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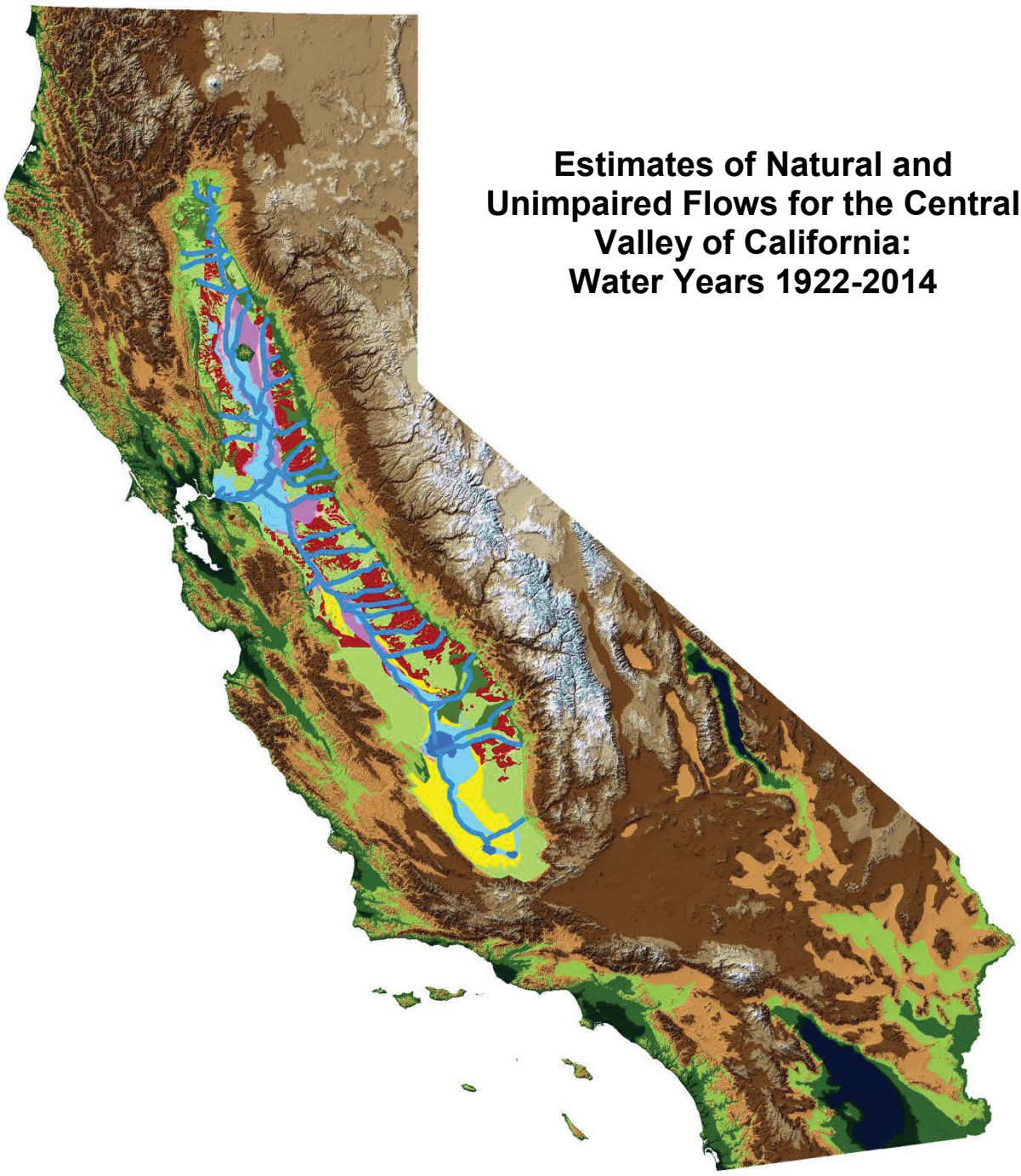

Estimates of Natural and Unimpaired Flows for the Central Valley of California: Water Years 1922-2014

March 2016 (DRAFT)

Department of Water Resources, Bay-Delta Office

FOREWORD

This report summarizes estimates of “natural” and “unimpaired” flows for all areas in the Central Valley tributary to the Sacramento – San Joaquin Delta (Delta) for the period spanning water years 1922-2014. A major objective of this report is to clarify the conceptual differences between natural and unimpaired flows. In spite of the Department’s previous attempts to distinguish between natural conditions and its calculation of theoretical unimpaired flows, unimpaired flow estimates have frequently been used as a surrogate measure of natural conditions, presumably because natural flow estimates were unavailable.

