at Paradise Cut, the flood-waters, flowing over the bank of the cut—21.6 feet above datum—towards the portion of Old River comprised between the head of Middle River and the mouth of Tom Paine Slough, pursue a general direction across the basin varying between the limits of north 41° west and north 65° west, following the ground's slope, which varies from 0.79 to 1.13 per mile, whereas the slope by the river is, at flood stages:

From San Joaquin City to Paradise Cut, 0.43 feet per mile.

From Paradise Cut to the head of Old River, 0.55 feet per mile.

From the head of Old River to the head of Middle River, 0.61 feet per mile.

From the head of Middle River to Mohr's Landing, 0.48 feet per mile.

From the head of Middle River down its channel to Kidd Ranch levee, 0.40 feet per mile.

From Paradise Cut to Middle River, 0.54 feet per mile.

From Paradise Cut to the mouth of Tom Paine Slough, 0.52 feet per mile.

The flood-waters, leaving the upper crevasses at Kassons' Cut and Kassons' Landing, flow across the basin in a general direction north 25° to north 33° west as far as a point opposite Paradise Cut, and thence north 57° west to the mouth of Tom Paine Slough, following the grade of the basin from 1.33 to 1.45 feet per mile; whereas this is, by the channel, from the head of Middle River to Tom Paine Slough, 0.46; from Tom Paine Slough to Mohr's Landing, 0.50 feet per mile.

The crevasses should be closed.

In view of these facts, I am of the opinion that either there must be a much greater capacity provided in the channels of Old and Middle Rivers from and below the point of junction, and the levees along the heads of the islands must be made much higher and stronger than they are at present, or the crevasses in the banks of the main river above must be closed, to give any assurance of the prevention of the disasters which occur to the island property. And, even if the island levees could be made to resist this flood which is precipitated upon them, there must always result the wide-spread inundation of the lands south of the islands and west of the river, if the crevasses are left open.

Effect of the crevasse discharge.

This unregulated escape of waters from the main river through the crevasses, and their rapid passage across the country to the Old and Middle River channels, disarranges the regimen of the whole flood movement, and it cannot be expected that any plan of reclamation in the San Joaquin Valley for the region below the mouth of the Stanislaus can be made to succeed as long as it is permitted.

Alternative plans for improvement.

If the main river and its branches below the point of this escape are not of sufficient capacity to pass the ordinary floods that are brought from above, then, either their channels must be enlarged, or water must be diverted from them in a regular and systematic manner. If water is to be permitted to escape to the west, it must be taken in a channel along the edge of the high land, on a grade approximating a mean between that above and below, and brought to the Old River channel at a point about two miles above Mohr's Landing. It should not be permitted to run down the steep slope of the country by the shortest route to the heads of the islands, because it will be very difficult to provide way thence for its prompt passage onward.

Old and Middle Rivers.

Now the Old and Middle River channels are very much contracted and very tortuous in their alignment. Old River can be greatly improved without material interference with existing works, but Middle River, near its head, cannot, for the levees stand close upon its banks on each side.

The leveeing already done.

There has been a most shortsighted treatment of these rivers of the San Joaquin near the heads of the islands. The channels themselves are narrow, and the levees have been built almost as close to the banks as they could be placed. This is notably the case on each side of Middle River near its head, and on each side of the main river for about eight miles below the point of division.

Effect of the leveeing.

Thus, here are two of the lines of escape for the floods restricted in capacity as much as they could well be. While the third line—Old River below the head of Middle River—an exceedingly irregular and contracted channel in itself, is called upon to carry the great volume of floods precipitated upon it by the rush of waters across the country, which could readily be carried away in the channels, in due proportion, if they were treated aright.

The levees should have been set back.

There was no good excuse for placing these levees where they are, except the lack of system in the general treatment of the whole subject; and it is but just to say that those who now control the works are not, as a general thing, responsible for the results of this lack of foresight. The banks, in the location spoken of, were firm, and did not slope away from the edges of these channels so rapidly that the levees might not have been set 150 to 250 feet further back on each side. Had this been done, and the space outside the levees cleared of undergrowth, there would not now exist a condition of things which it will be difficult to remedy without sacrificing works already constructed.

CHANNEL IMPROVEMENT.

Old River.

The Old River channel should be very much straightened and enlarged across the head of Union Island, and at some points on the west side of the island also. This work has been commendably begun by the present owner of the adjacent property; but it certainly seems that an improvement, in which the whole flood region is interested, should not be left to local private enterprise.

Main River.

