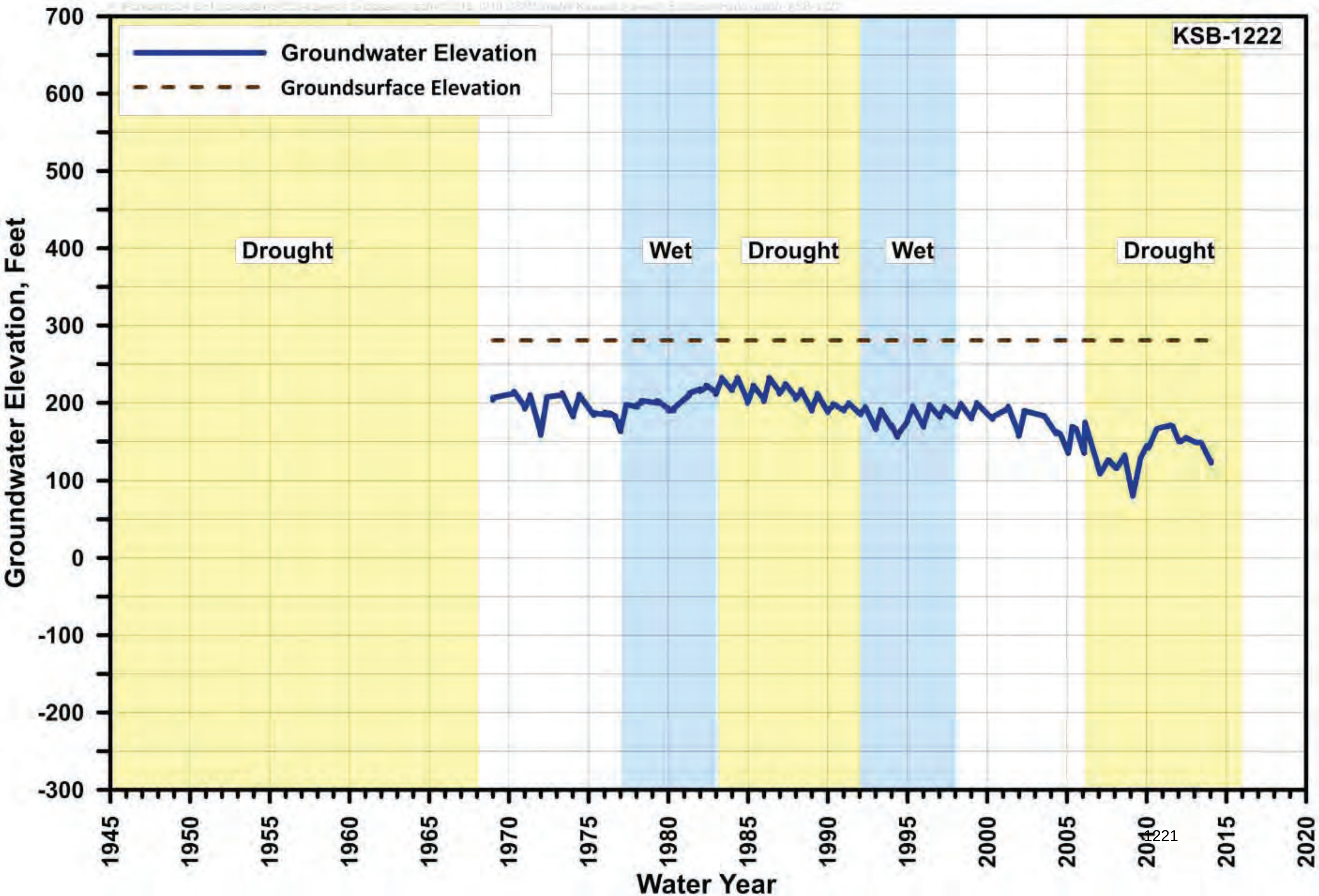
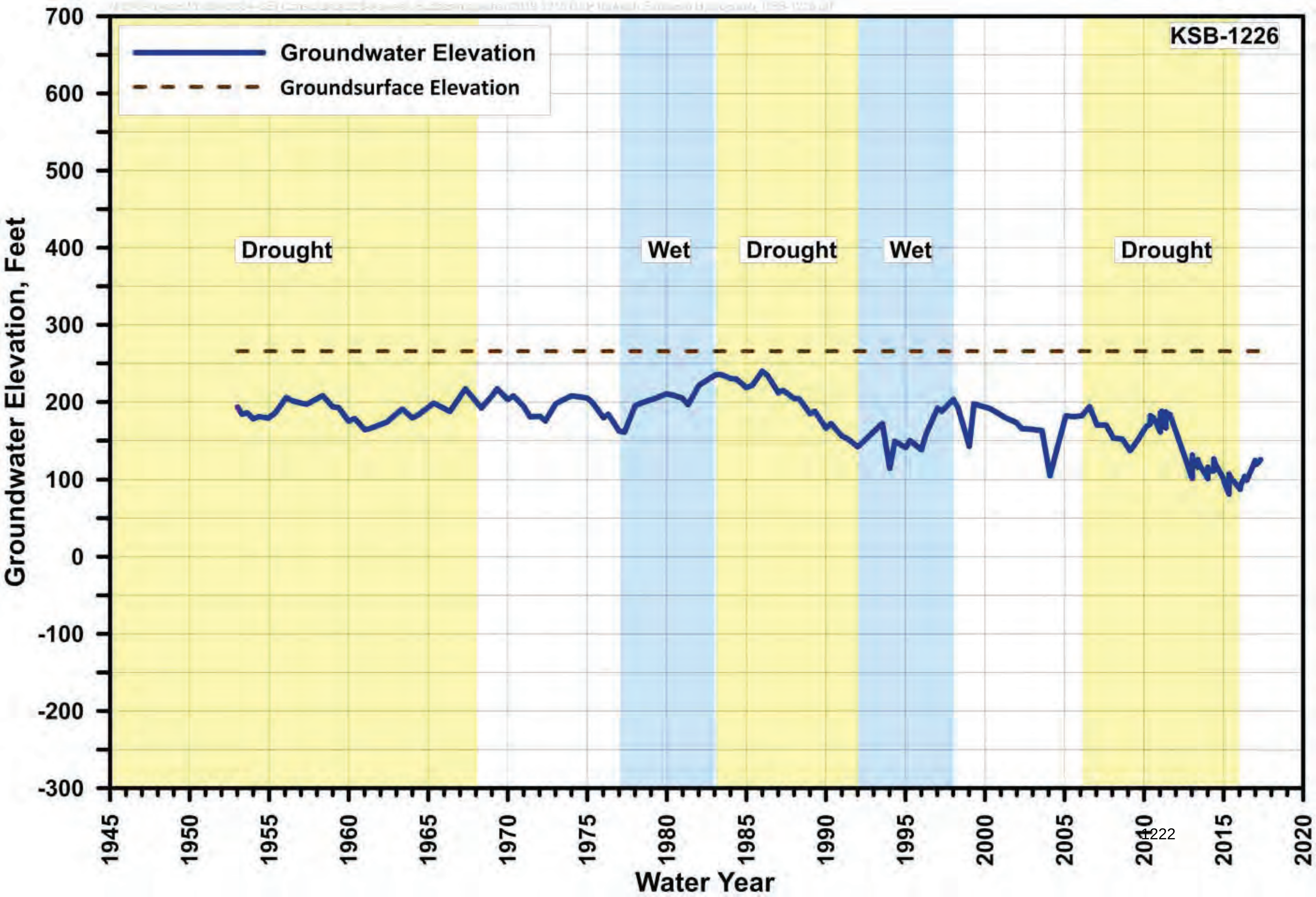
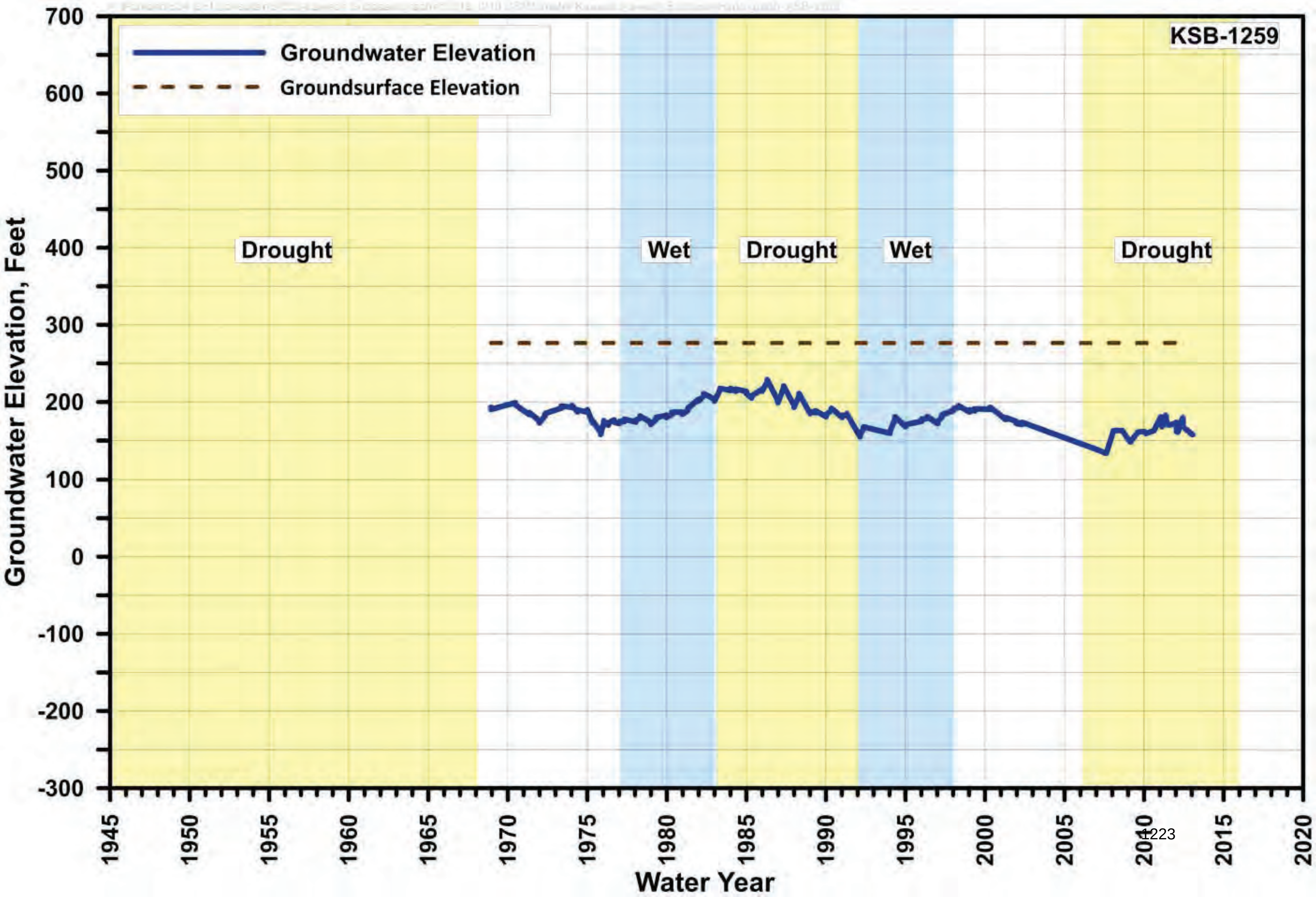
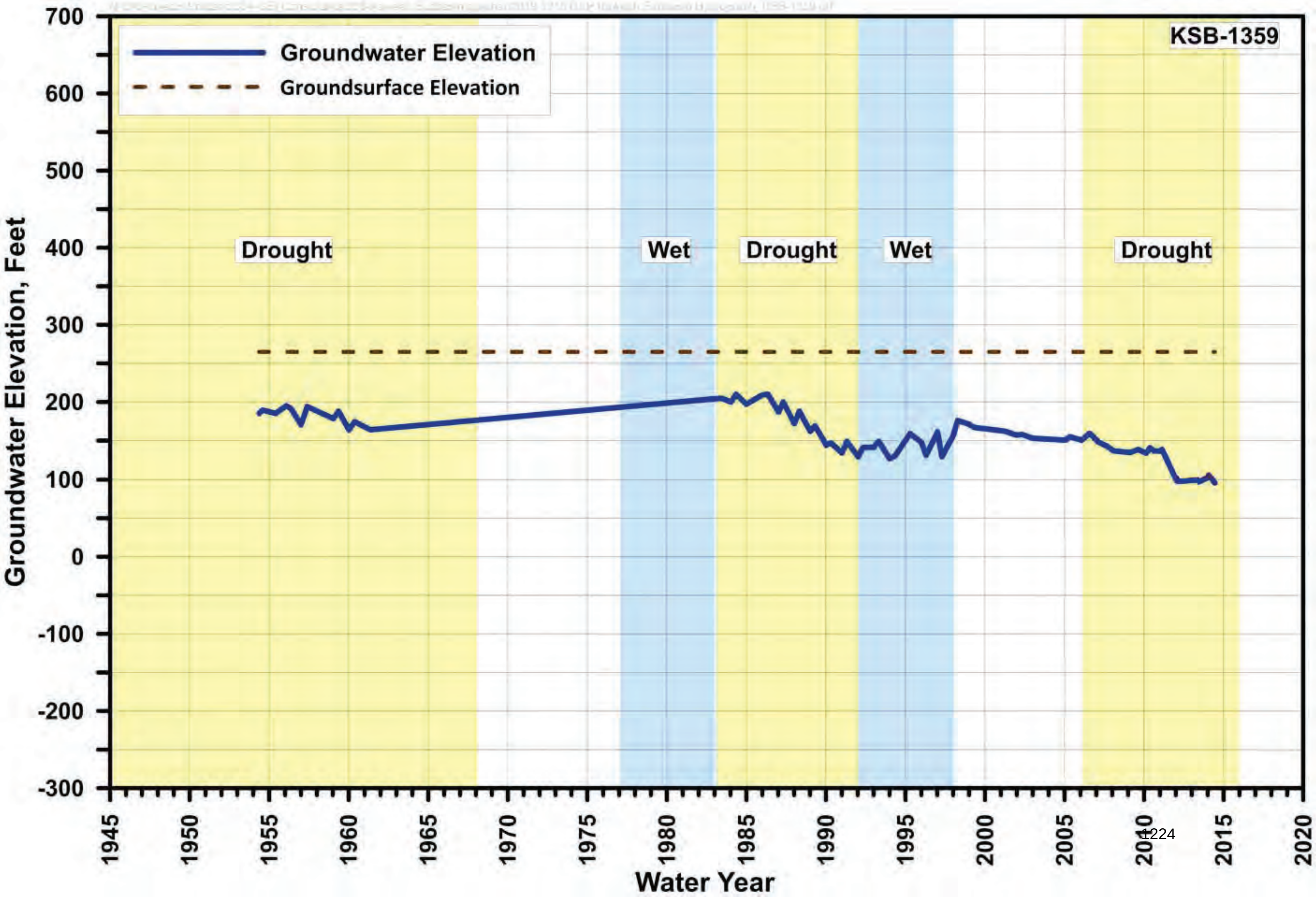


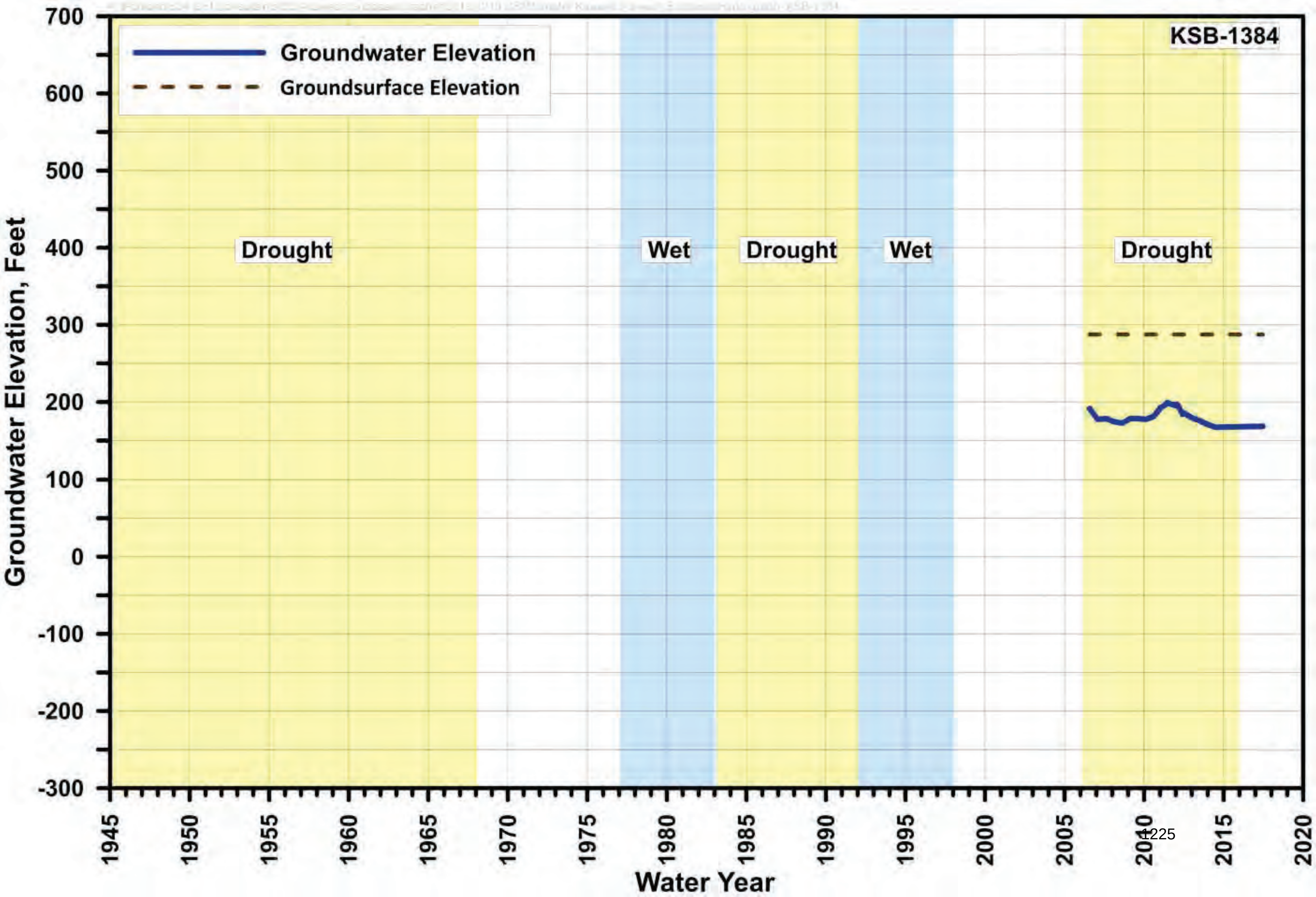
KSB-1222
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Water Year

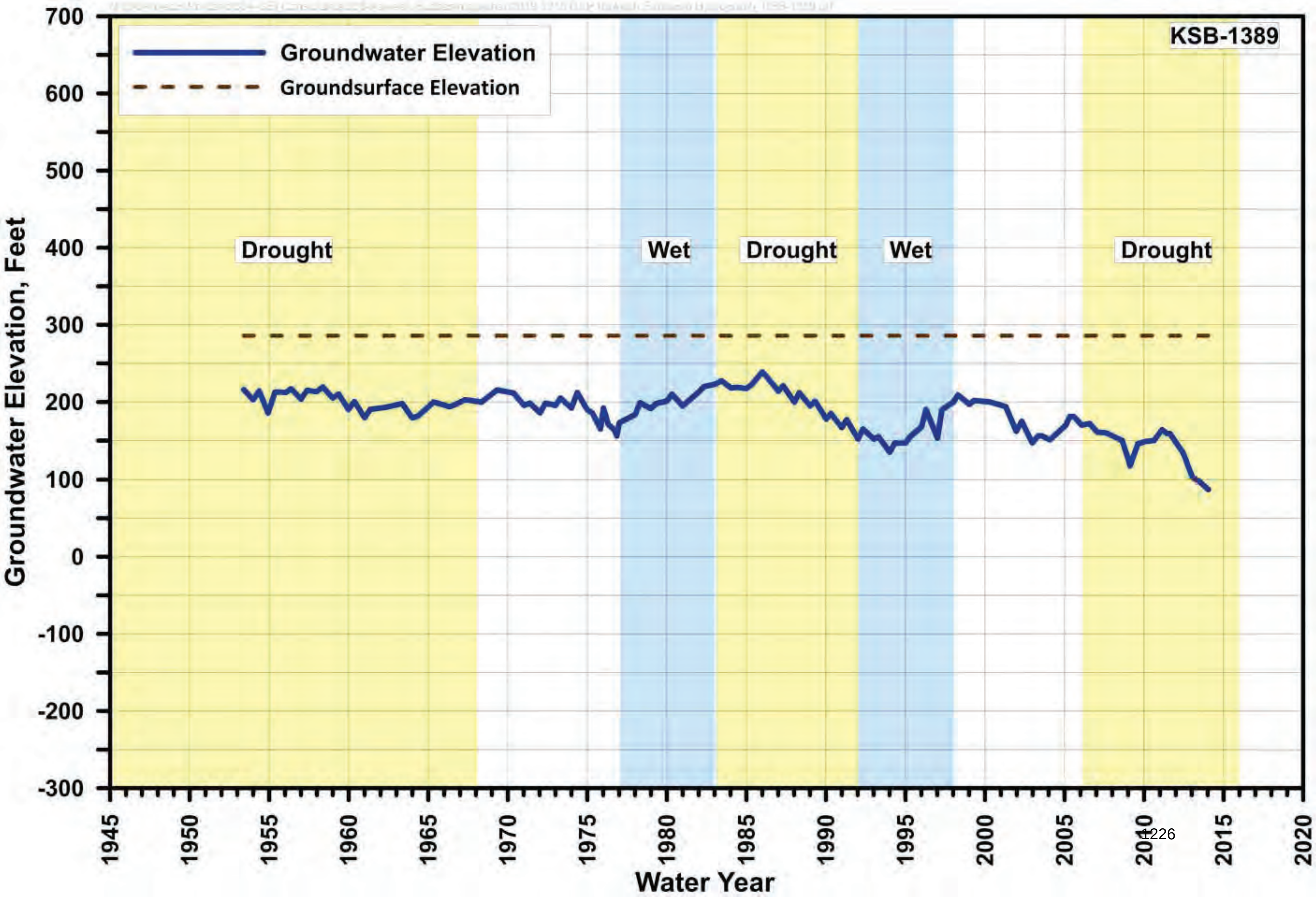

KSB-1226
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Water Year



Groundwater Elevation
Groundsurface Elevation
KSB-1259
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Water Year