This report, which contains the Department’s first published estimates of natural flows in the Central Valley tributary to the Delta, builds upon a series of publications that chronicled the Department’s efforts to update estimates of unimpaired flow as new hydrologic data became available. The first edition, published in 1980, was titled *California Central Valley Natural Flow Data*. Subsequent editions in 1987, 1994, and 2007 were re-titled *California Central Valley Unimpaired Flow Data* in recognition of the conceptual differences between natural and unimpaired flows.

EXECUTIVE SUMMARY

Purpose of Report

This report summarizes estimates of "natural" and "unimpaired" flows for all areas in the Central Valley tributary to the Sacramento – San Joaquin Delta (Delta) for the period spanning water years 1922-2014. A major objective of this report is to clarify the conceptual differences between natural and unimpaired flows. In spite of the Department's previous attempts to distinguish between natural conditions and its calculation of theoretical unimpaired flows, unimpaired flow estimates have frequently been used as a surrogate measure of natural conditions, presumably because natural flow estimates were unavailable. This report contains the Department's first published estimates of natural flows; these estimates are derived from complex simulation models and are based on published estimates of natural vegetation cover and associated evapotranspiration.

Summary of Findings

This report documents and compares a variety of natural and unimpaired flow estimates, including rim watershed inflows, valley floor water supply, and Delta inflows and outflows. Comparisons of Delta inflow and outflow estimates demonstrate that unimpaired estimates are consistently (and significantly) higher than natural estimates.

Annual average Delta outflow estimates are compared by 40-30-30 water year type, as well as over the long-term average, in Figure ES-1. For the long-term average, the annual unimpaired Delta outflow estimate (28.1 MAF) is 43 percent higher than the natural Delta outflow estimate of 19.7 MAF. Unimpaired outflow estimates are higher than natural flow estimates, primarily because the former estimates do not account for overbank flows and the resulting evapotranspiration associated with natural wetlands. The relative seasonal (i.e. monthly) distributions of unimpaired and natural Delta outflow estimates are not widely different. However, the relative distribution of unimpaired Delta outflow tends to be smaller in the winter (and larger in the other seasons) compared to natural Delta outflow. In sum, the findings of this report show that unimpaired flow estimates are poor surrogates for natural flow conditions.

Sensitivity analyses were conducted on several key model inputs and parameters. These analyses, supported by 30 model runs, suggested an uncertainty range of approximately ± 10 percent. Potential evapotranspiration from riparian and wetland vegetation was found to be the most sensitive model parameter.

Conceptual Differences between Natural and Unimpaired Flows

In this report, the term "unimpaired" flow is used to describe a theoretically available water supply assuming existing river channel conditions in the absence of (1) storage regulation for water supply and hydropower purposes and (2) stream diversions for agricultural and municipal uses. Unimpaired flow estimates are theoretical in that such conditions have not occurred historically. In pristine watersheds which have undergone little land use change, unimpaired flow estimates provide a fixed frame of reference to develop relationships between

precipitation, runoff, and water supply based on long-term hydrologic records. For many years these relationships were based on the assumption of stationarity, i.e. that the past is a good indicator of the future. However, global warming now requires hydrologists and water resources managers to analyze non-stationary processes, requiring more sophisticated tools and techniques to quantify future water supplies. This report updates and extends the Department's previous published estimates of unimpaired flows for 24 Central Valley subbasins and the Delta. Monthly unimpaired flows are presented for water years 1922-2014.