The aggregate carrying capacity of these channels can be greatly increased also by improving the waterway of the main river at five or six notable points within the first five miles below the head of Roberts Island, where it has some very sudden turns; not by making cut-offs in all instances, but by reducing the rate of curvature, by causing the points to cut and the bends to fill, through a proper use of spur-dikes. This will not interfere greatly with the present levee system, and is the least that can be done here for the rectification of the evils. And again, there should be a certain straightening of the channel on the east side of Rough and Ready Island, where the main river divides for a short distance, as hereafter explained in some remarks made on the subject of improving the navigation of the stream.

General system necessary.

Here, again, is an instance similar to those cited in the Sacramento Valley, wherein organization extending over the whole field is essential to achieve success and prevent injustice; for the works necessary to relieve this flood region are largely those which should be undertaken at the expense of wide areas of country, embracing many reclamation districts, and it cannot be expected that there will be a unity of opinion and action amongst all concerned unless there be some organization under State supervision. Of course, those persons most interested might combine upon some general works which would accomplish much good, but they would be bearing burdens not justly their due.

FLOODS AT THE LOWER END OF THE LARGE ISLANDS.

Yielding of the levees.

It has been said that the disasters which have occurred at the lower end of the large islands and upon other similar island property in the neighborhood, have been occasioned generally by the levees or their foundations yielding to the pressure of the waters during flood stage in the spring.

Waterway sufficient.

This is not the result of a lack of cross-sectional waterway in the channels to pass the land drainage brought from above. Indeed, if the size of these lower river channels was regulated by the volumes of the land drainage waters alone, they would be insignificant as compared to what they now are, as described in the first chapter of this part of my report. The tidal action regulates the size of the rivers, in the regions where the levees give way from lateral pressure, and it would take embankments but little higher than those which have been constructed generally around the islands in the San Joaquin delta to form sides to the great natural drains high enough to insure the passage of the floods, if only those levees could be made to stand.

The lower river problem, one of levee building.

There is no doubt but that all ordinary floods can be carried away through existing channels below Rough and Ready Island, and a point on Old River at a corresponding distance from its mouth, between embankments of moderate height, if those structures can be made to resist the lateral pressure of the water. This flood problem, then, resolves itself into one of levee building—how to build a levee on an unstable foundation with the material which is at hand. And this opens up a separate and distinct subject, which I hope to have the opportunity in the near future to consider, but which the time now at command will not permit of my doing justice to, though much instructive and valuable data is at hand for use as matter in the discussion.

Levees must be sunk to stable foundations.

It may be said, though, that the plan followed under nearly similar conditions in older countries, has been to sink the levees through the yielding super-crusts to the hard sub-strata, and that such experience as has been had here goes to prove this to be the true course to pursue; and at any rate I am of the opinion that this is the only plan which will prevent disaster, and that the greater portion of the material for levee construction on these lower islands must be obtained from the bottoms of the channels by means of dredging machinery in some form, and I believe that the time will come when all leveeing in the lower islands will be carried on upon this general plan. There are substitutes which will be temporarily effective, and as such are worthy of consideration and adoption in some cases, but from which no permanent good can be expected. These will be discussed at length hereafter, together with the whole subject.

IMPROVING THE NAVIGATION OF THE SAN JOAQUIN RIVER.

In the first part of this chapter I have spoken of the importance of treating the San Joaquin River to improve its navigation; and in the preceding chapter will be found some discussion as to the method of improvement of the tidal compartments of rivers.

Tidal action in the San Joaquin.

The San Joaquin, below Stockton channel, is eminently a tidal river, and all that has been said heretofore concerning the beneficial effects of the tidal action, and the methods of increasing these effects, applies with full force here especially, though much good may be accomplished for the channel as far up as the head of Old River, by a careful treatment and guidance of the same great agent.

The main river below Old River.

From the upper end of Old River—in point heretofore also spoken of as the head of Roberts Island—the main river pursues a course in general direction north 50° east to the head of Rough and Ready Island, 9.2 miles by a straight line, and 13.2 miles by the meanderings of the stream. Here the channel again divides, the main river turning to the right, and what is known as Burns' Cut-off to the left. From the head to the foot of Rough and Ready Island the distance, in a straight line, is 2.2 miles; by the main river it is 4.7 miles, and by Burns' Cut-off 3.7 miles.

Stockton channel.

Stockton channel, a tidal arm during low-water stages, joins the main river channel from the east 0.85 mile below the point of division in the river at the head of the island, and during flood stages of the streams brings down a portion of the waters of the Calaveras River, whose proper mouth is at a point about two miles further down stream.

The main river below St. Catherine's.

The main river channel past Rough and Ready Island—particularly below the Stockton channel—is exceedingly crooked, and for its upper half very narrow. From the foot of Rough and Ready Island the river extends in a general direction of N. 55° 30′ W. for a distance of 12.7 miles by a straight line, or 22.1 miles by the channel, to the lower point of junction with Old River, being joined by the Middle River channel in the sixteenth mile. As it will be seen by the considerable difference between the distance over this route in a straight line and that by the channel, the river is exceedingly crooked, but it rapidly widens out from 280 feet at the head to a broad estuary 1,800 feet across at the lower end of this portion of its route.