KSB-1359
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Water Year


KSB-1384
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020


KSB-1389
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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1995
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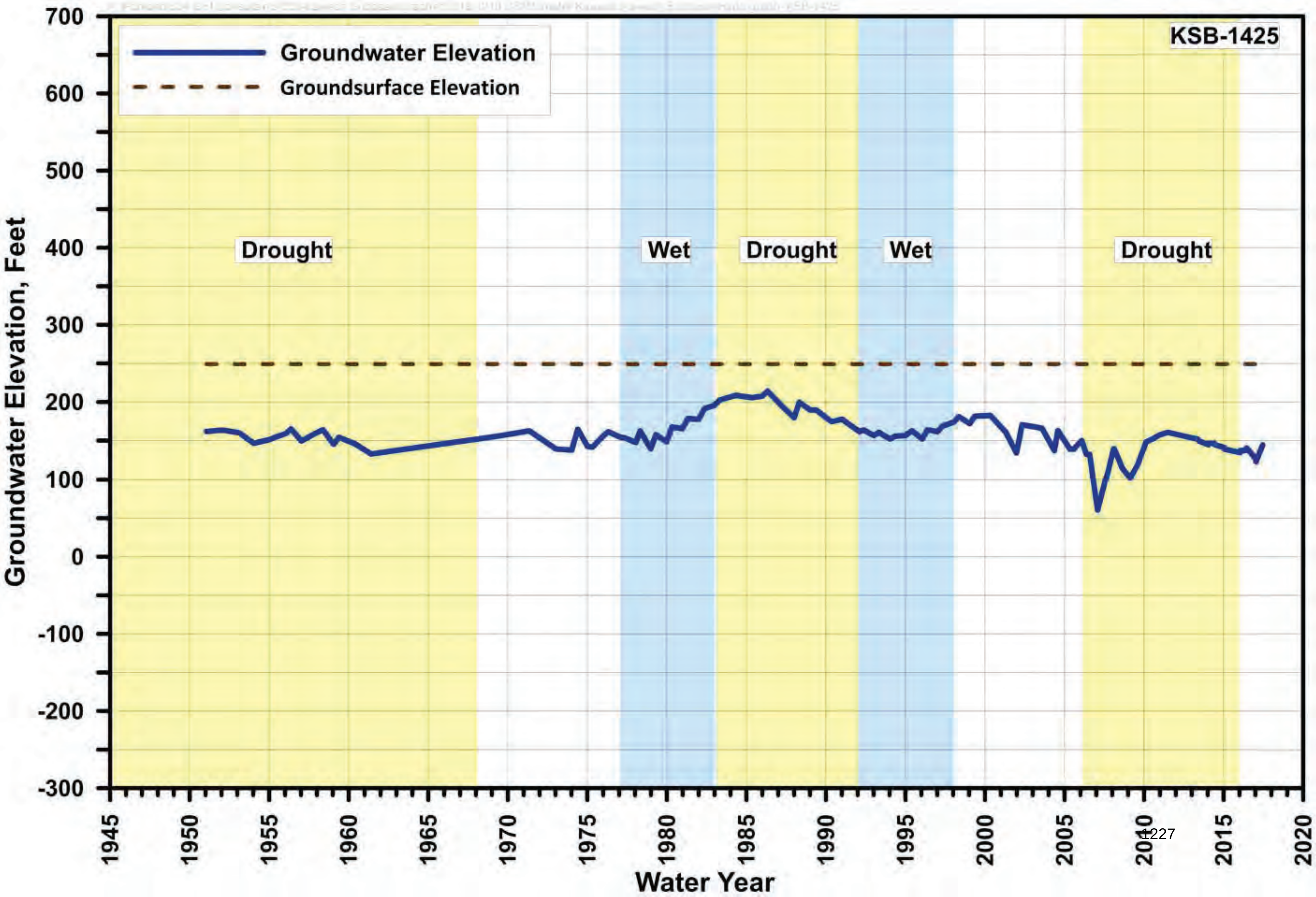
2005
2010
2015
2020
Water Year



KSB-1425
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
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1970
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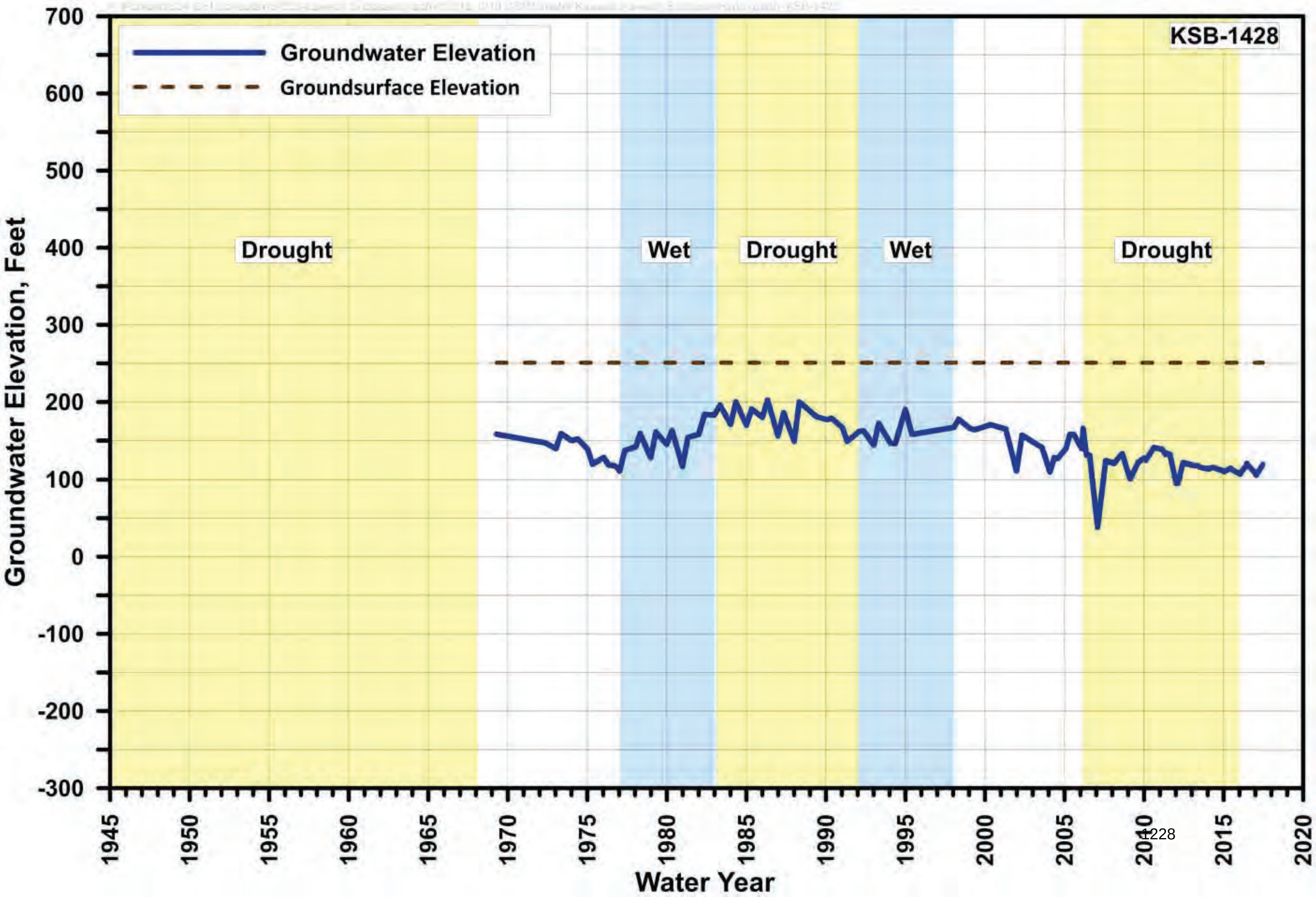
1980
1985
1990
1995
2000
2005
2010
2015
2020
Water Year


KSB-1428
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
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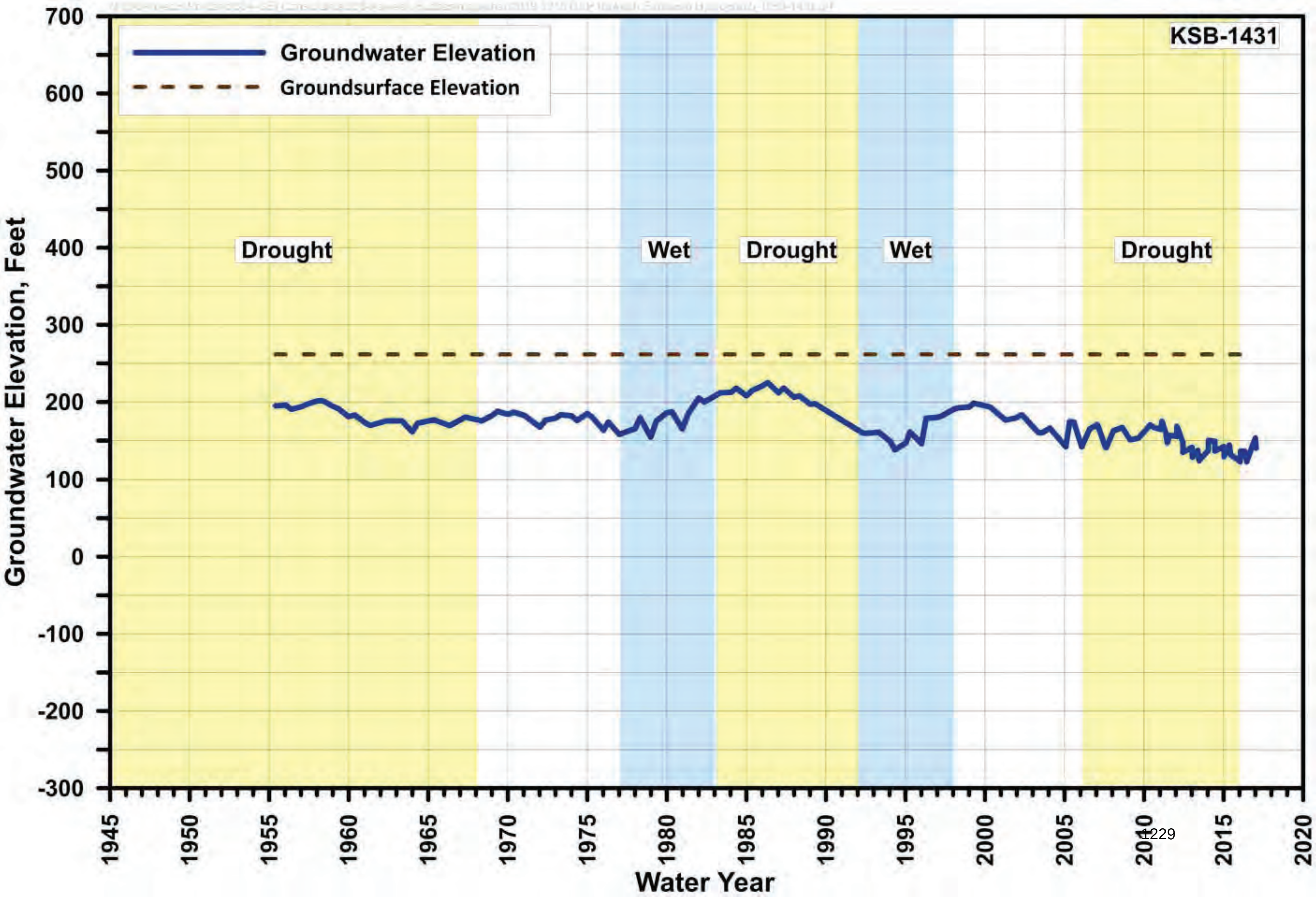
2020
1228



KSB-1431
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
1965
1970
1975
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1995
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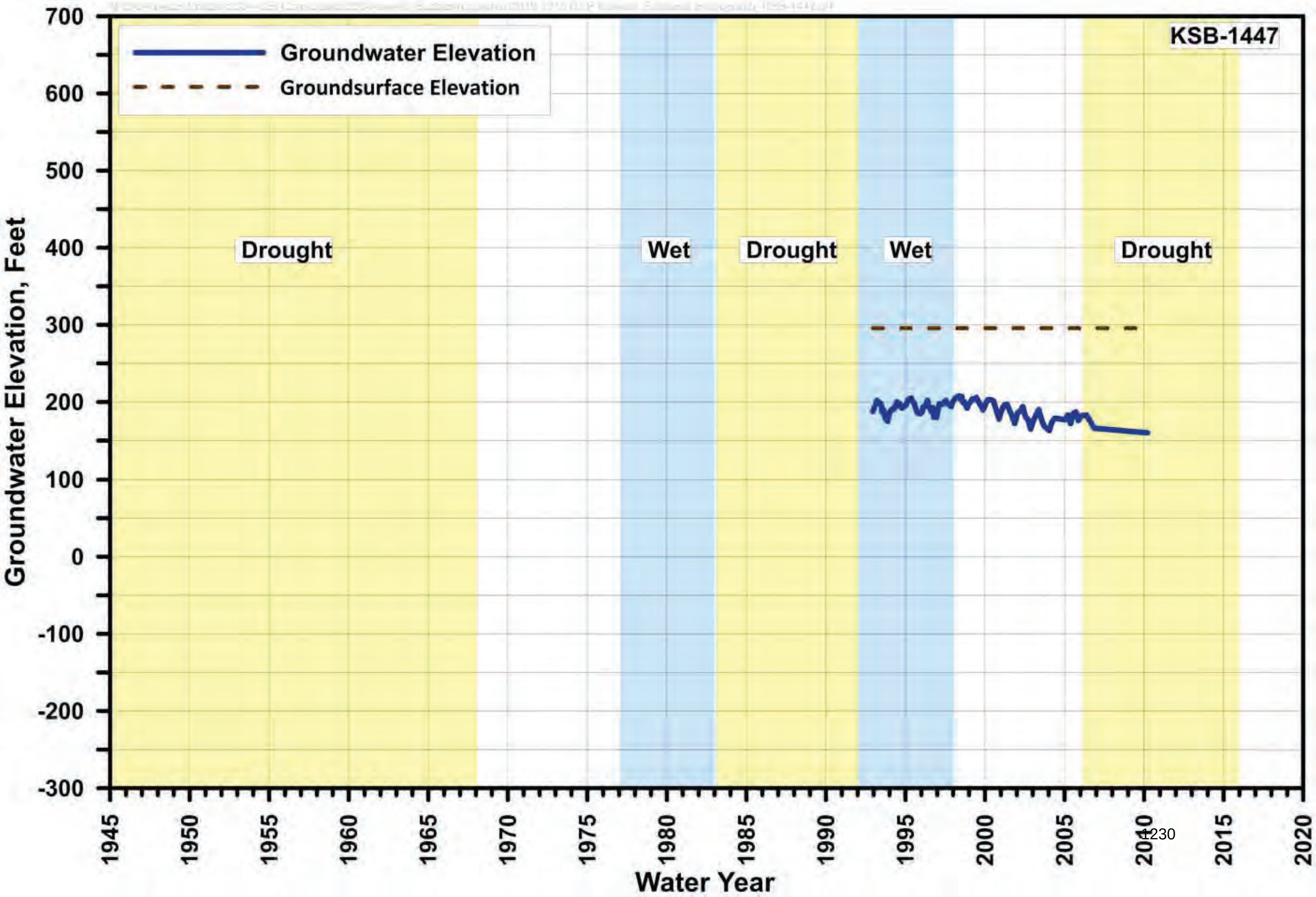
2005
2010
2015
2020



KSB-1447
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
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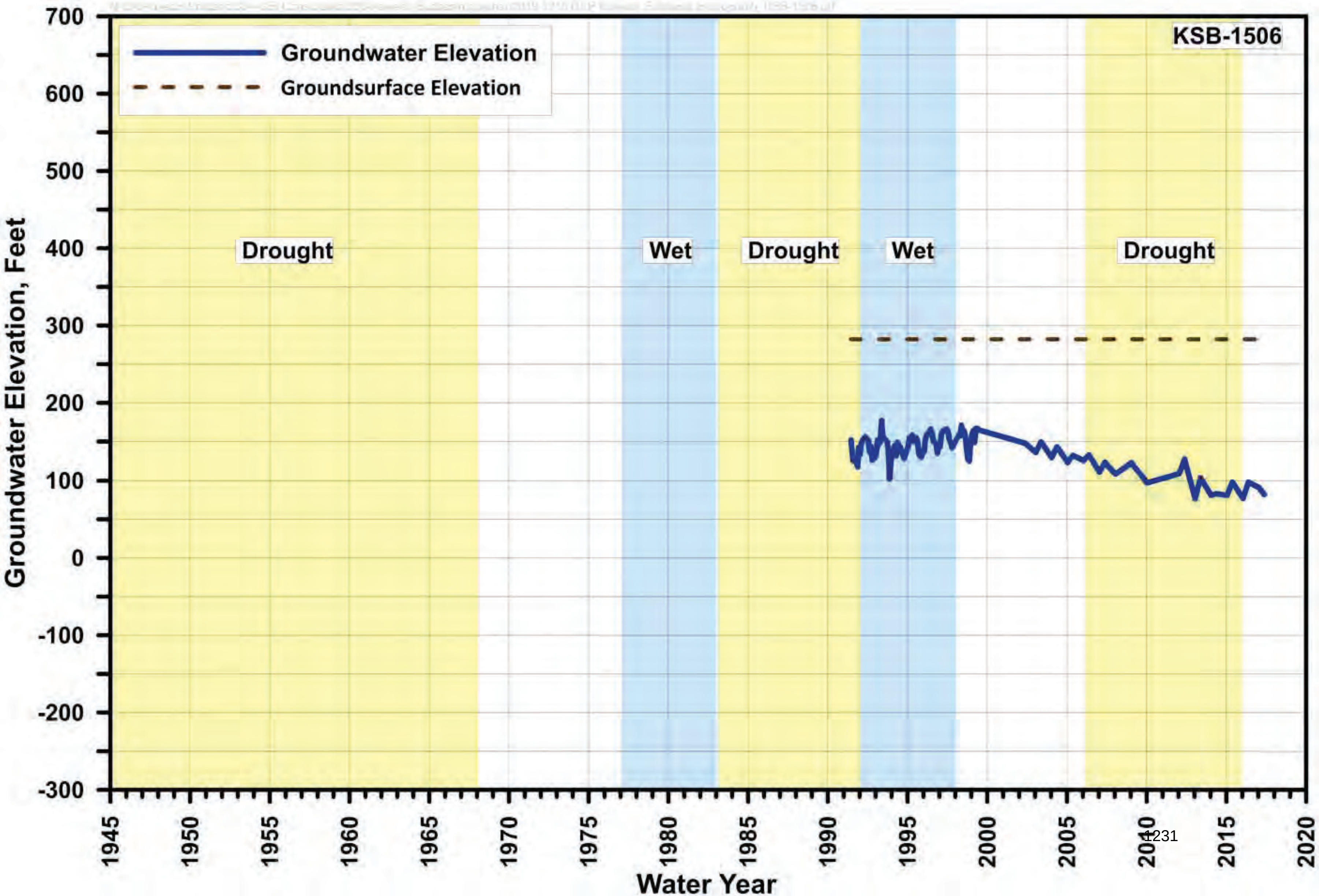
2005
2010
2015
2020
Water Year



KSB-1506
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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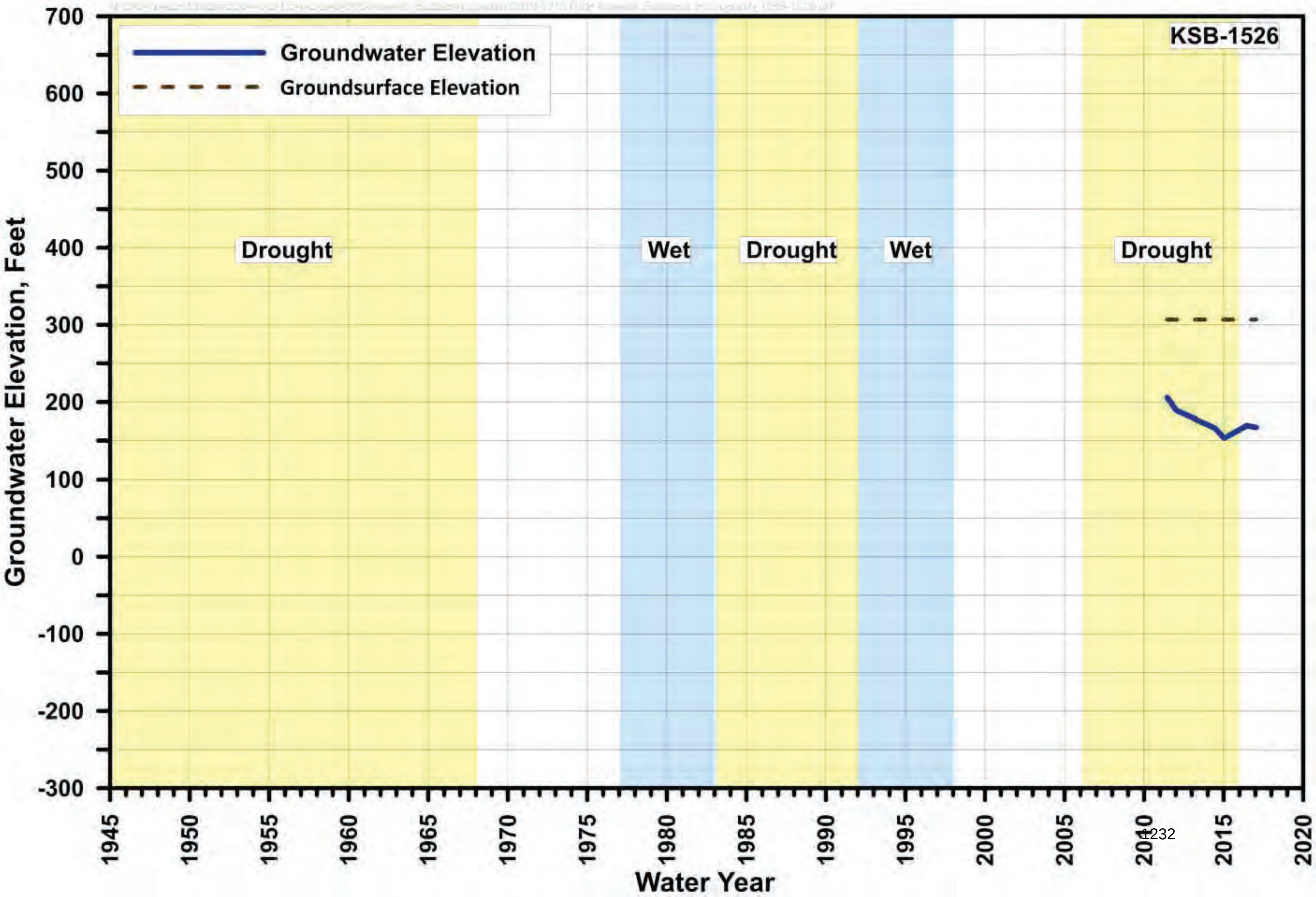
2010
2015
2020
Water Year


KSB-1526
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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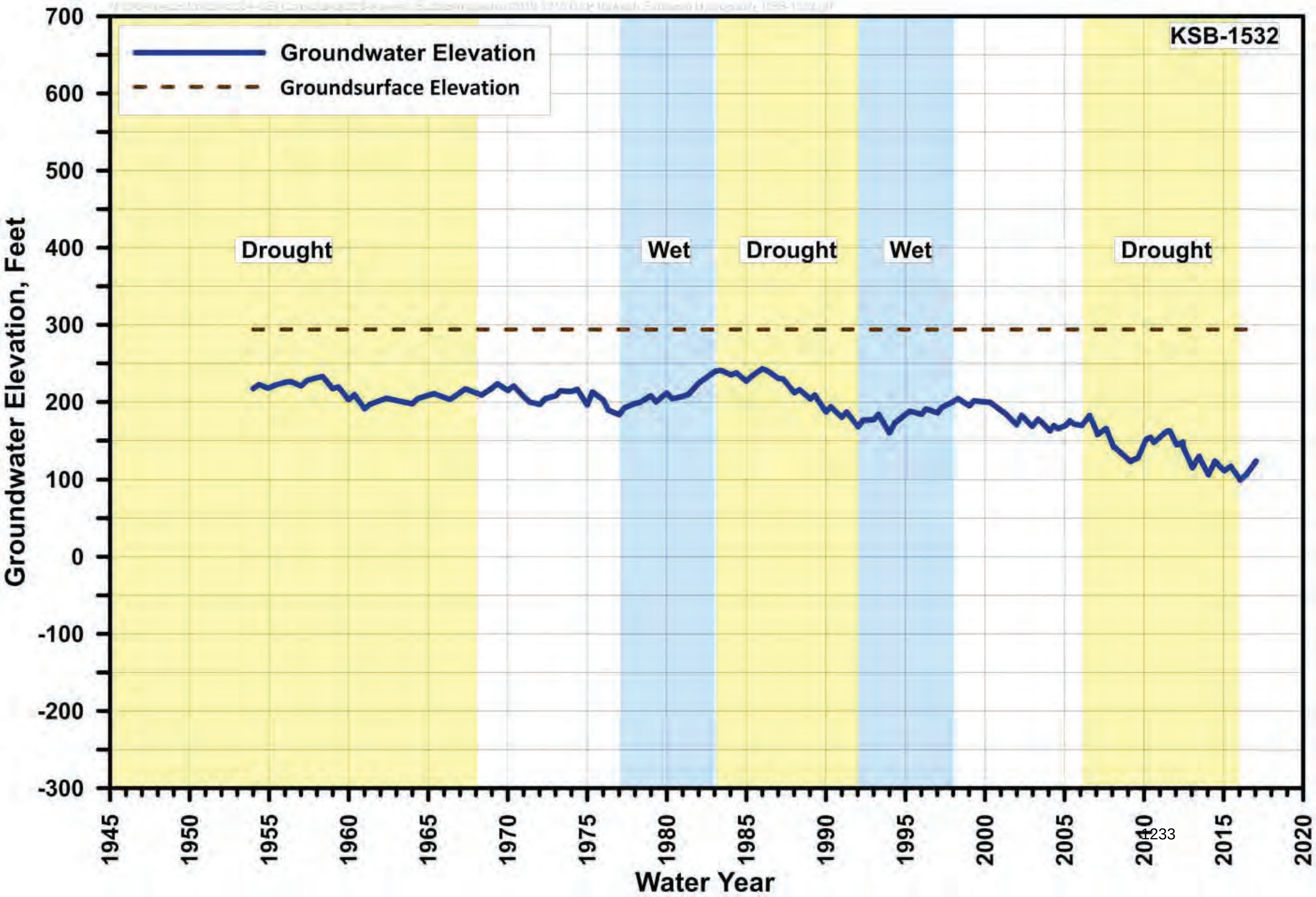
2015
2020
Water Year