The term "natural" flow is used in this report to describe the flows that would have occurred absent all anthropogenic influences and is considered to represent the period circa 1850 prior to significant landscape changes following the California Gold Rush. These influences have dramatically affected Central Valley flows, including inflows to the Delta. For example, changes in land use, including (but not limited to) the clearance and drainage of wetlands, have affected the amount and timing of surface runoff. Groundwater pumping has impacted groundwater elevations and groundwater inflows to streams and rivers. Flood control measures, including an extensive network of levees, have ended the natural cycle of bank overflows and detention storage.

The estimates of natural flow provided in this report are not to be confused with estimates of actual flows that occurred under Paleolithic or more recent conditions prior to European settlement. Rather, these estimates assume the contemporary precipitation and inflow pattern to the valley floor (i.e. water years 1922-2014) with the valley floor in a natural or undeveloped state: before flood control facilities, levees, land reclamation, irrigation projects, imports, etc.

Summary of Methods

Methods used to estimate natural and unimpaired flows are detailed in the main body of the report. While methods used to estimate unimpaired flows generally follow the approach established in previous Department publications, those used to estimate natural flows are new. This new methodology relies on two complex models to simulate hydrology of the Central Valley rim watersheds and floor:

- SWAT (Soil Water Assessment Tool), a precipitation-runoff model, was used to simulate stream flows for most rim watersheds. SWAT, which is a public domain model developed by the U.S. Department of Agriculture, provides a tool for evaluating future potential impacts of climate change.
- C2VSim, an integrated hydrologic model, was used to simulate groundwater and surface water hydrology on the Central Valley floor. C2VSim is a Central Valley application of the Department's IWFM model.

The new approach to estimate natural flow, which is based on published estimates of the region's natural vegetation cover and associated evapotranspiration, was designed to overcome information gaps that were identified in previous unimpaired flow publications:

First, the ground water accretions from the very large area of the Central Valley floor probably were considerably higher under natural conditions but no data are available. Second, the consumptive use of the riparian vegetation and the water surfaces in the swamps and channels of the Central Valley under a natural state could be significant but are difficult to estimate. Third, during periods of high flow, Central Valley rivers would overflow their banks and water could be stored in the valley for long periods of time and could interact with item two. Fourth, the outflow from the Tulare Lake Basin under natural conditions is difficult to estimate.

SWAT-based estimates of natural rim watershed flows are somewhat different from the values used to estimate unimpaired rim watershed flows. These differences, as discussed in the main body of the report, were found to be small and therefore do not bias conclusions regarding differences between natural and unimpaired flows.

Previous Unimpaired Flow Reports

This report, which contains the Department's first published estimates of natural flows in the Central Valley tributary to the Delta, builds upon a series of publications that chronicled the Department's efforts to update estimates of unimpaired flow as new hydrologic data became available. The first edition, published in 1980, was titled *California Central Valley Natural Flow Data*. Subsequent editions in 1987, 1994, and 2007 were re-titled *California Central Valley Unimpaired Flow Data* in recognition of the conceptual differences between natural and unimpaired flows.