Navigation on the San Joaquin.

The navigation of the San Joaquin below Stockton is most important, for this place is the great interior grain mart of the State. And the river above might afford a line of passage for the heavy freights and produce of the largest body of agricultural lands on this coast, which, if ever brought to a high state of cultivation under irrigation, will demand cheap water transportation. Even now this upper San Joaquin freighting is a business of large proportions for six to ten weeks each spring, while the waters are high from the effects of the melting snows; but the wretched condition of the channel above the head of the islands stops boating before the supply of water really fails.

Tidal influence in improving the San Joaquin.

On the lower river, below the head of Roberts Island, the improvement of the navigation of the channel must be accomplished by assisting the tidal scour, which, as explained heretofore, is capable of greatly improving channels under similar circumstances. We have not now in the San Joaquin the sand-flow to contend with, as spoken of in connection with the lower Sacramento river improvement, though the time may not be far in the future when here, too, will arise the same troubles from a similar cause.

Character of channel rectification.

But the tidal movement is very much impeded by the various sharp turns, acting as partial dams, which the channel takes, and the removal of these obstructions to the free swell and ebb of the waters is essential to the success of any treatment of the stream to improve its navigation.

Location of necessary improvements.

The chief location for rectifications of this kind is in the two miles of distance next below the Stockton channel, where four cut-offs should be made, reducing the length of channel way from 4.7 miles to 3.6 miles of distance. There should also be a similar rectification at the head of Rough and Ready Island, and as before noticed, several, others located within the five miles next below the head of Robert's Island. Studies in detail of the exact extent and effect of these works will shortly be completed, upon the large-scale detail maps in this office.

Channel improvement above Old River.

While, below the head of Robert's Island and the point of division of the stream the channel should be straightened, at least where the most abrupt bends exist, as far down as the broader and more commodious river below Rough and Ready Island, and, while it would be well that this portion of the river be widened materially, as a flood-carrying channel, by setting the levees back further, above the point mentioned, the reverse order should be the rule.

Comparison with the upper Sacramento.

This is a case in every respect similar to that explained more fully in speaking of the upper Sacramento channel improvement. The San Joaquin changes character at the head of Old River, very much as the Sacramento does at the head of Butte Slough. The river above is wider and on a greater grade than that below, is more irregular both as to width and depth, and has less stable banks.

Character of improvements above Old River.

To improve the upper river for navigation it will be necessary to bring it to a low water width proportioned to the volume of water it habitually carries as the result of land drainage, for it is for the most part beyond the reach of the tides. This will necessitate contractions of its channel at the wider places to a width about uniform with the narrow points, so that the water will preserve a uniform depth. Such results are best accomplished as a general thing, by means of spur-dikes, as heretofore spoken of, but arranged so as not to project the contents upon the opposite bank, and cause cutting away at those points.

Prevent cut-offs above Old River.

And again, the longer the course the water is kept in, the less will be its gradient and the greater the depth of flow at the low stages; thus, aside from the fact that shortening the stream above the head of Roberts Island would tend to precipitate the floods upon the contracted channels below, the interests of navigation at all stages, except when the river is full, demand that it shall be kept at least as long as it is now.

Effect of the crevasses.

And, furthermore, the escape of waters from this river during floods, as described, through the crevasses on the west, must tend strongly to produce silting in the main channel below them, and however gradual and imperceptible this may be now, the effect will be disastrous in the end.

TO CONCLUDE,

I am of the opinion that to insure against flooding in the island region and improve the navigation of the river:

First—The crevasses known as Paradise Cut and Kasson's Cut, as well as others of smaller dimensions on the same side of the river, between San Joaquin City and the head of Old River, should be closed.

Second—The river, from the Stanislaus down to the head of Old River, should be brought to near uniform width in the low water channel, and leveed throughout on both banks.

Third—That cut-offs should not be permitted above the head of Old River, but should be made in a number of places below that point.

Fourth—The Old River channel should be much straightened and enlarged across the head of the islands.

Fifth—The whole treatment should be directed to improving the main river and the Old River channels, as presenting great advantages over the Middle River; and the general treatment should be similar to that recommended for the Sacramento River.

And I believe, with a judicious system of works, the prospect is more favorable for the entire prevention of disasters to the levees, during all flood seasons except such as 1862, in this region than it is in the Sacramento Valley.

Very respectfully submitted.

WM. HAM. HALL,
State Engineer.

REPORT

OF THE

STATE ENGINEER

TO THE

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