KSB-1532
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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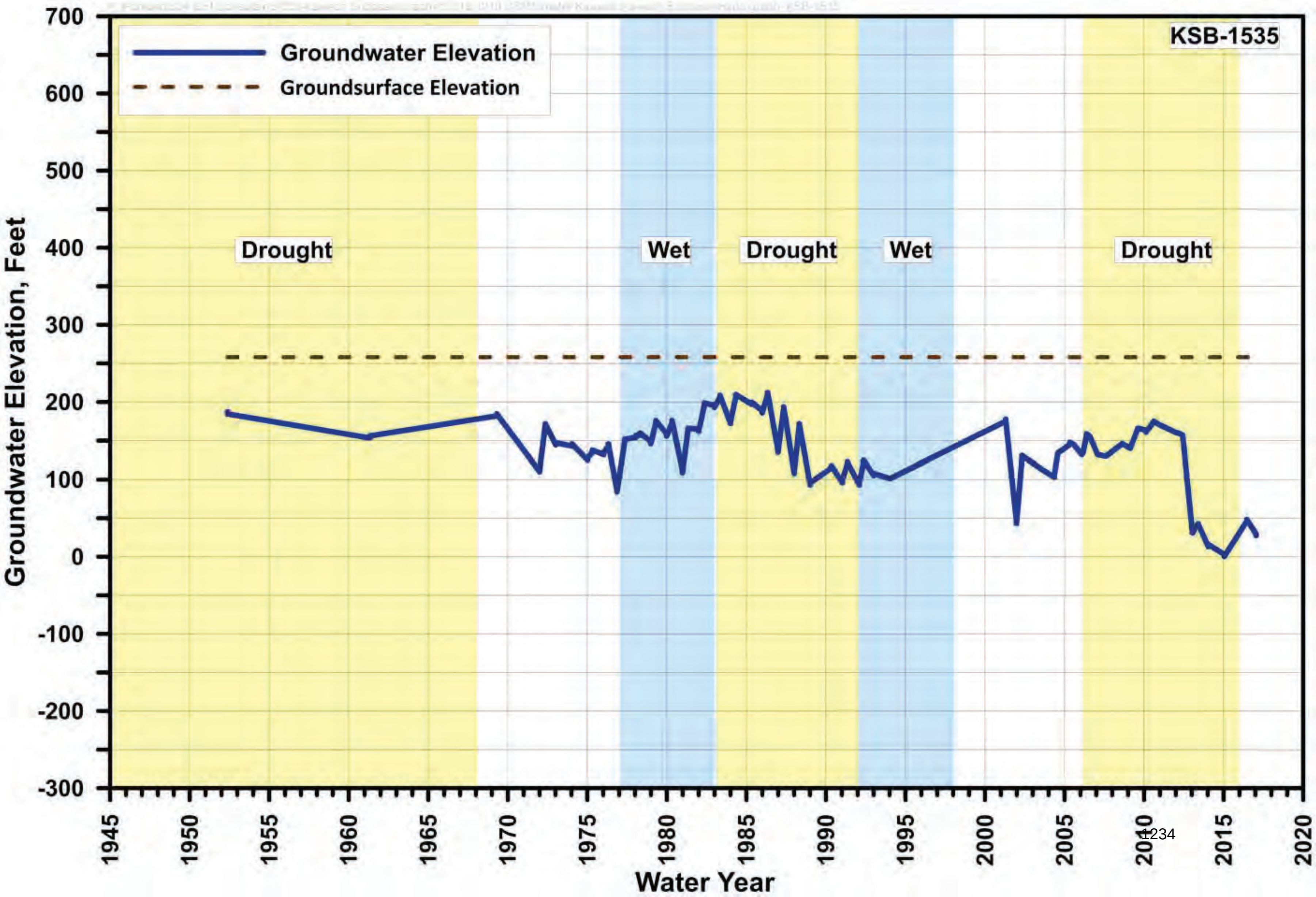
2020


KSB-1535
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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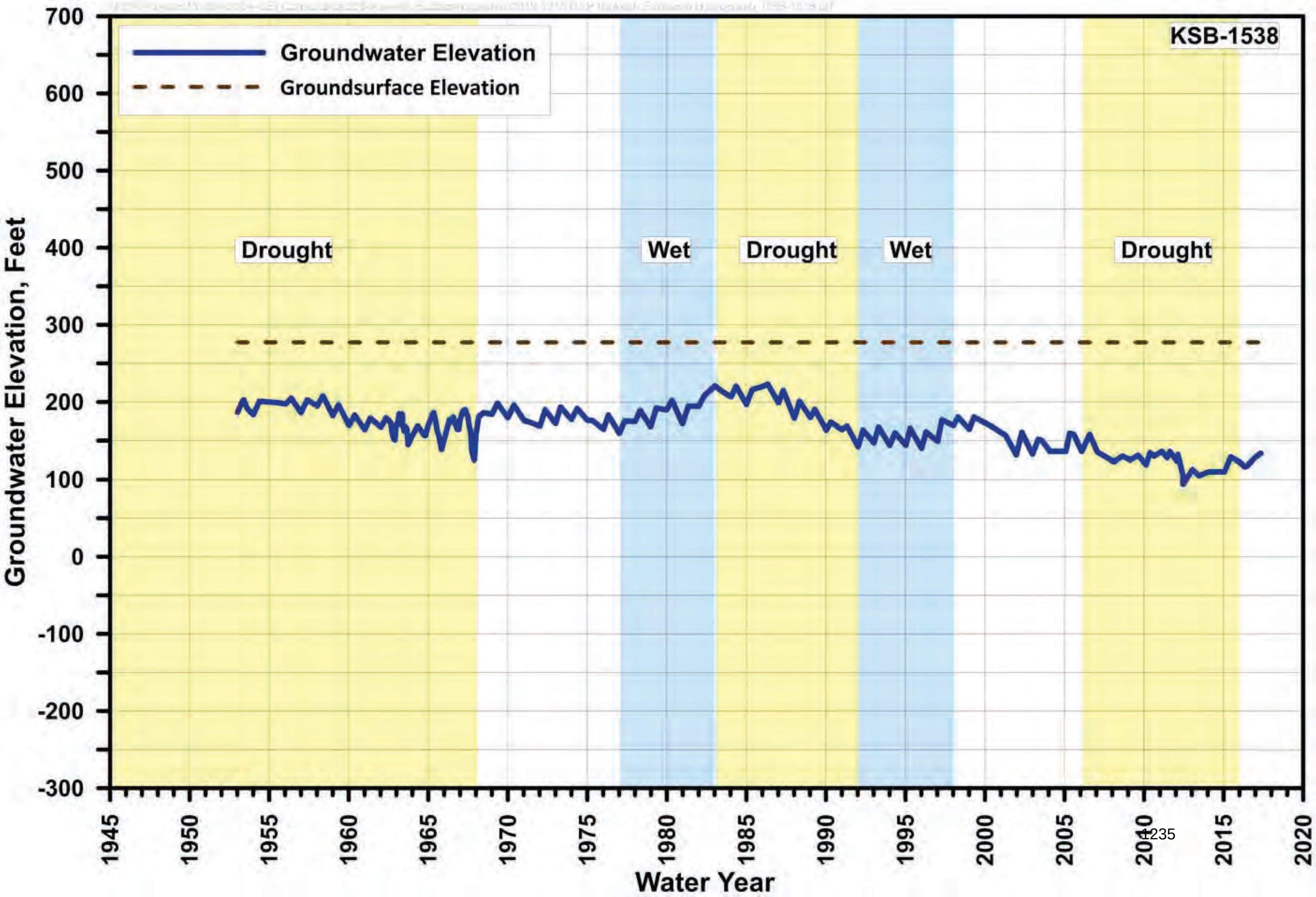
2015
2020



KSB-1538
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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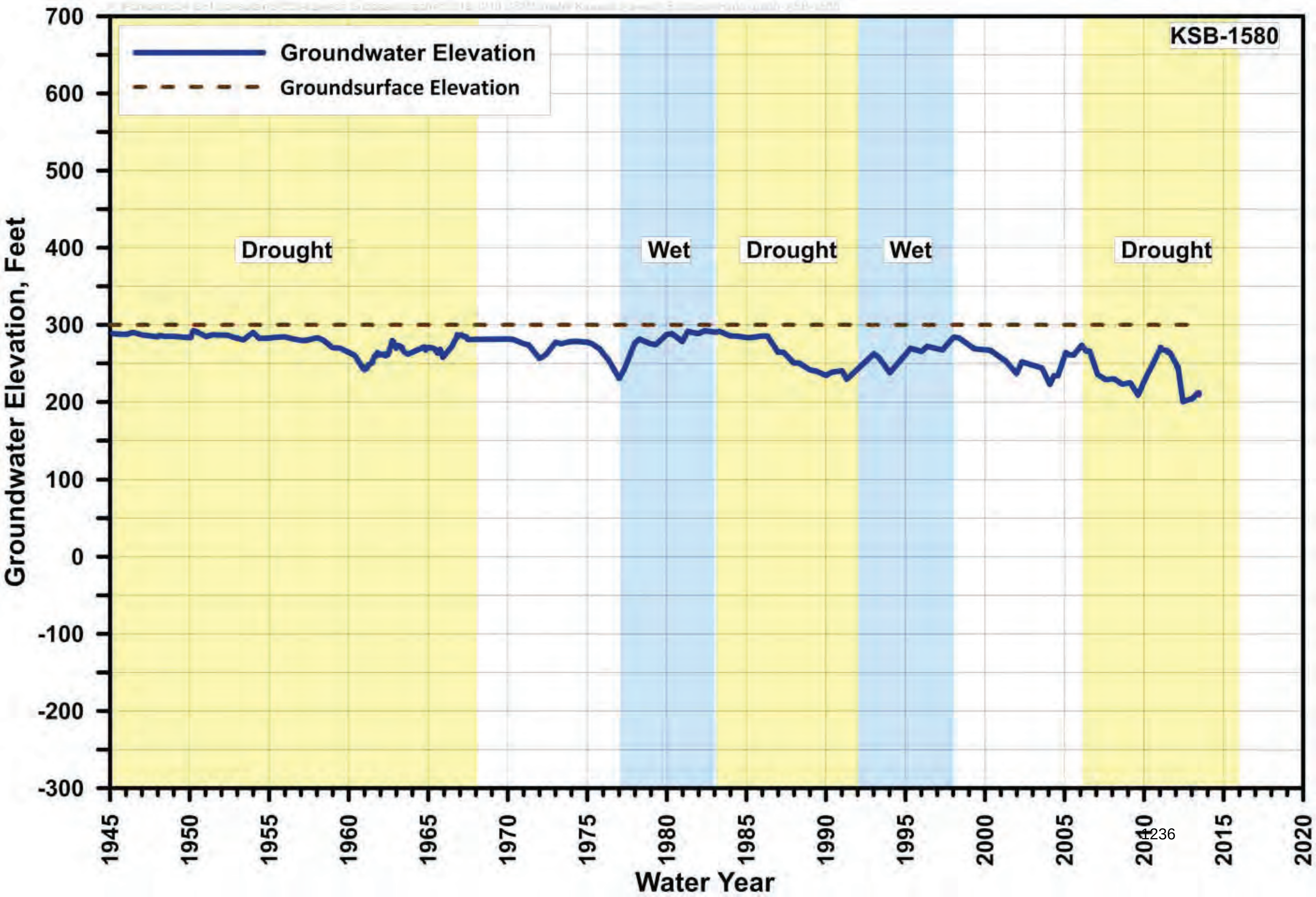
2010
2015
2020
Water Year


KSB-1580
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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2005
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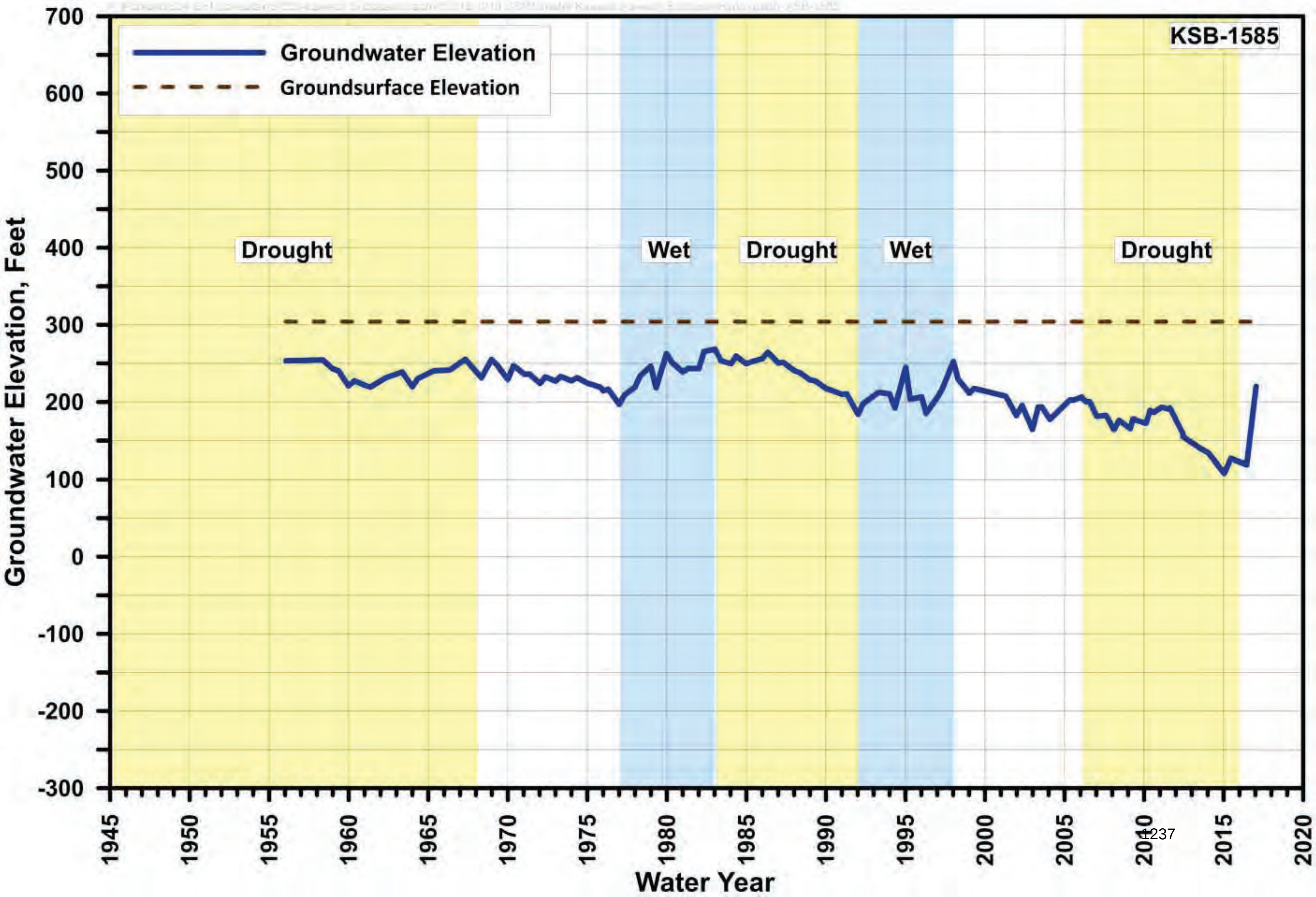
2015
2020



KSB-1585
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
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-200
-300
1945
1950
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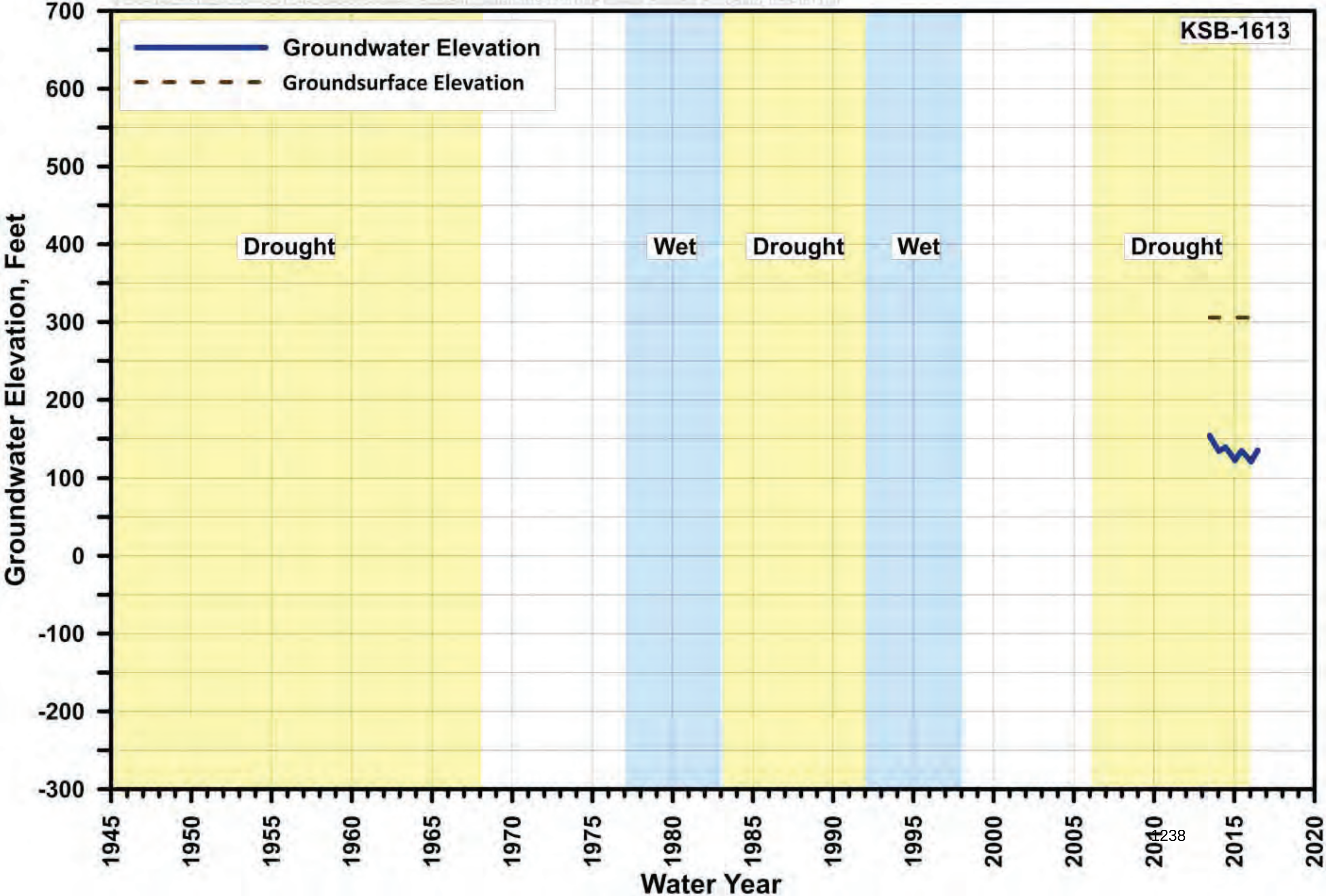
2015
2020


KSB-1613
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
1960
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1980
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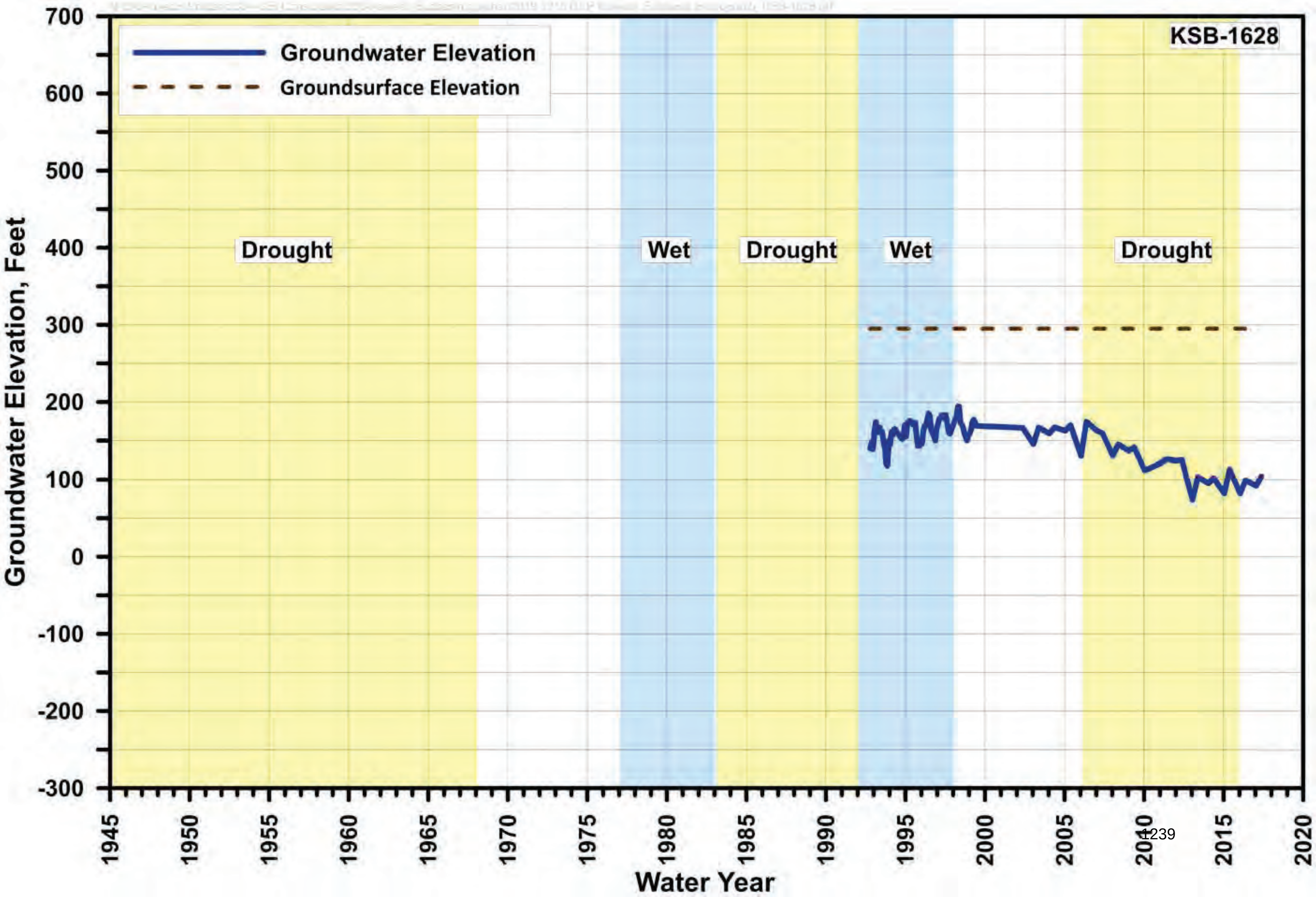
1990
1995
2000
2005
2010
2015
2020
Water Year