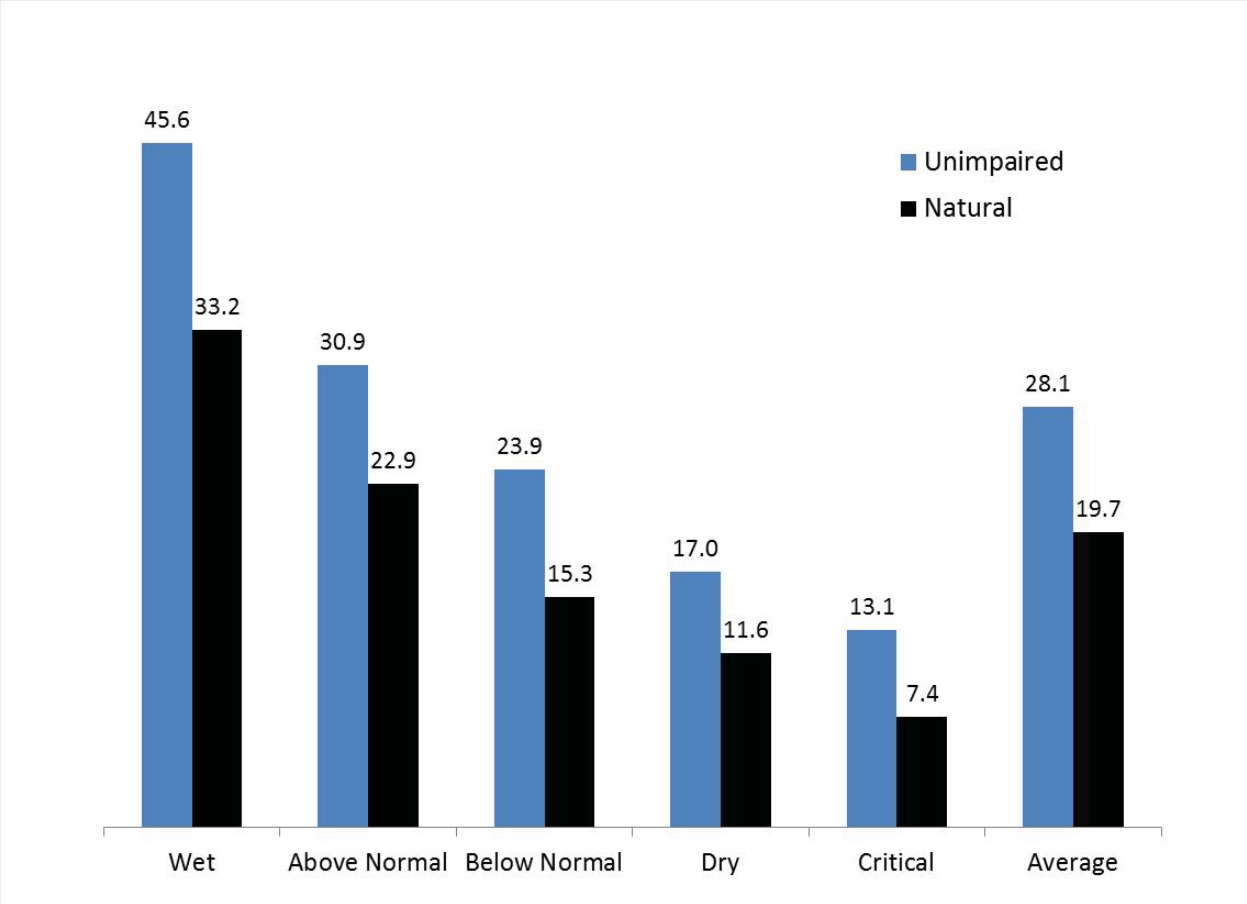

Figure ES-1. Average Annual Unimpaired and Natural Net Delta Outflow (MAF)

This chart compares annual average "unimpaired" and "natural" Delta outflow estimates (in units of million acre-feet) for the 93-year hydrologic period spanning water years 1922 through 2014. Comparisons are shown by 40-30-30 water year type as well as the full period average. This chart clearly shows that unimpaired flow estimates are significantly higher than natural flow estimates under all hydrologic conditions. Under average conditions, the annual unimpaired flow estimate is 43 percent higher than the natural flow estimate.

Table B-29. Delta Unimpaired Total Outflow Estimated Flow in TAF

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1922	352	485	1672	1536	4544	3493	4581	7671	5498	1379	495	336	32042
1923	413	809	3300	2548	1624	1794	4195	4136	2218	1070	407	370	22884
1924	423	393	489	594	1336	674	1098	1089	353	258	191	192	7090
1925	343	892	1192	1177	6907	2678	4726	4320	2206	831	414	323	26010
1926	370	514	731	942	4287	1986	4634	2327	860	378	243	232	17504
1927	308	2486	2447	2975	8879	4538	6034	4814	3399	1077	426	334	37717
1928	370	1666	1331	1743	2621	7556	4533	3308	1180	509	294	267	25379
1929	289	536	735	690	1362	1460	1788	2644	1467	462	202	223	11859
1930	228	265	2897	1885	2353	3588	3005	2484	1624	506	265	266	19364
1931	294	450	374	921	862	1319	1273	1186	461	188	157	167	7652
1932	279	380	2460	1877	2850	2960	3078	4590	3180	987	347	233	23220
1933	244	280	426	854	660	2222	2159	2600	2613	558	241	214	13071
1934	262	317	1319	1792	2014	2137	1712	1087	600	243	176	173	11830
1935	264	947	911	2663	2038	2982	7852	5344	3140	812	347	253	27553
1936	352	376	548	4295	7951	3493	4595	4152	2547	842	332	256	29738
1937	275	290	484	661	3870	4741	4663	5624	2638	755	294	235	24529
1938	362	2023	6203	2505	8515	11250	7549	8668	5808	2017	718	470	56088
1939	591	663	865	877	961	2251	2472	1527	655	314	221	258	11655
1940	393	323	723	5245	8218	8227	5588	4286	2011	626	334	322	36297
1941	407	642	4663	6186	7669	6755	6340	6775	3818	1624	635	460	45974
1942	484	713	4742	6122	7395	2980	5848	5632	4736	1700	616	439	41406
1943	457	1257	2349	6808	3907	7552	5082	4110	2469	1067	511	379	35948
1944	435	493	580	921	1958	2604	2158	3681	1890	811	337	267	16134
1945	367	1412	1821	1278	5831	2903	3303	4274	2843	1015	424	302	25774
1946	693	1565	6432	3427	1655	2834	3984	4041	1795	696	384	315	27821
1947	419	1046	1265	671	1951	3068	2496	2153	1169	393	273	250	15153
1948	714	607	514	2168	783	2065	5408	5155	3650	929	403	344	22740
1949	377	494	748	601	1138	4737	3764	3731	1570	443	297	258	18158
1950	294	400	439	2446	3631	3011	4375	4124	2241	665	319	301	22246
1951	1039	6116	8157	5085	4592	3452	3208	3582	1655	640	379	314	38218
1952	483	1091	4693	6204	5654	5591	7505	8608	5125	2207	762	509	48431
1953	454	530	2675	7269	1847	2635	3814	3841	3711	1426	537	446	29185
1954	458	909	869	2906	3727	4619	5505	3609	1507	642	414	379	25543
1955	395	859	1695	1701	1149	1458	2283	3567	1951	572	317	302	16248
1956	322	636	12885	10989	5411	3817	4069	5980	3839	1601	628	478	50656
1957	646	614	622	908	3363	4196	2711	4441	2629	748	406	438	21722
1958	962	923	1957	3325	11071	7010	9014	7791	4697	1733	781	545	49809
1959	503	540	598	2699	3560	2276	2488	1925	1046	443	308	528	16912
1960	374	353	464	1037	4266	3859	2794	2598	1323	432	290	284	18073
1961	337	808	1587	1064	2588	2312	2261	2347	1230	400	333	295	15562
1962	343	602	1384	1010	5715	3165	4390	3423	2647	866	374	293	24214
1963	3245	793	2361	2275	6140	2802	7432	5783	2886	1199	535	440	35891
1964	591	2012	969	2096	1174	1308	2120	2676	1622	507	305	264	15642
1965	361	1111	11821	8124	2813	2354	6051	4289	2997	1359	812	409	42501
1966	432	1746	1369	2655	2102	2967	3770	2735	888	433	315	301	19712
1967	312	1614	3951	5214	3240	5325	5569	7593	6197	2804	777	461	43056
1968	502	561	987	2157	4829	3160	2440	2324	1082	479	465	345	19331
1969	490	996	2396	11595	7572	5117	6950	8569	4955	1928	697	484	51750
1970	651	691	4245	14526	4055	4134	2096	3048	2038	768	445	371	37068

Table B-29. Delta Unimpaired Total Outflow Estimated Flow in TAF contd.