KSB-1628
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
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1980
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1995
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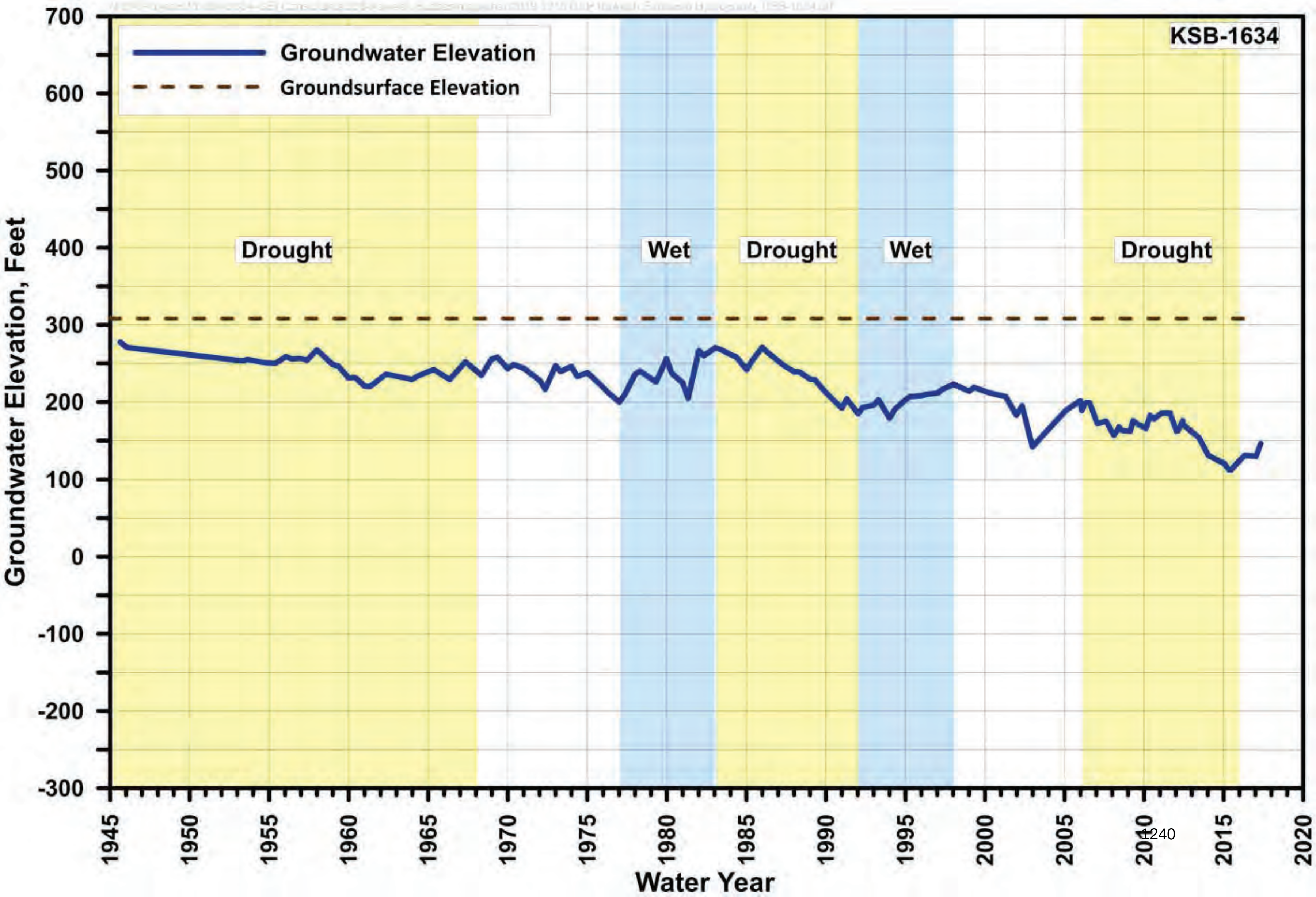
2005
2010
2015
2020
Water Year


KSB-1634
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
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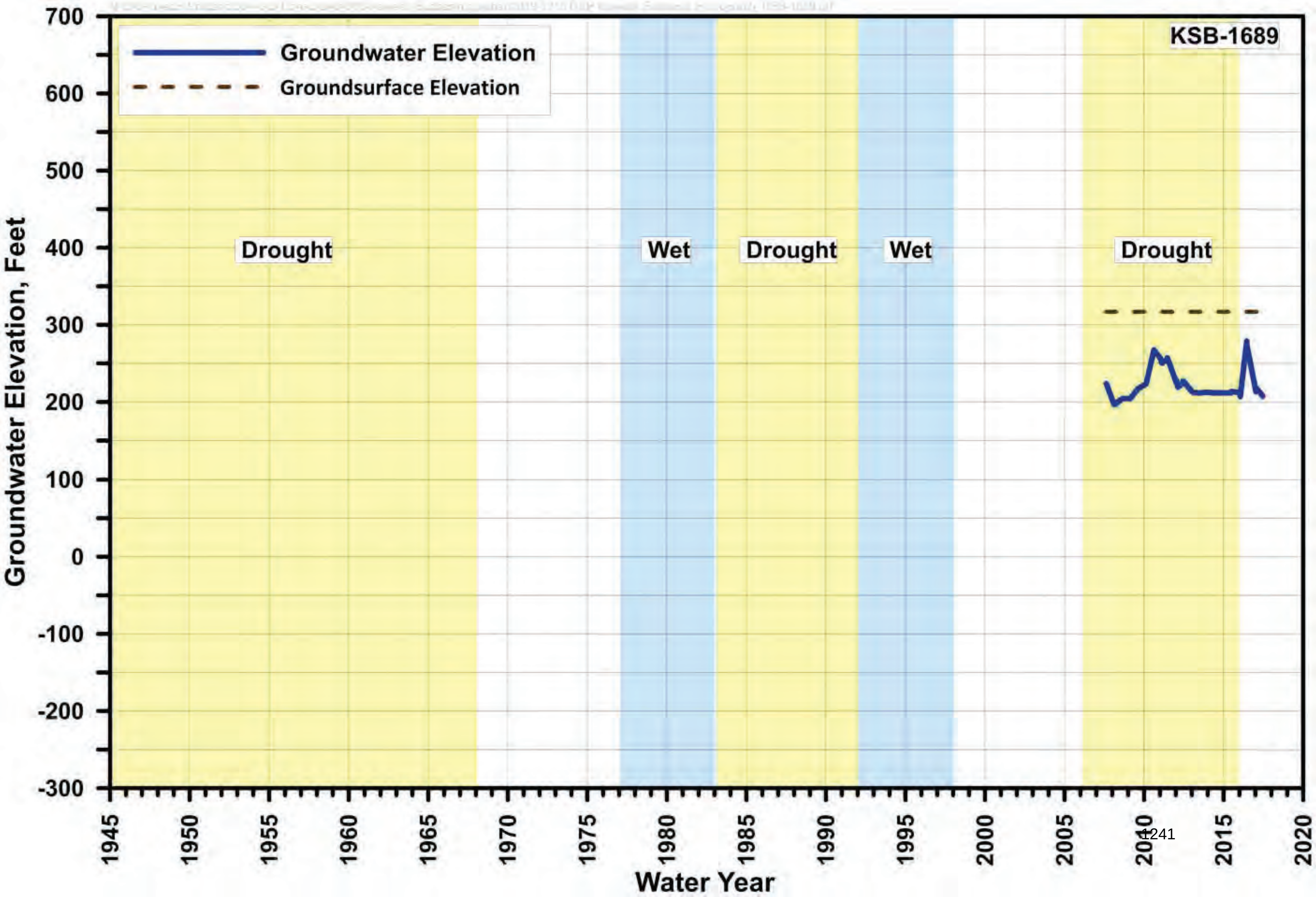
2010
2015
2020
Water Year


KSB-1689
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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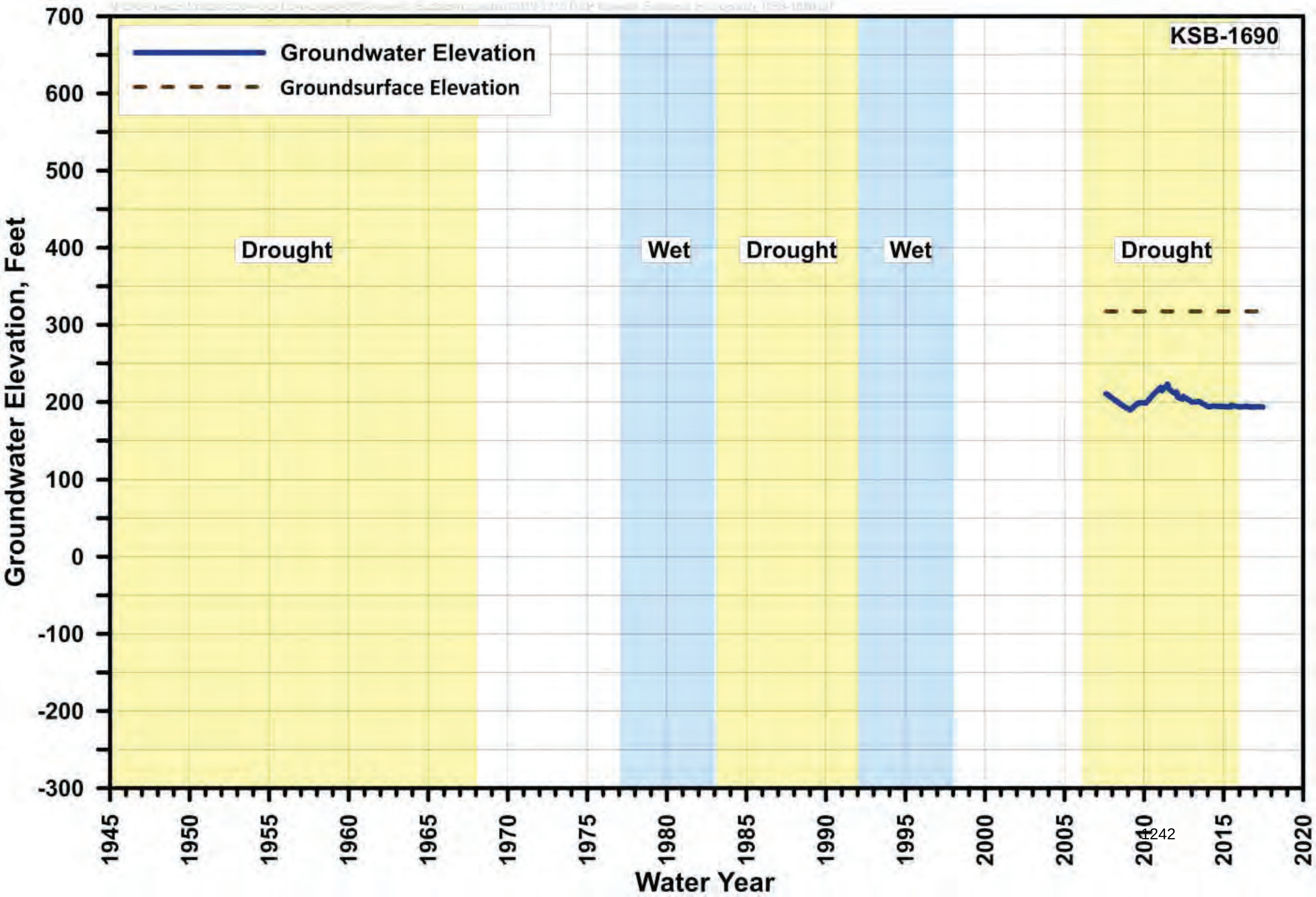
2010
2015
2020
Water Year



KSB-1690
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
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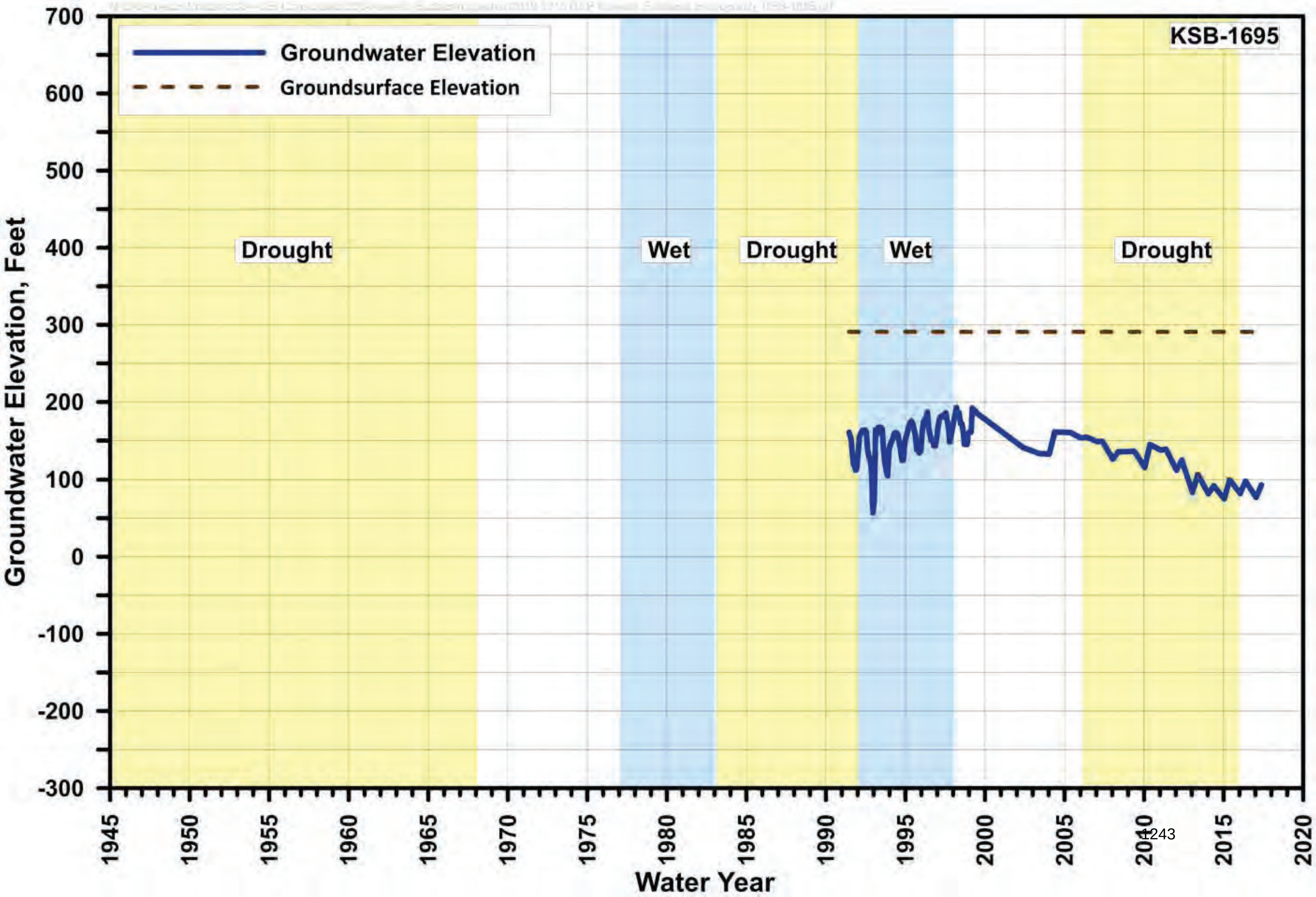
2020


KSB-1695
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
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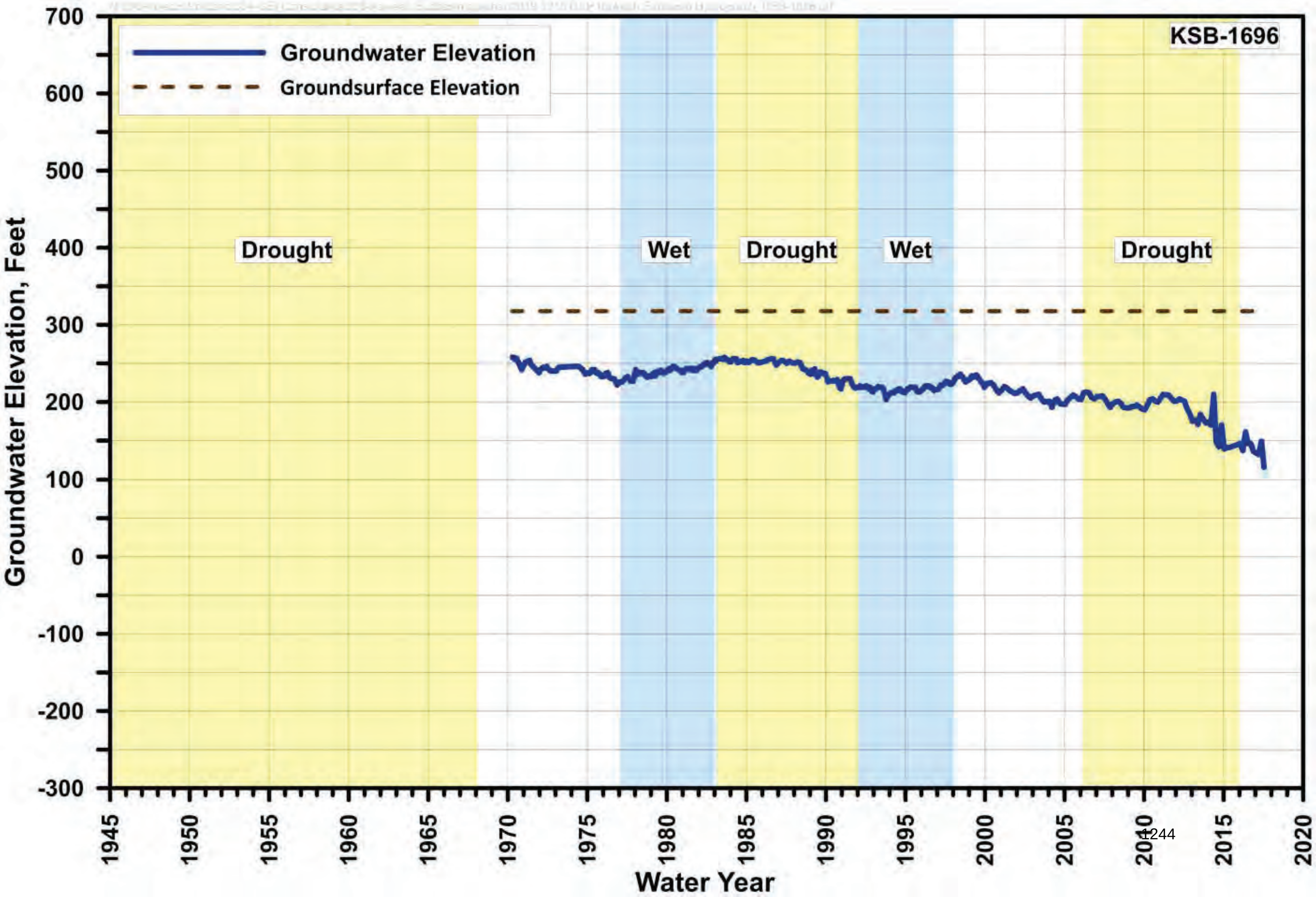
2015
2020
Water Year



KSB-1696
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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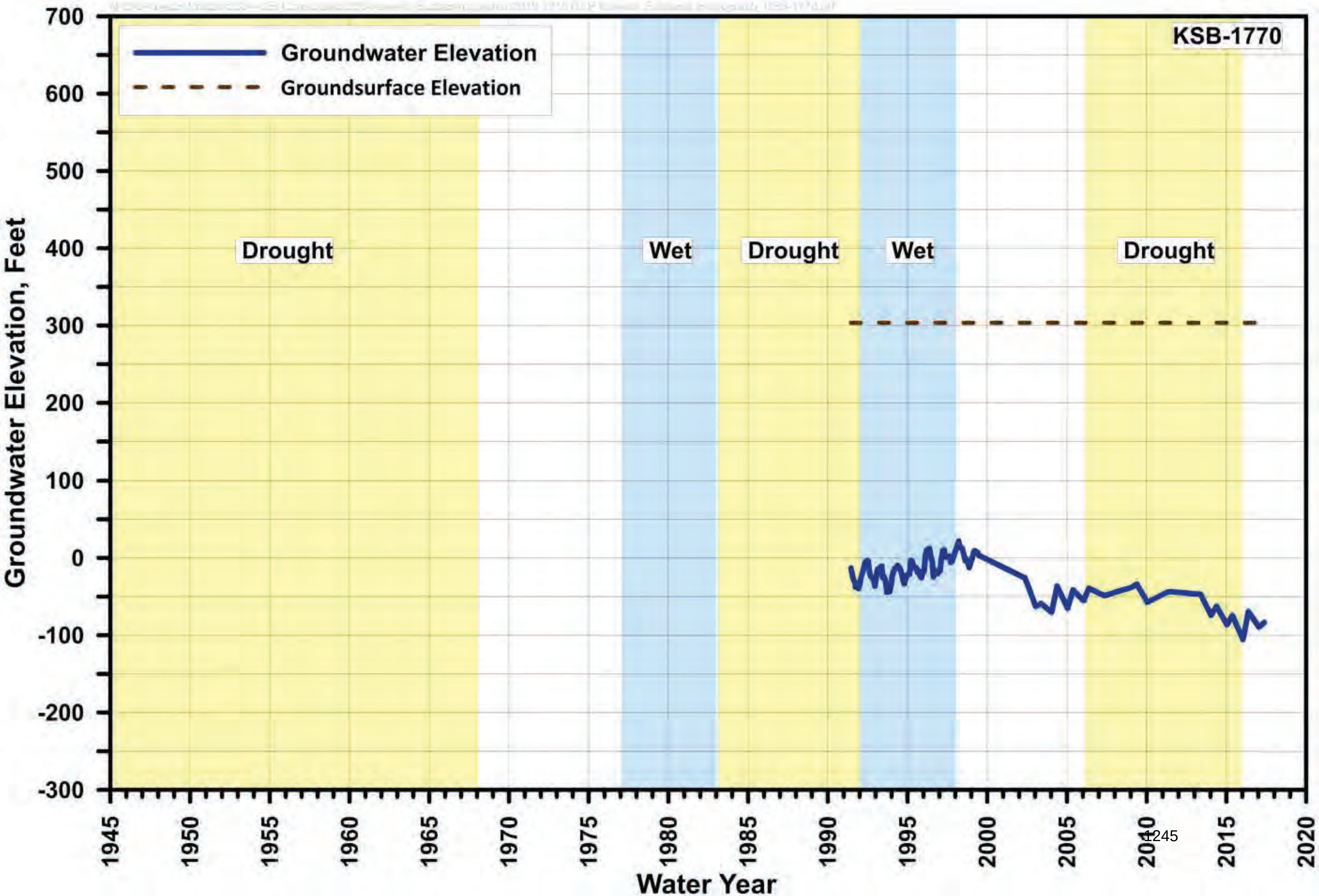
2015
2020
Water Year



KSB-1770
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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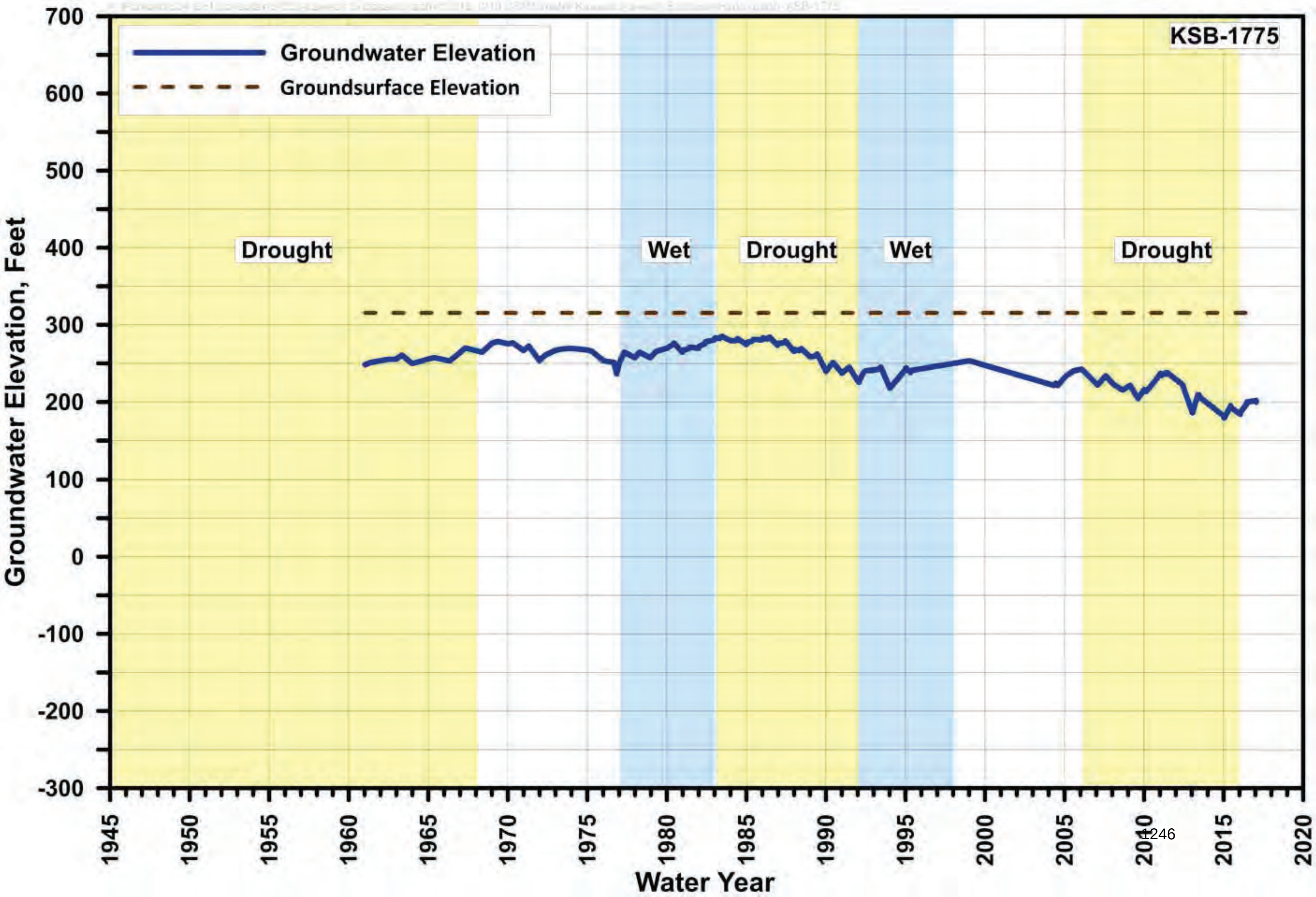
2015
2020
Water Year



KSB-1775
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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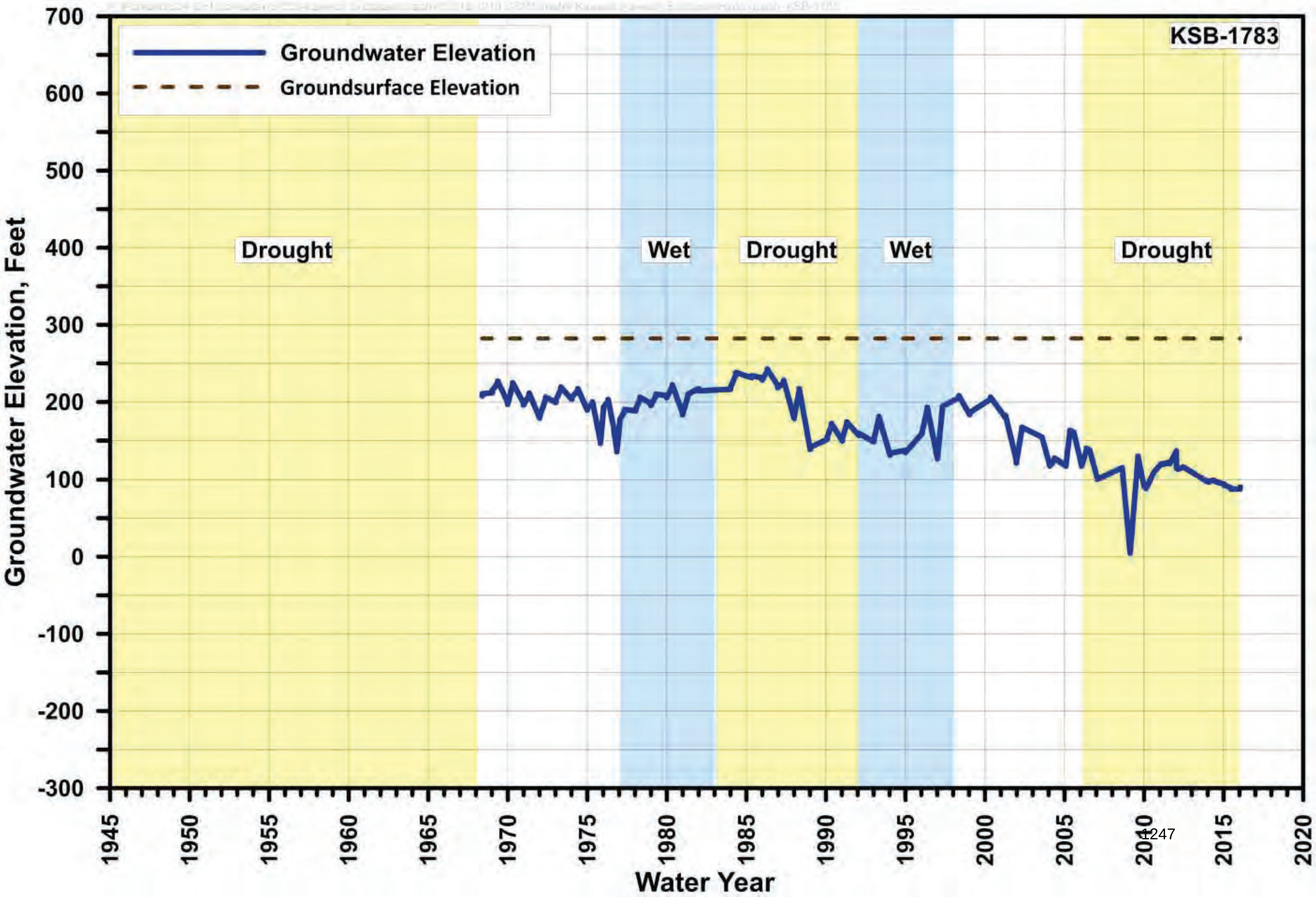
2020


KSB-1783
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
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-100
-200
-300
1945
1950
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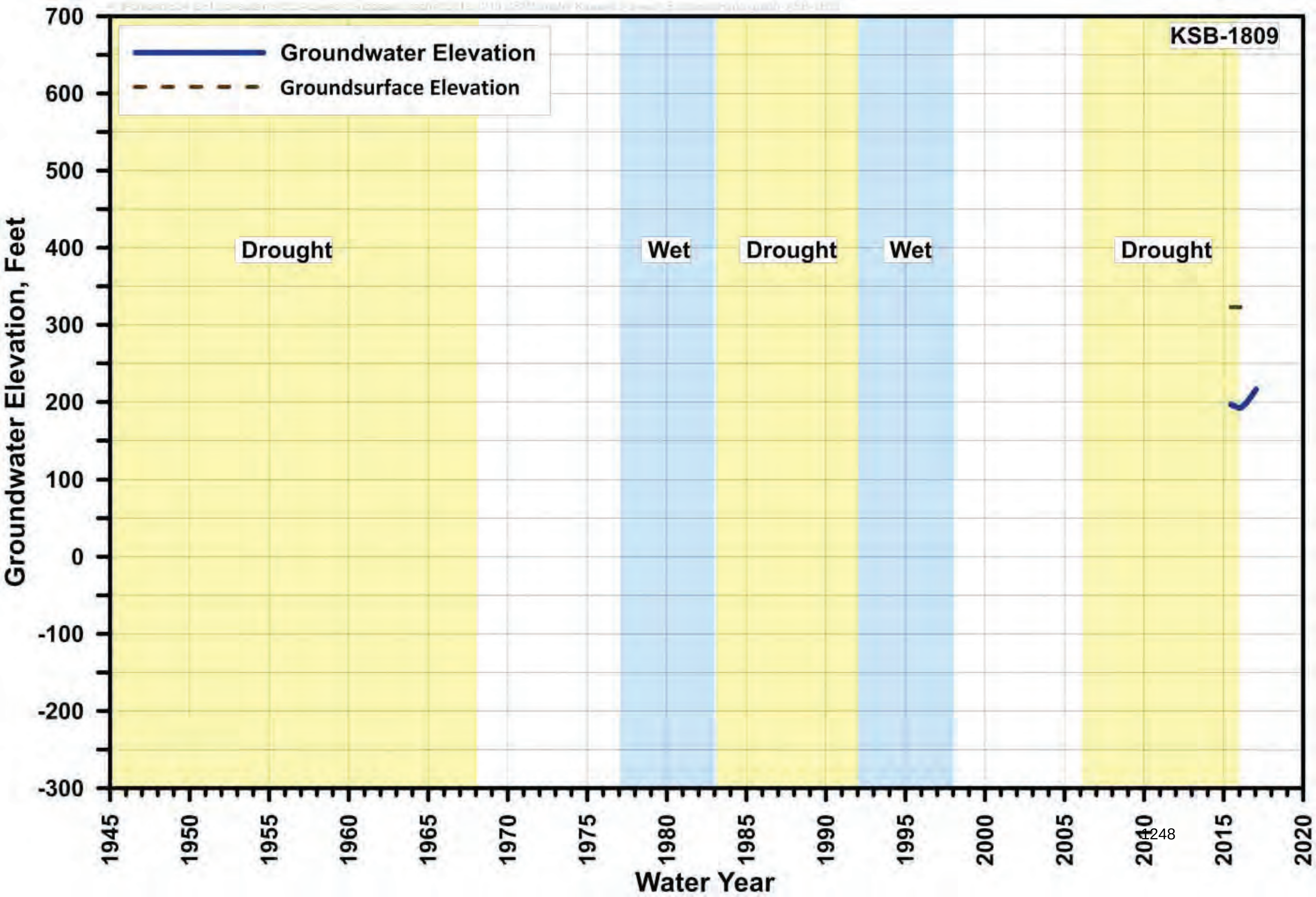
2015
2020
Water Year


KSB-1809
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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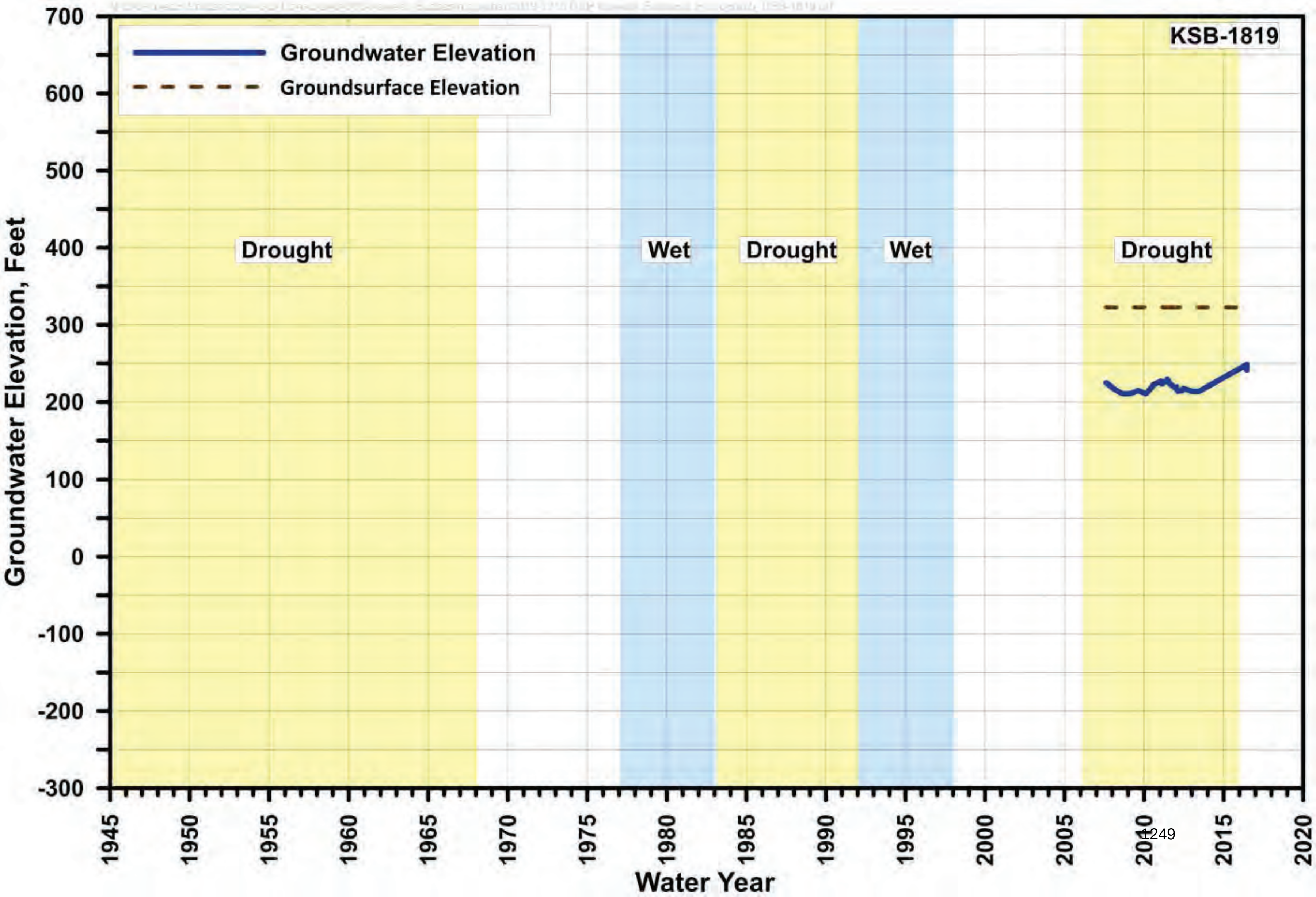
2015
2020
Water Year


KSB-1819
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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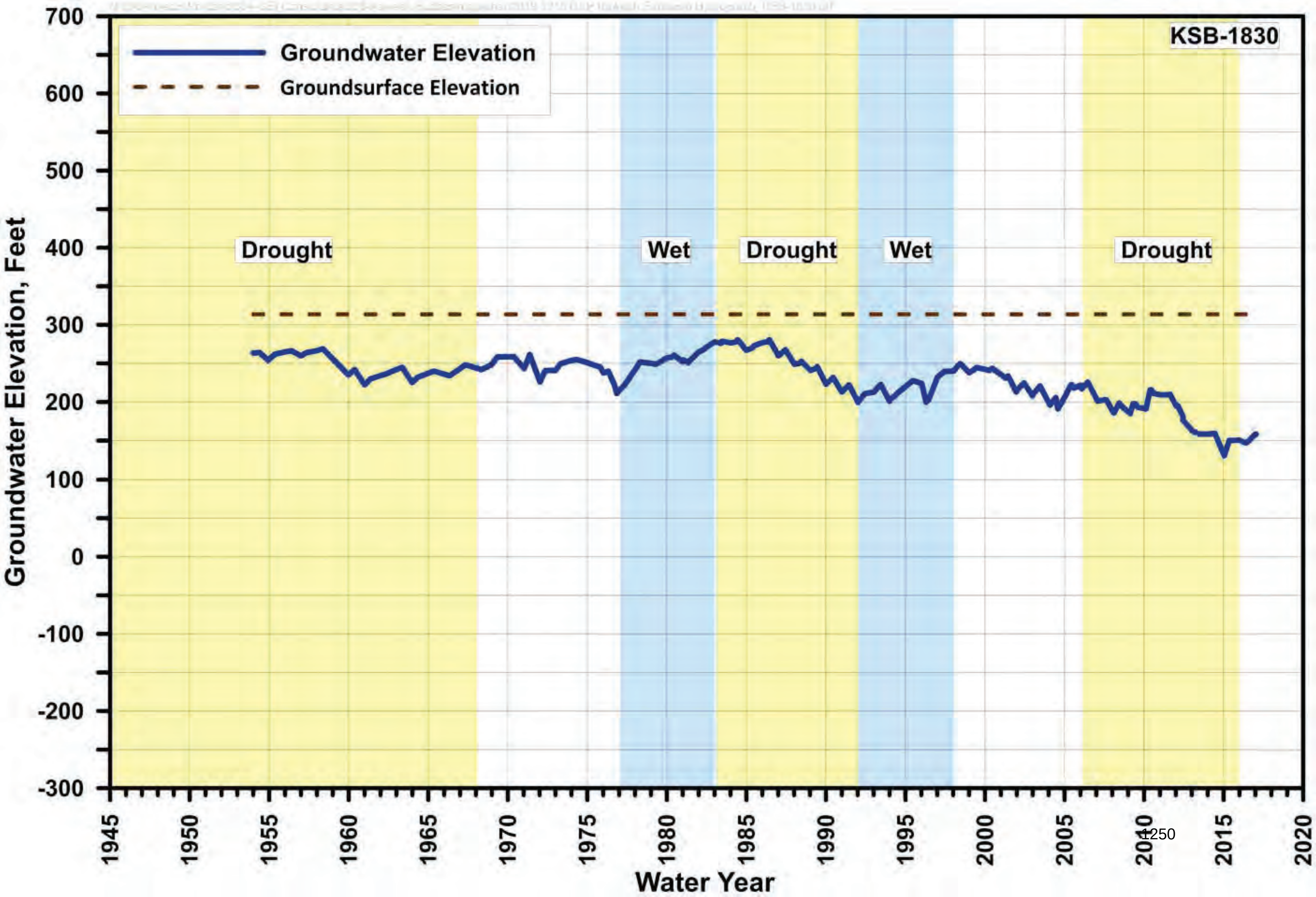
2015
2020
Water Year



KSB-1830
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
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-100
-200
-300
1945
1950
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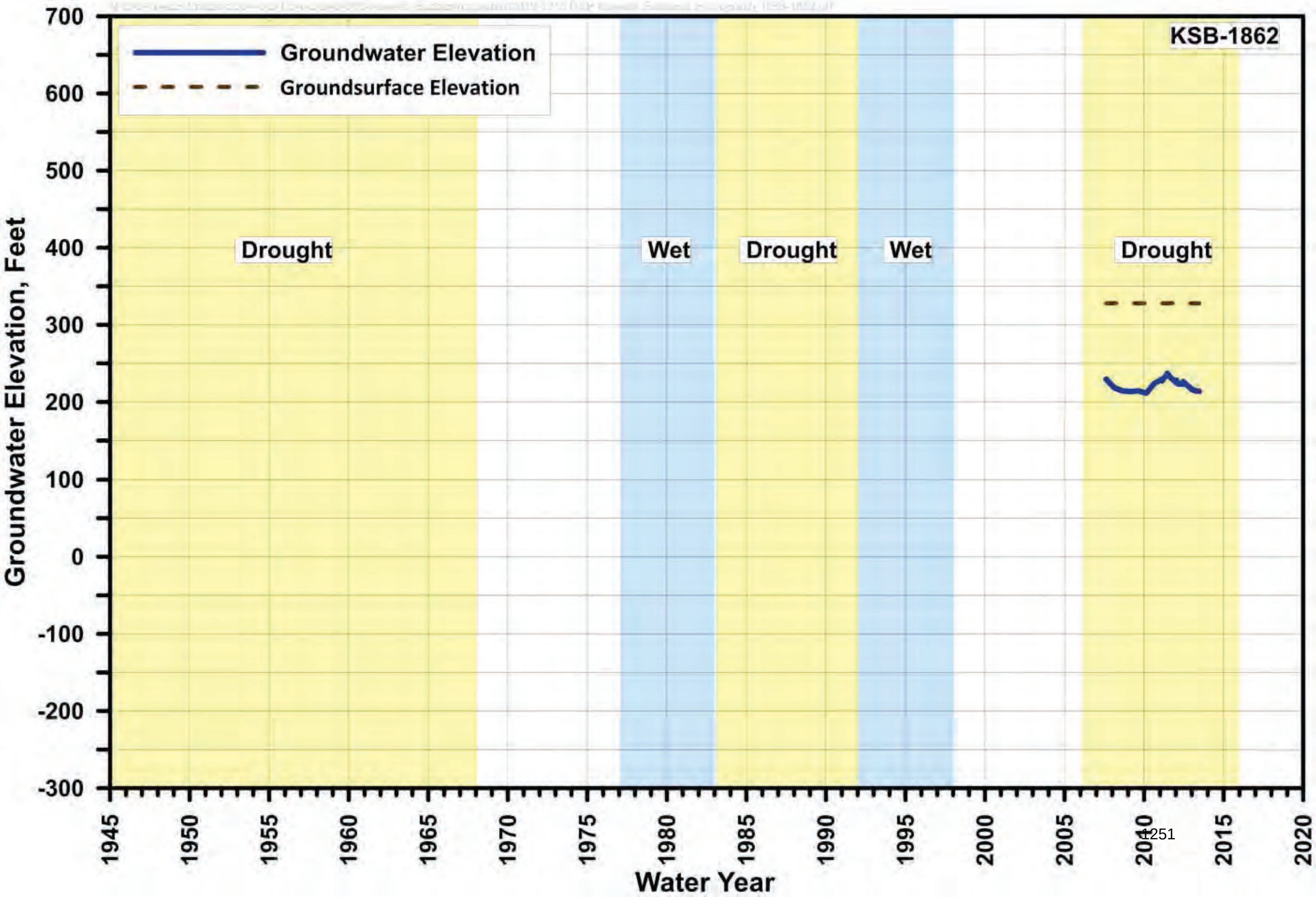
2020
Water Year