Water Year	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Total
1971	479	2429	4703	4075	2220	4641	3936	4638	3610	1215	528	450	32924
1972	523	714	1513	1634	2154	3772	2833	2828	1558	498	325	423	18775
1973	619	1547	2285	6204	5749	4681	3736	5309	2366	717	444	405	34063
1974	675	5664	4983	9216	2724	8373	6476	5304	3485	1405	626	473	49403
1975	508	631	984	1189	4339	6578	3718	6150	4427	1256	594	514	30888
1976	955	942	820	671	968	1472	1441	1469	532	327	431	381	10411
1977	359	386	353	497	469	548	663	908	685	273	240	331	5711
1978	296	487	2304	8462	5040	7297	5860	5522	4132	1759	623	759	42541
1979	380	546	550	1996	3163	3974	3188	5056	1823	651	369	317	22014
1980	684	1026	1694	9443	8709	5059	3759	4162	3136	1775	542	496	40485
1981	442	426	1061	2162	2089	3127	2604	2250	978	387	290	277	16093
1982	624	5313	7220	5303	7455	6737	11204	6735	3707	1845	766	864	57773
1983	1457	2691	5574	6784	9790	15899	6860	8736	8222	3989	1465	862	72330
1984	914	5142	9769	3907	3004	3774	2892	4003	2126	870	455	422	37277
1985	664	2314	1484	1009	1610	2048	3184	2299	991	387	305	441	16737
1986	510	851	1535	3307	16918	9854	3974	4100	2834	1004	473	572	45931
1987	541	418	544	866	1829	3234	1894	1541	582	341	248	250	12287
1988	317	489	2118	2490	1167	1404	1649	1674	911	361	230	203	13014
1989	262	1177	882	1035	1153	7721	4046	2425	1227	414	269	426	21039
1990	786	608	464	1554	1117	2116	1936	1884	1262	409	225	234	12594
1991	252	315	327	346	472	3688	2246	2617	1677	514	229	211	12894
1992	381	410	525	683	3351	2543	2467	1372	505	443	208	206	13095
1993	358	369	1620	6411	4808	7205	5147	5907	4120	1425	562	379	38311
1994	482	419	892	869	1540	1673	1693	1922	786	266	191	246	10978
1995	337	675	1363	12054	4018	14342	7170	8859	6215	3724	1133	623	60511
1996	470	464	2127	3474	8472	5683	4801	6417	2663	1023	502	402	36498
1997	488	1464	9292	17273	3883	2869	2987	3234	1718	648	483	420	44759
1998	544	1164	1600	7373	11967	6927	6139	7161	7667	3622	981	724	55868
1999	717	1631	2259	3288	6541	4838	4099	4854	2887	945	540	500	33099
2000	527	753	683	3206	7679	5240	4171	4090	1942	696	456	478	29921
2001	588	551	688	1039	2079	3129	2321	2674	657	393	300	315	14734
2002	336	1077	3515	3750	2140	2902	3193	2853	1414	454	326	290	22248
2003	294	825	4758	4399	2047	3121	4169	5703	2674	702	510	375	29578
2004	373	570	2983	2562	5680	4215	2947	2475	1152	535	325	295	24112
2005	701	676	2214	3776	2846	5206	3971	8488	4035	1577	553	407	34450
2006	447	702	8005	6853	4423	7720	12206	8228	4193	1465	619	469	55329
2007	487	714	1548	951	2825	2421	1937	1786	603	375	293	286	14225
2008	456	372	790	2579	2582	2088	2108	2906	1212	407	261	202	15964
2009	324	704	614	1058	3031	4506	2657	4722	1420	568	328	267	20199
2010	664	383	804	3507	2997	2968	4206	4370	4570	1226	437	346	26478
2011	918	1077	5841	2820	2804	9199	6636	5982	6421	2975	854	505	46030
2012	715	600	487	1141	783	3884	4520	2505	834	435	338	271	16514
2013	347	1419	5367	1668	1206	1920	2206	1514	774	350	276	276	17322
2014	396	396	396	396	396	396	396	396	396	396	396	396	10879
1922-2003 Average	**509**	**1099**	**2425**	**3600**	**4065**	**4218**	**4039**	**4133**	**2514**	**964**	**440**	**373**	**28380**
1922-2013 Average	**511**	**1051**	**2450**	**3468**	**3902**	**4198**	**4032**	**4111**	**2492**	**961**	**438**	**369**	**28050**