KSB-1862
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
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-100
-200
-300
1945
1950
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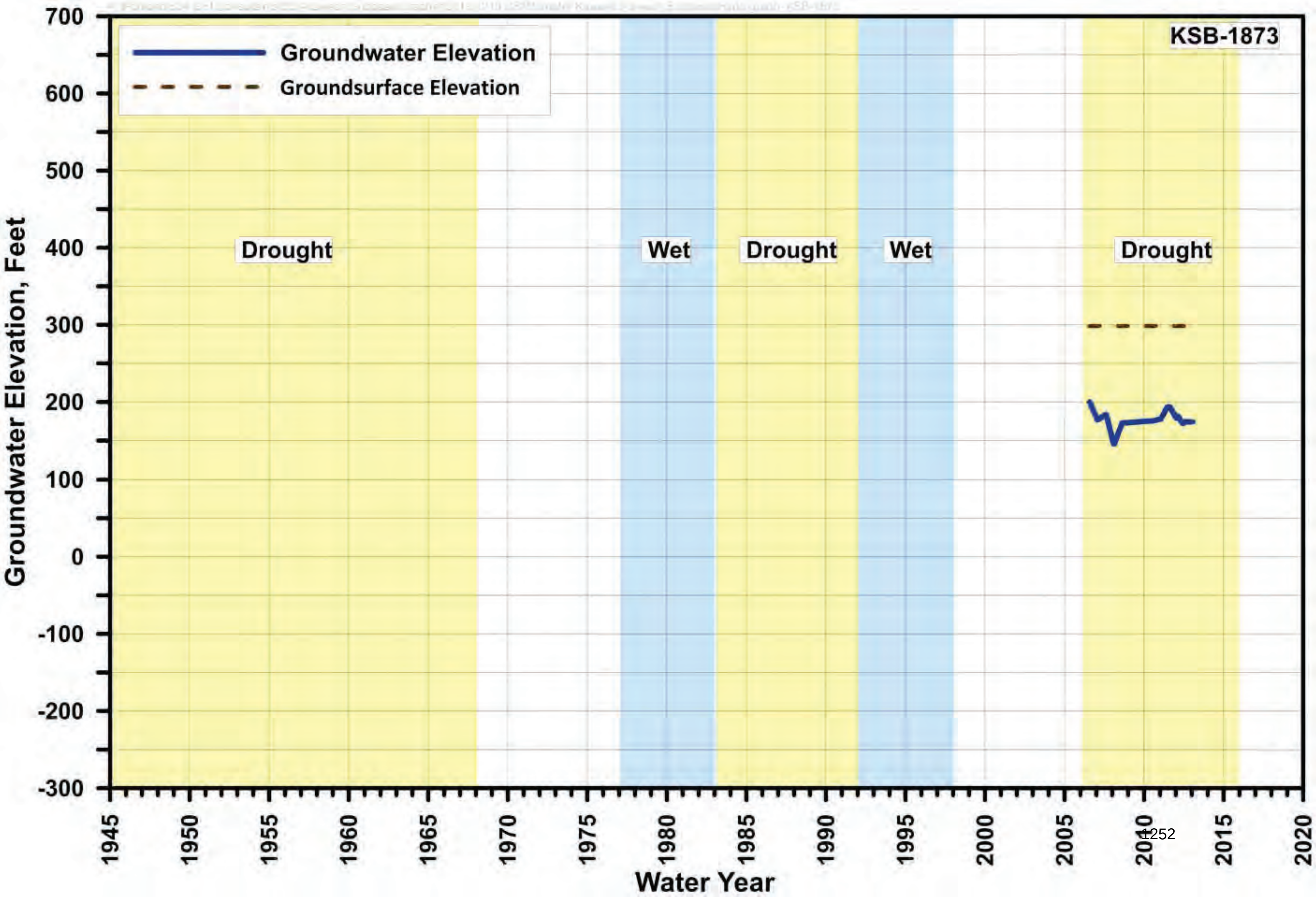
2015
2020
Water Year



KSB-1873
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
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-100
-200
-300
1945
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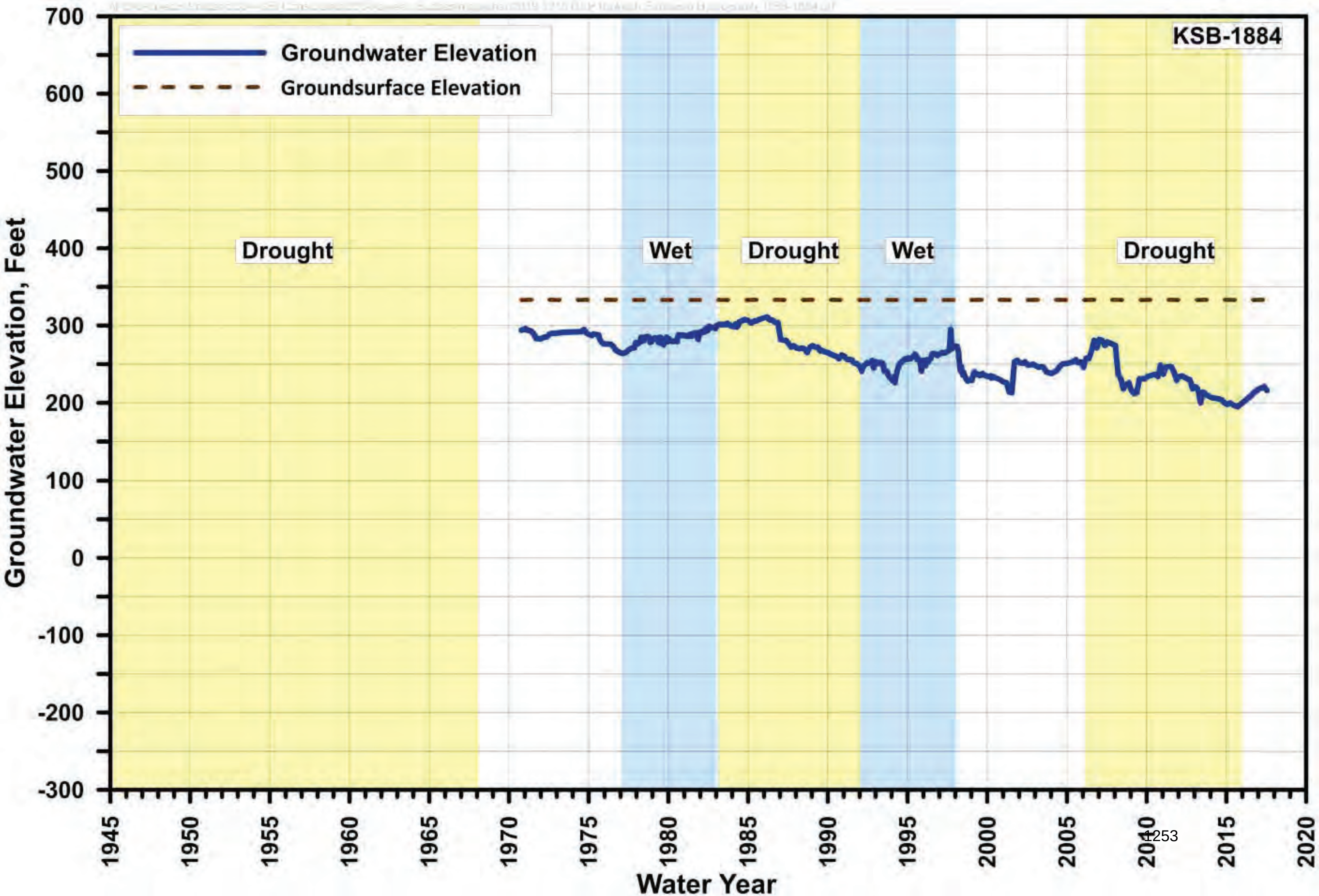
2015
2020
Water Year



KSB-1884
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
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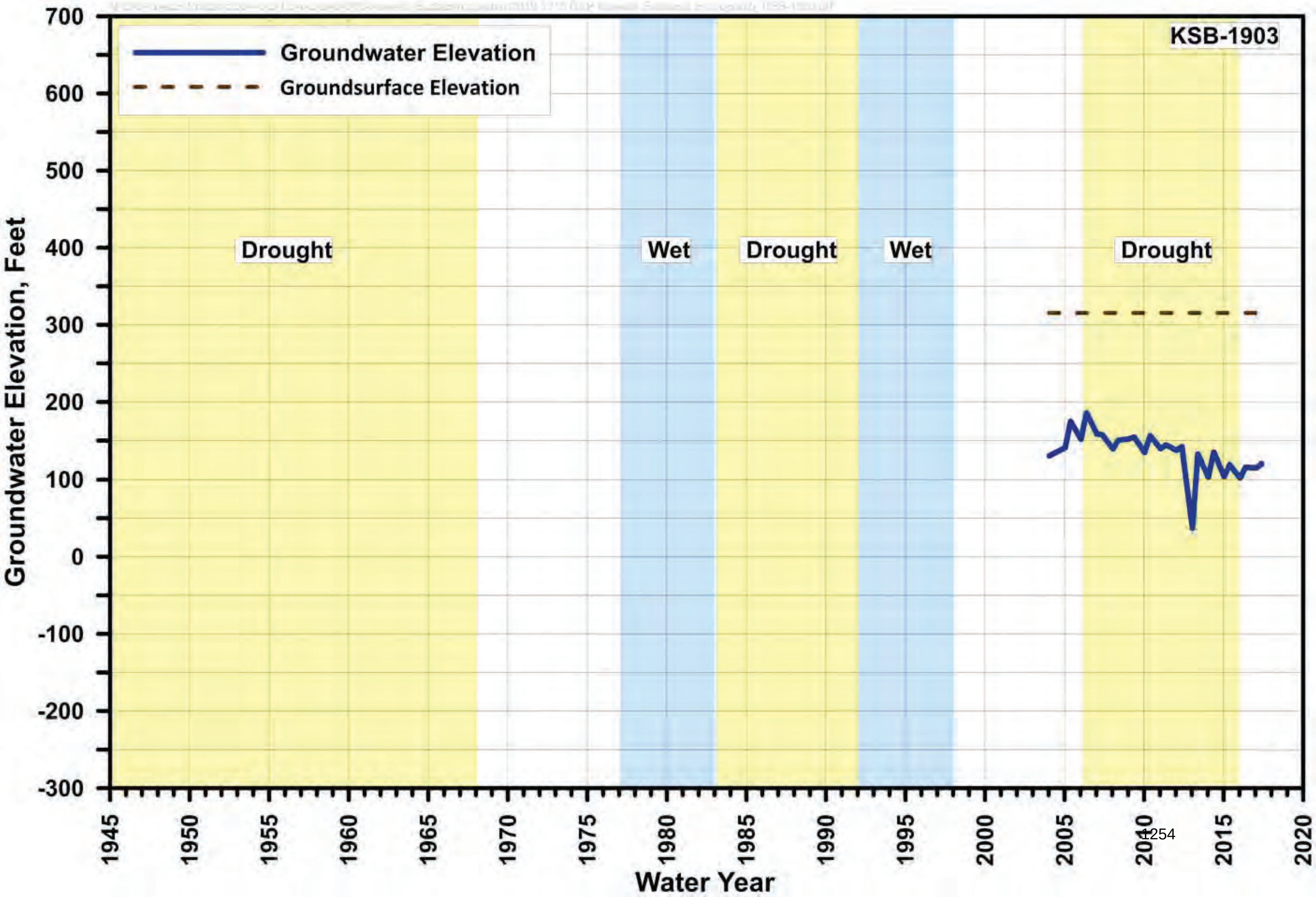

KSB-1903
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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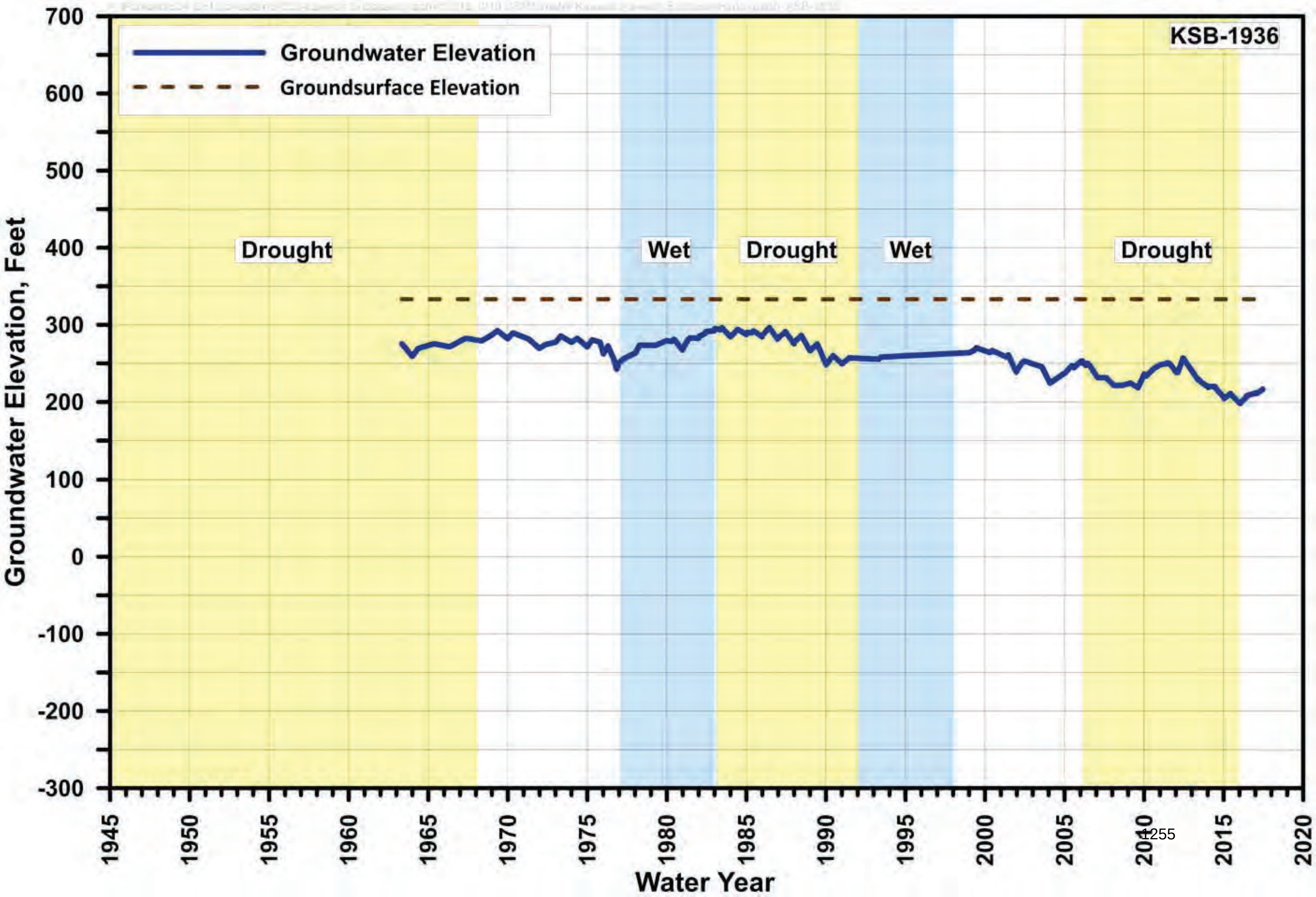
2015
2020



KSB-1936
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
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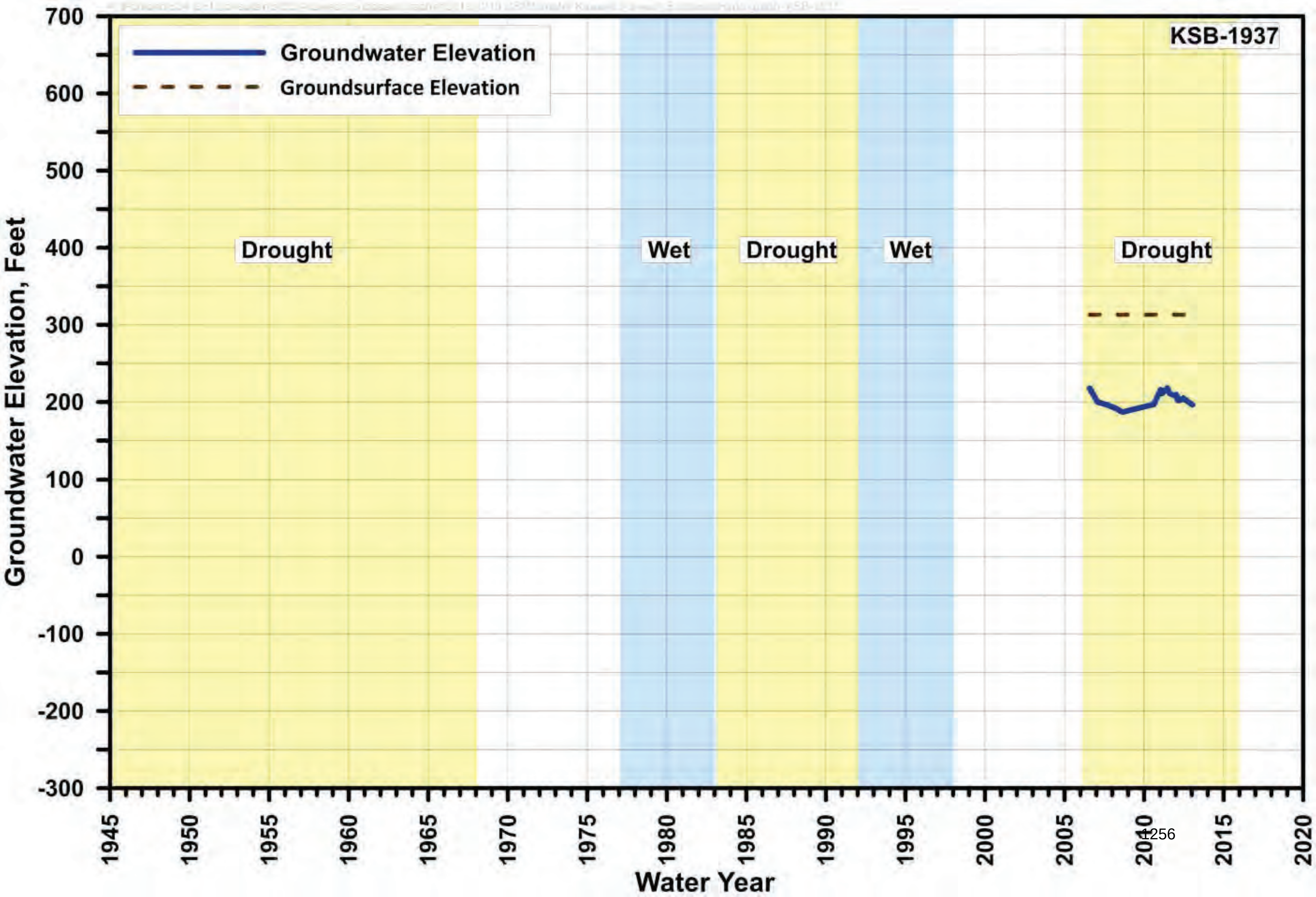
1985
1990
1995
2000
2005
2010
2015
2020
Water Year


KSB-1937
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
Water Year
1945
1950
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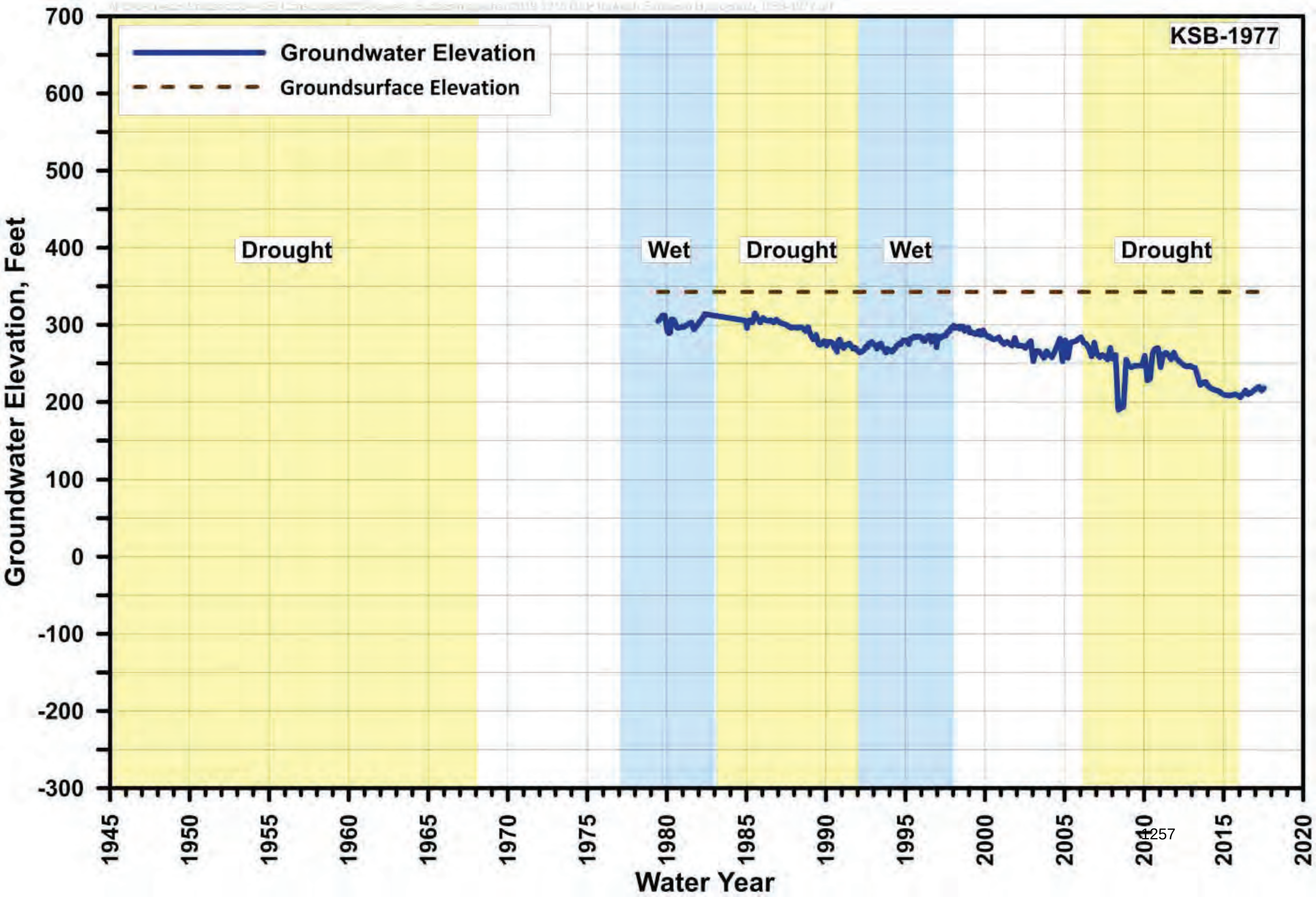
2015
2020



KSB-1977
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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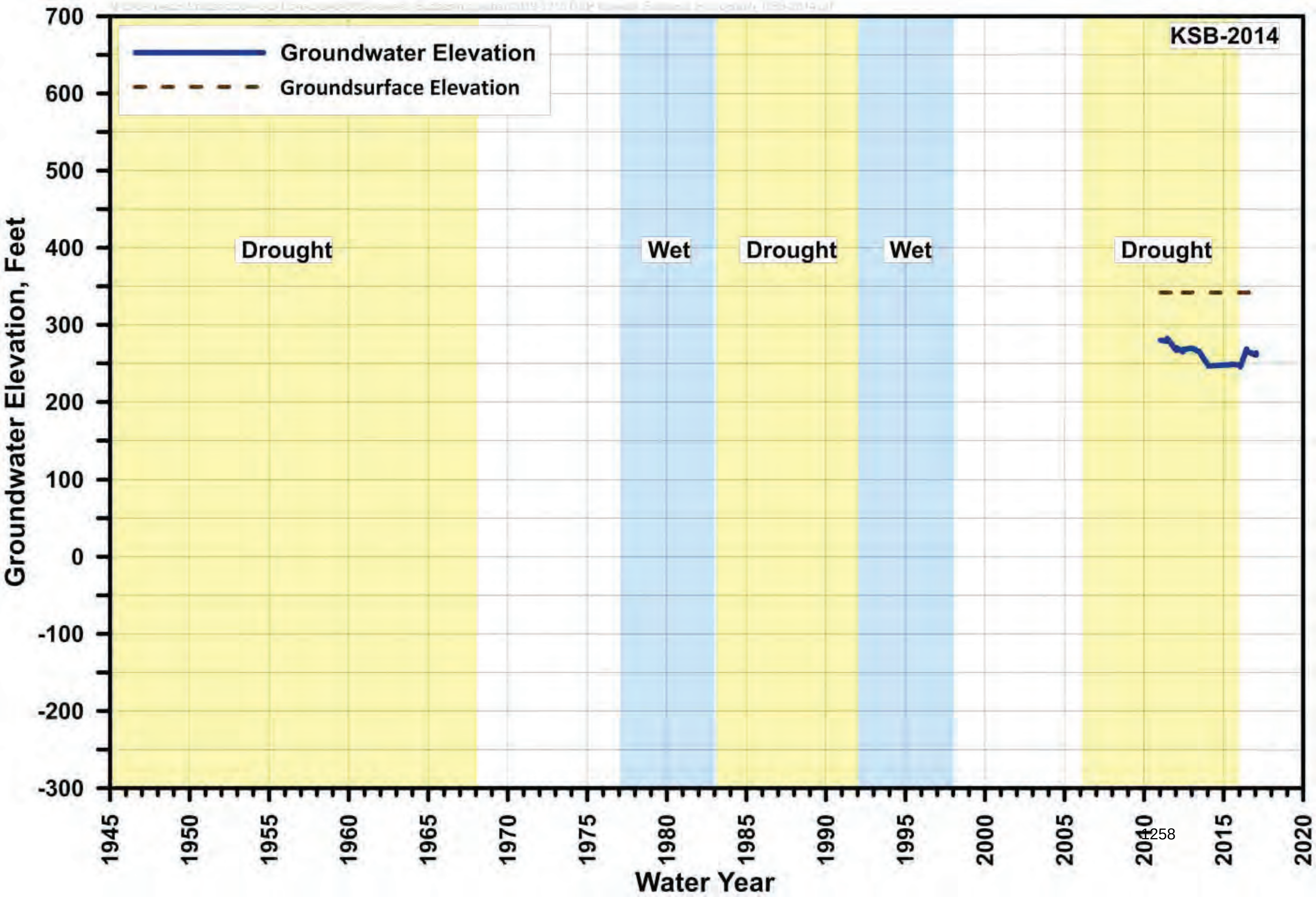
2005
2010
2015
2020
Water Year



KSB-2014
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
1955
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1985
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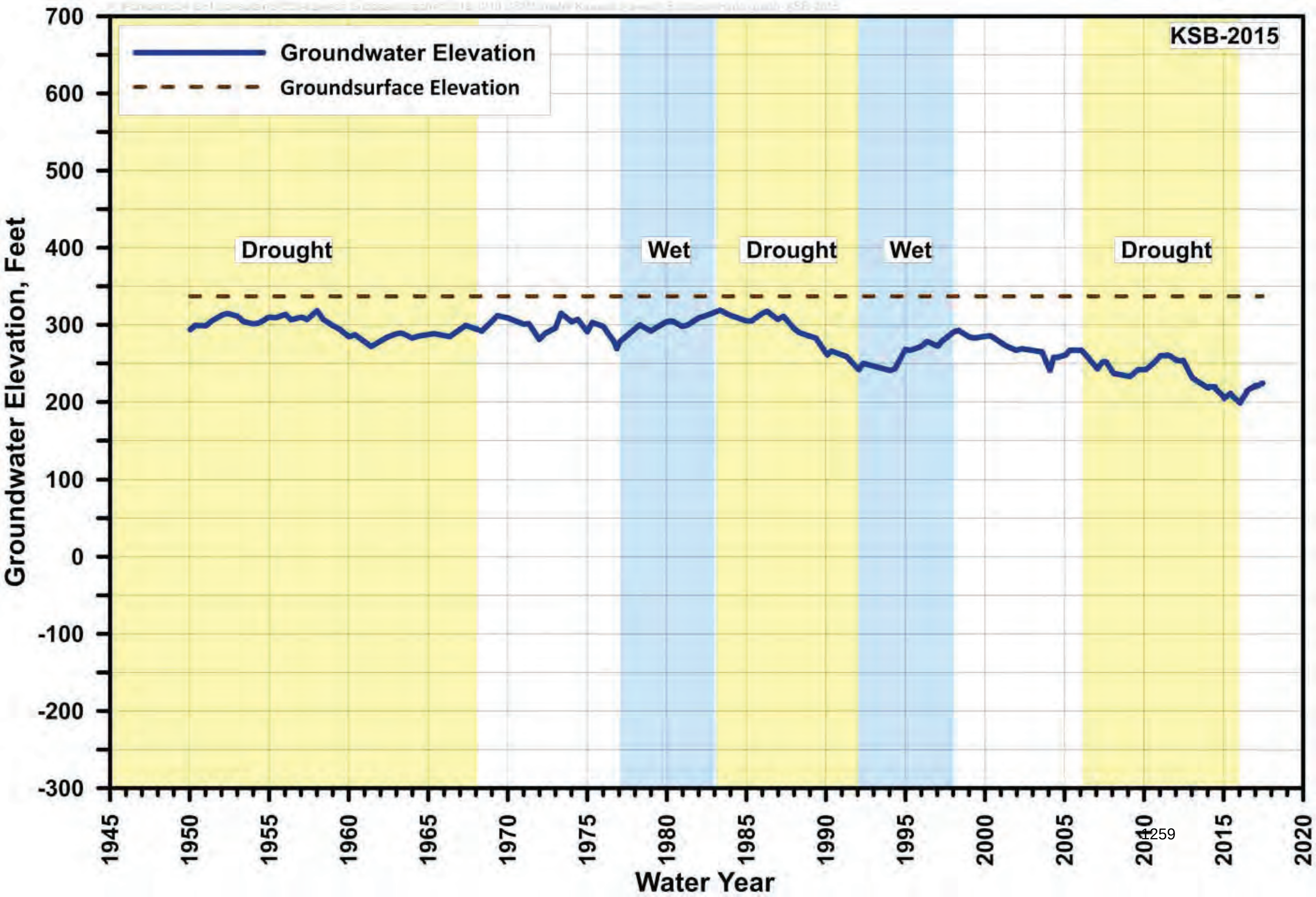
1995
2000
2005
2010
2015
2020
Water Year



KSB-2015
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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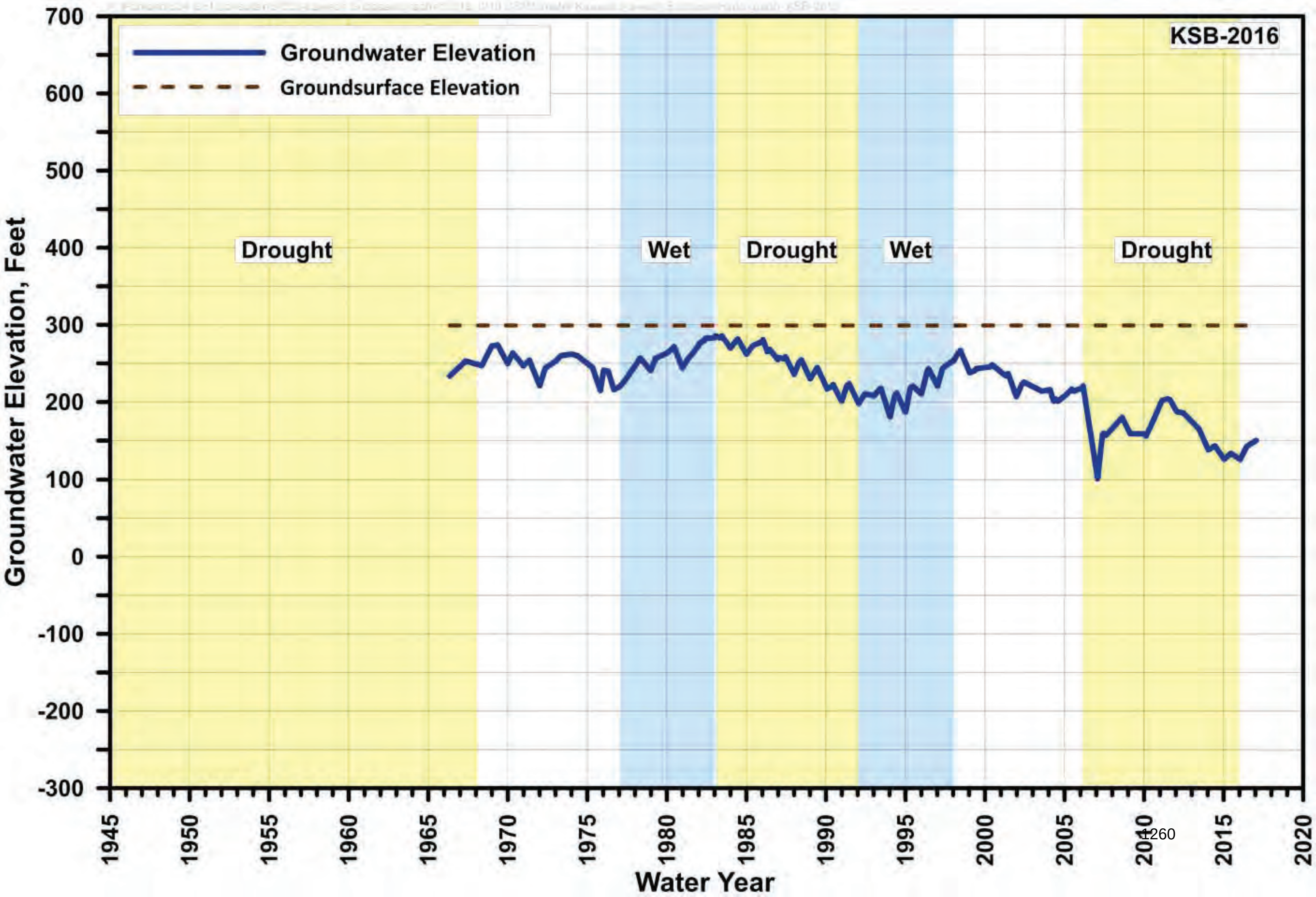
1995
2000
2005
2010
2015
2020


KSB-2016
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
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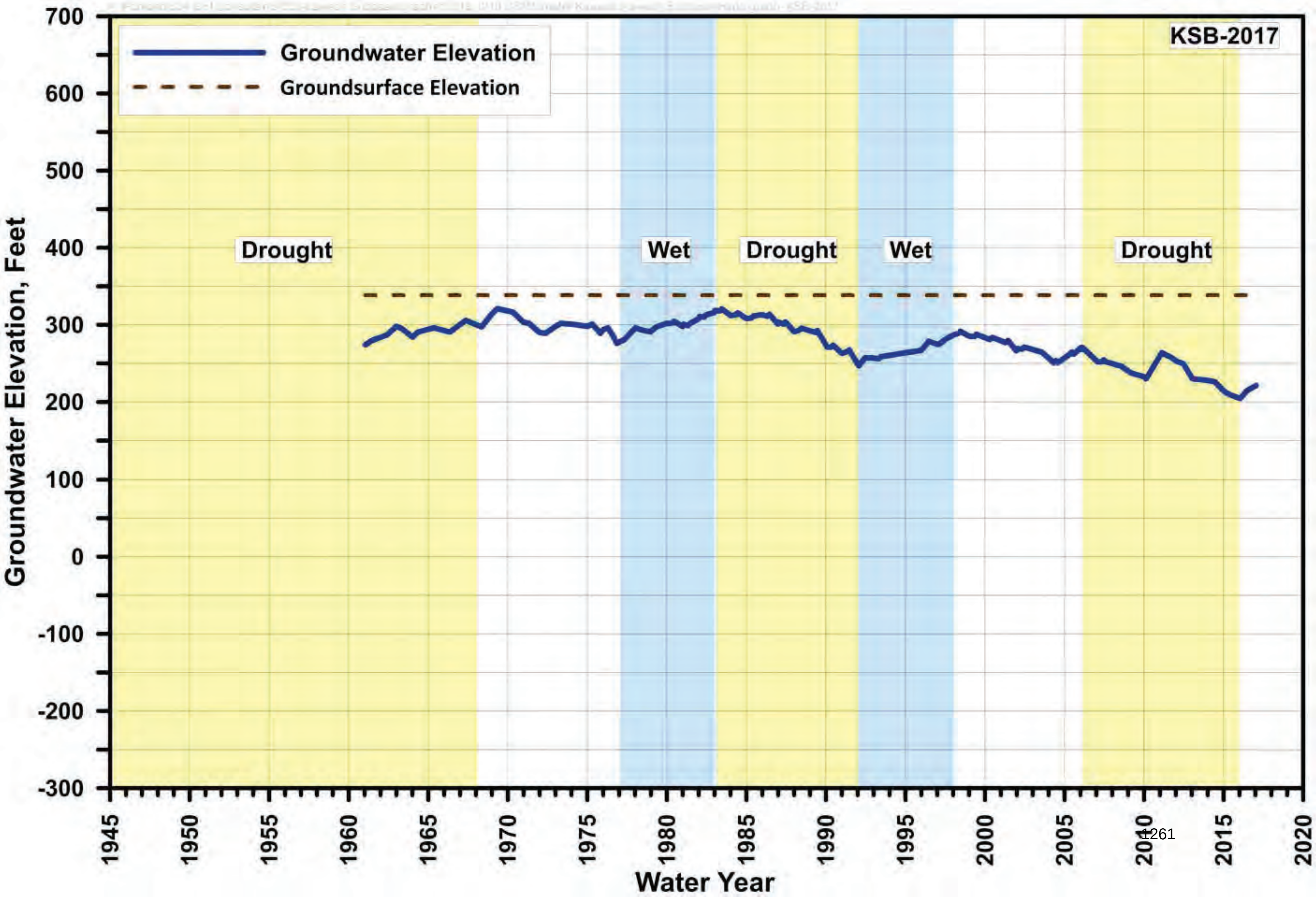
2010
2015
2020



KSB-2017
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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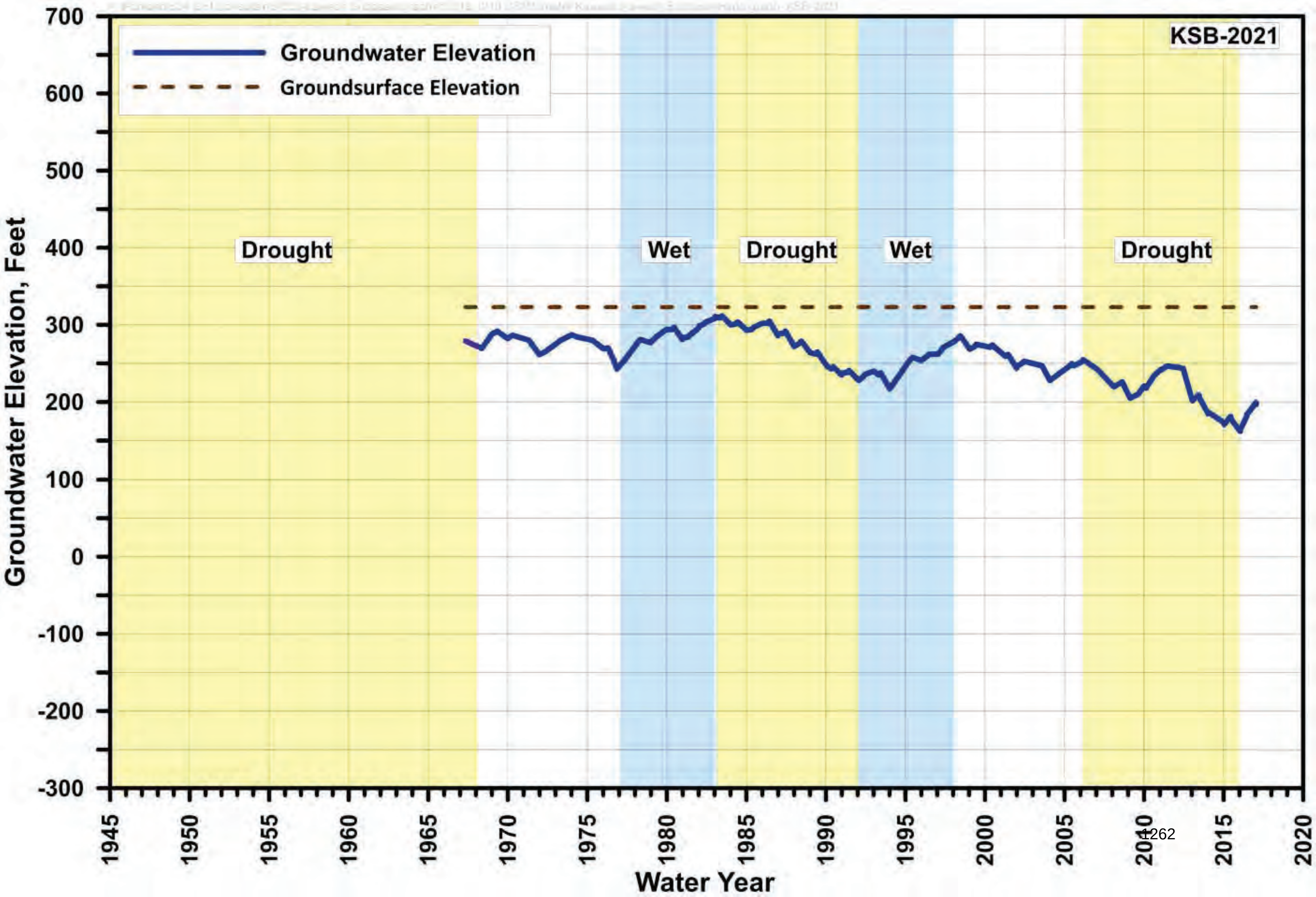
2010
2015
2020
Water Year



KSB-2021
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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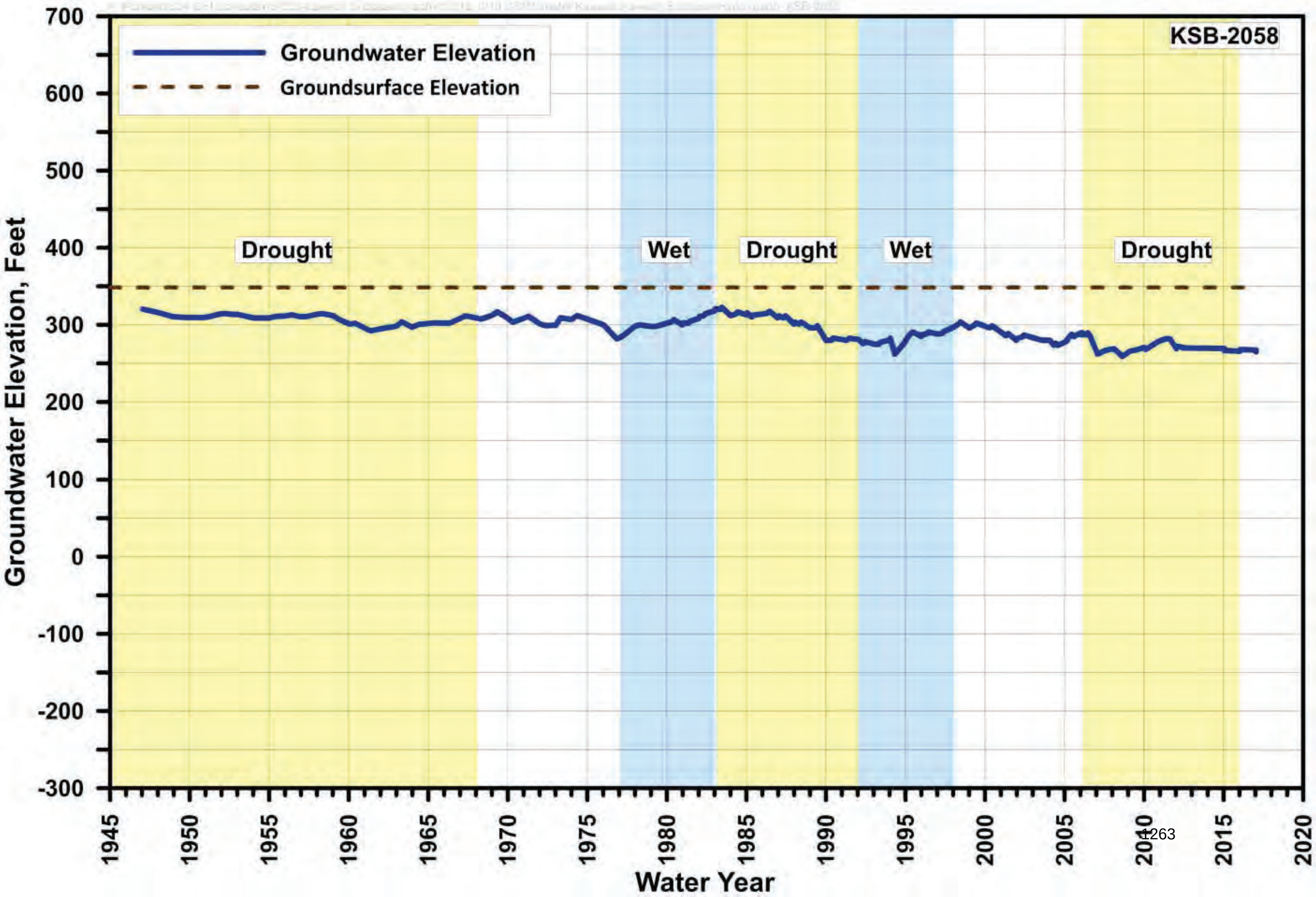
2010
2015
2020
Water Year



KSB-2058
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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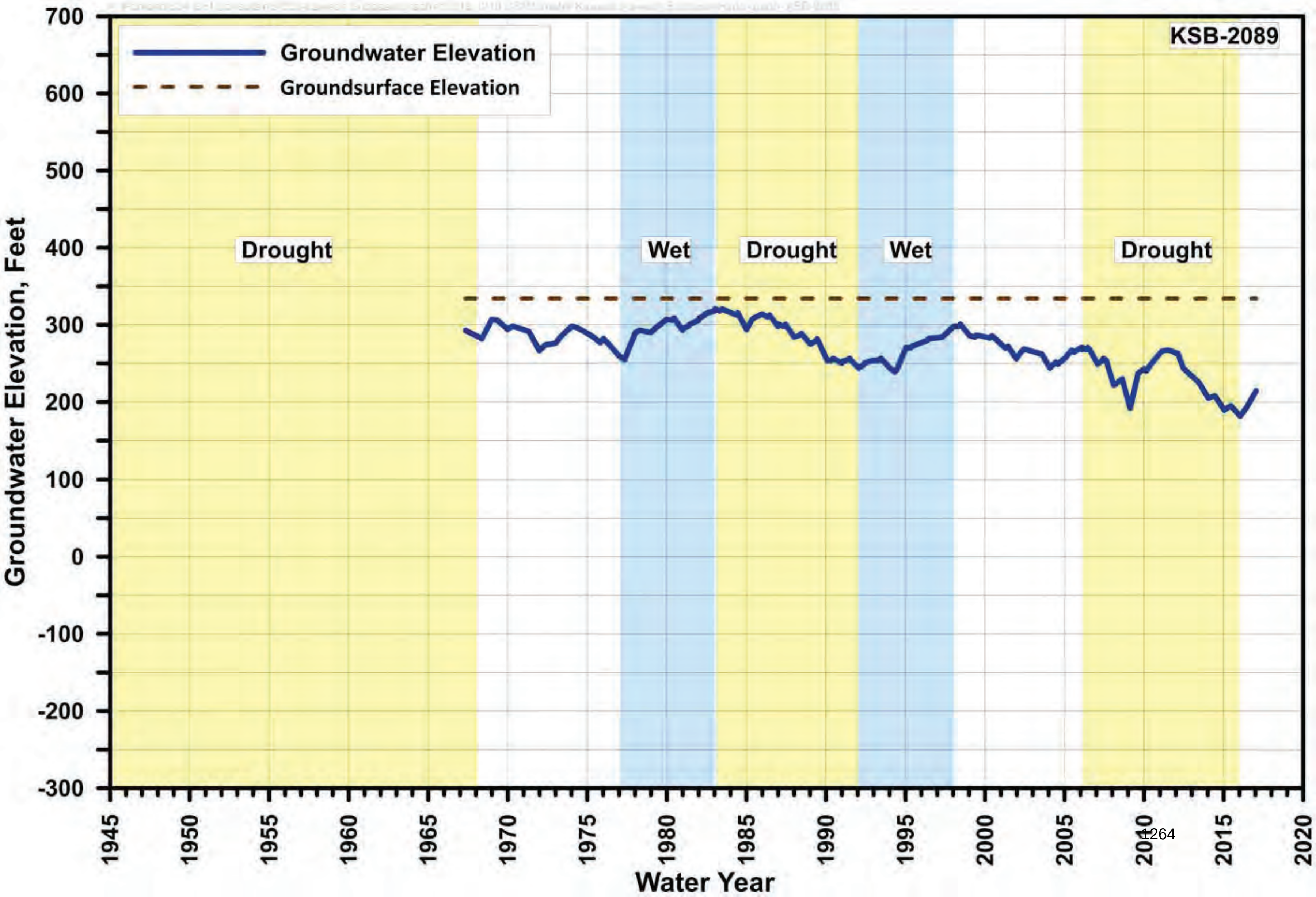
2010
2015
2020
Water Year


KSB-2089
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
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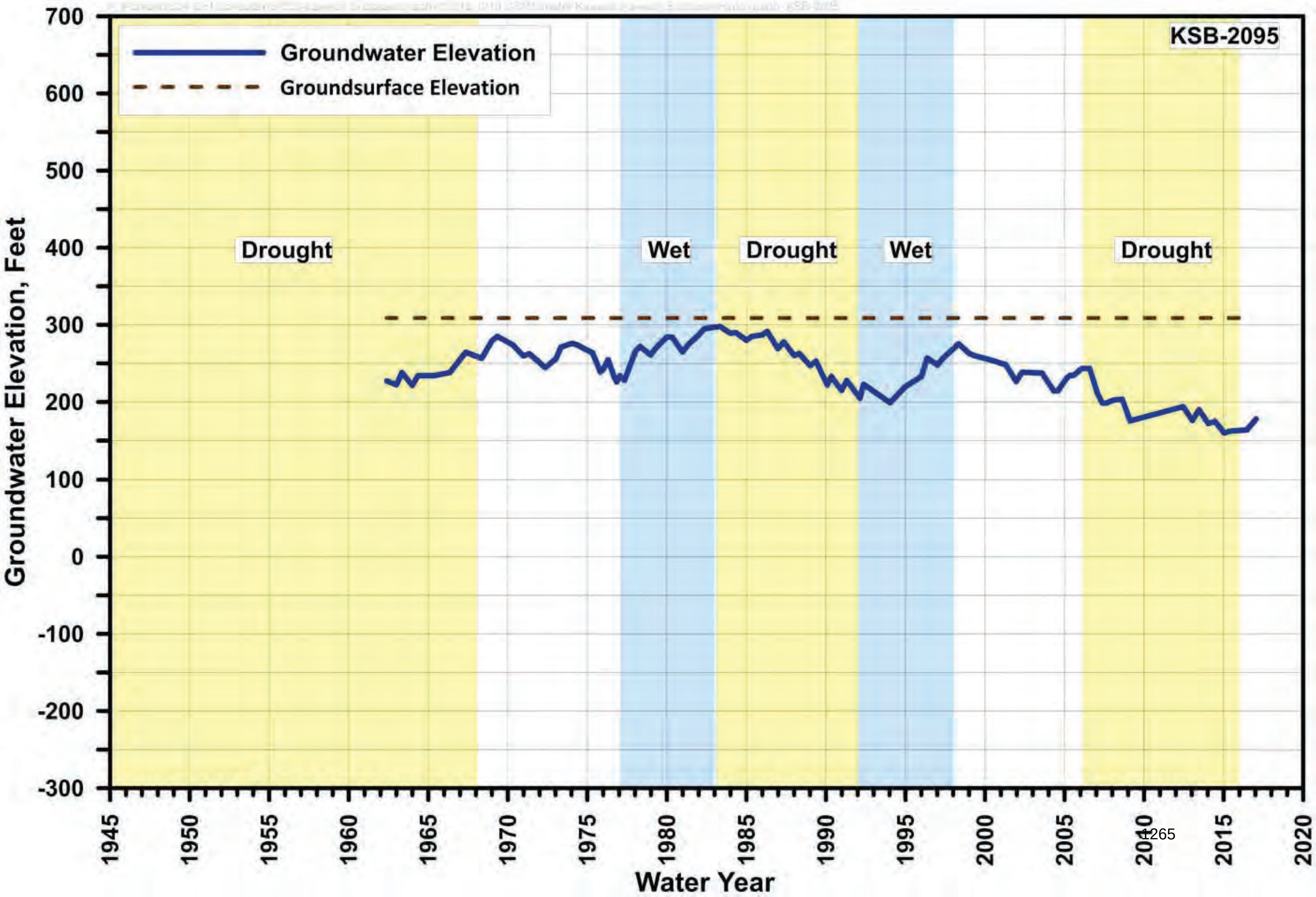
2010
2015
2020
Water Year



KSB-2095
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
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-100
-200
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1945
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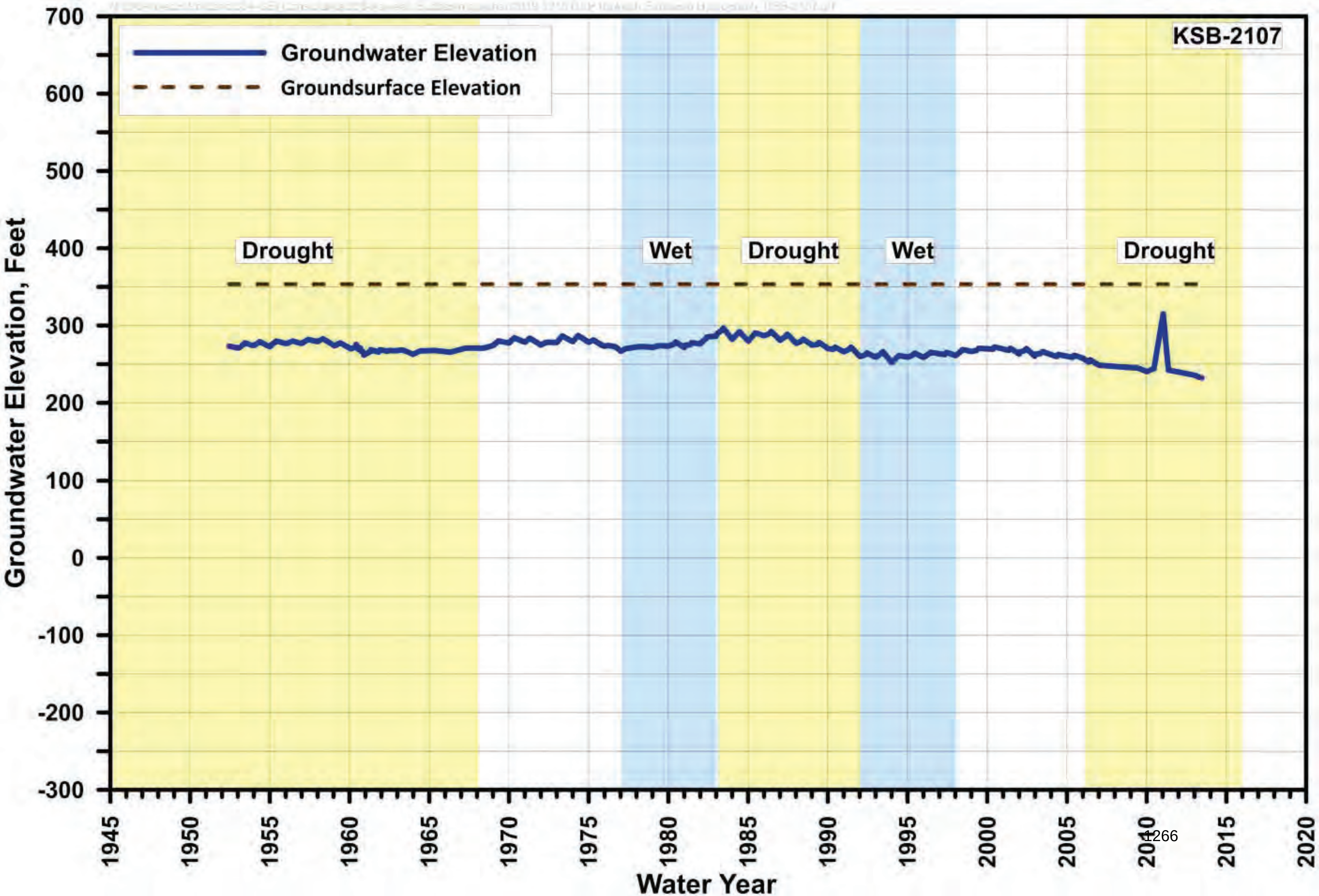

KSB-2107
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
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-100
-200
-300
1945
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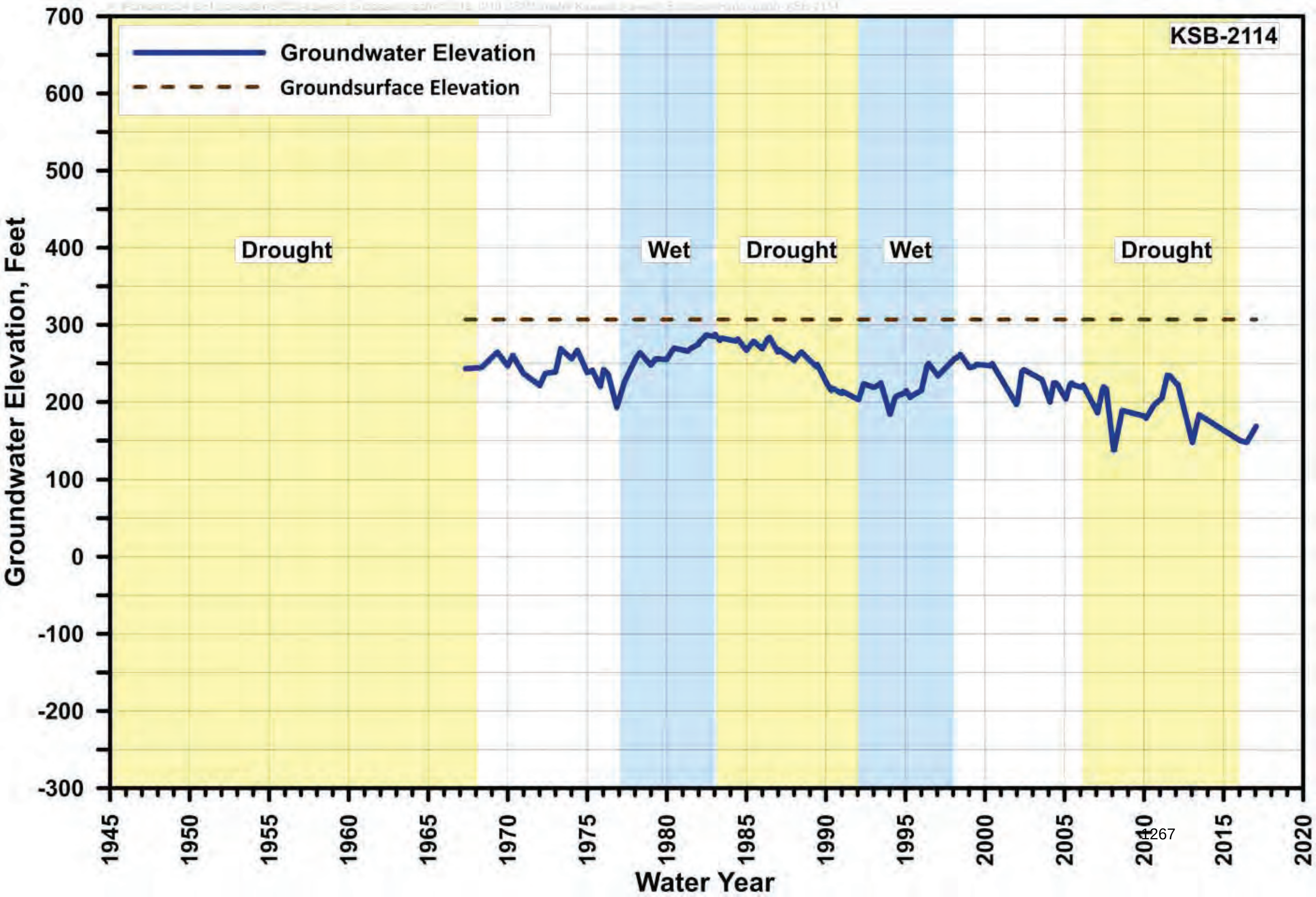
2015
2020
Water Year


KSB-2114
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
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-100
-200
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1945
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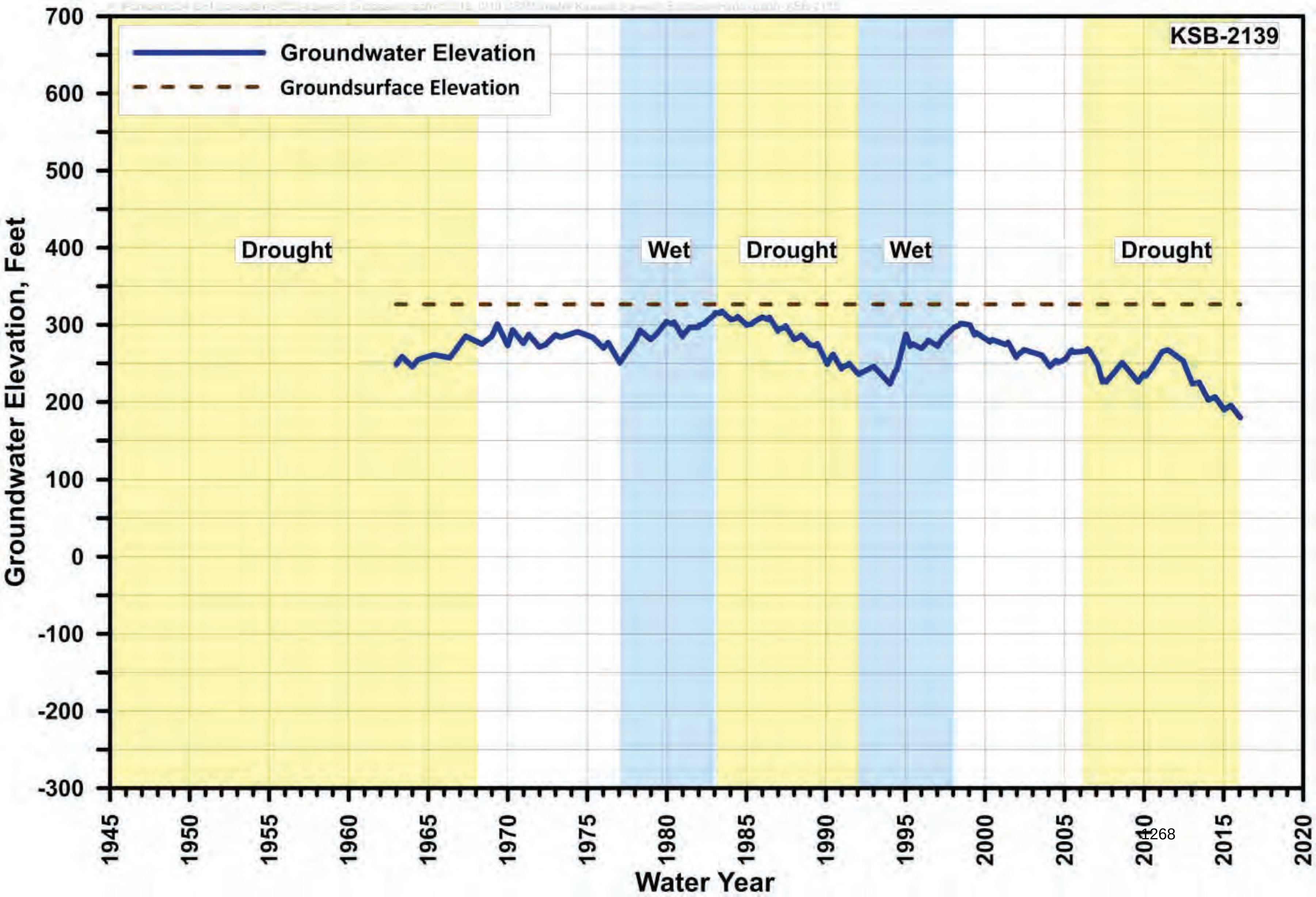
2015
2020
Water Year



KSB-2139
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
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-100
-200
-300
1945
1950
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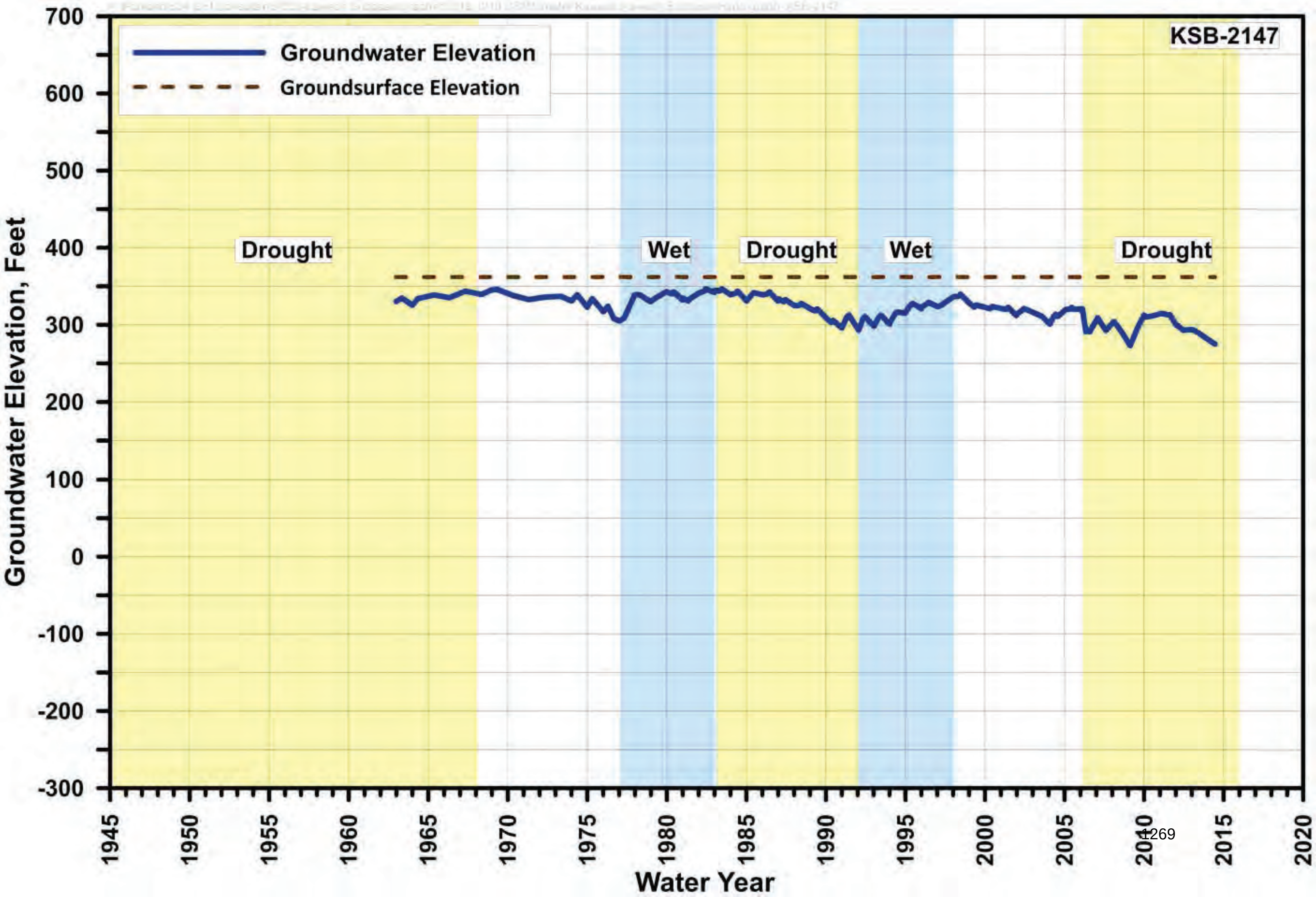
2010
2015
2020
Water Year


KSB-2147
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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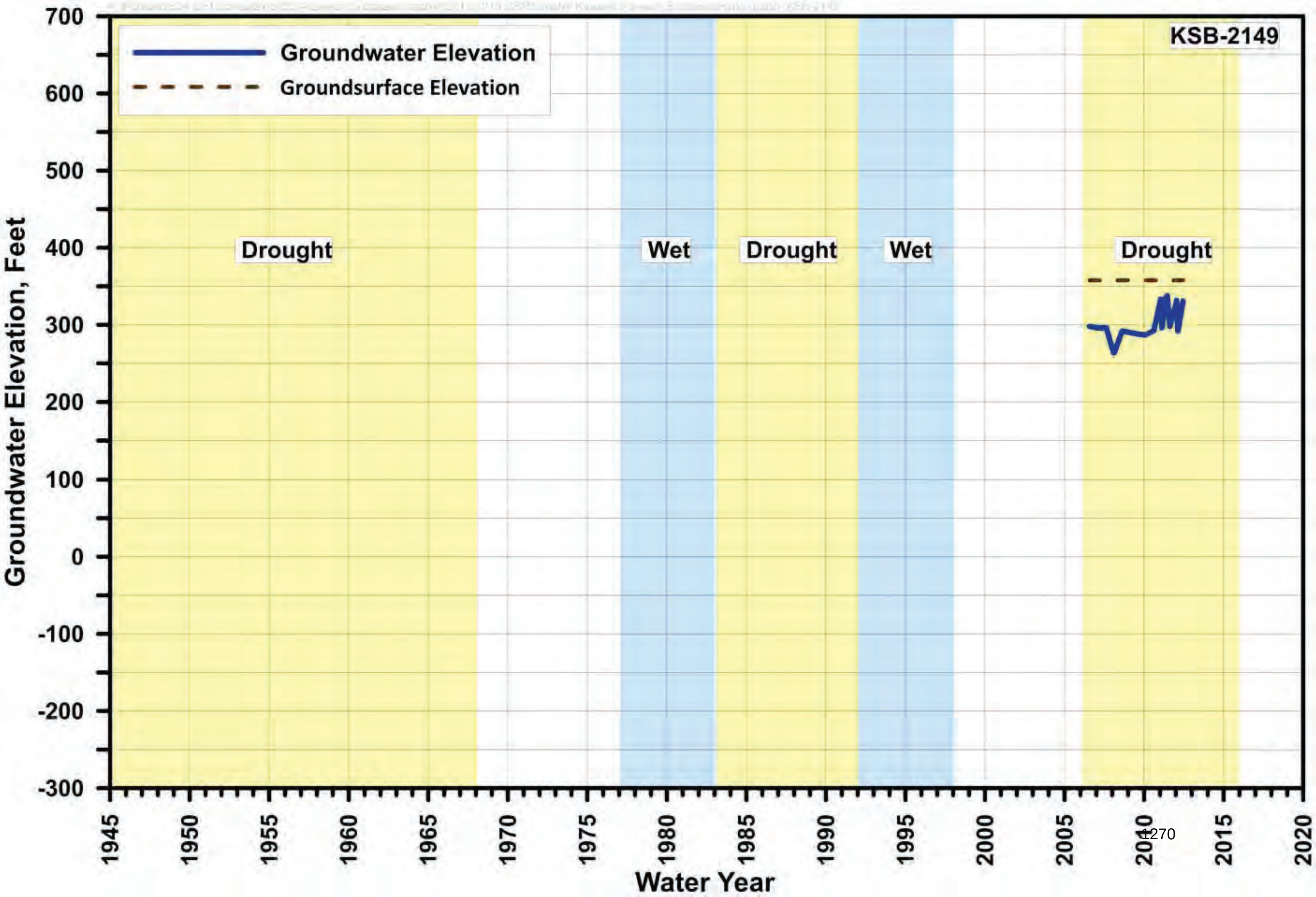
2015
2020



KSB-2149
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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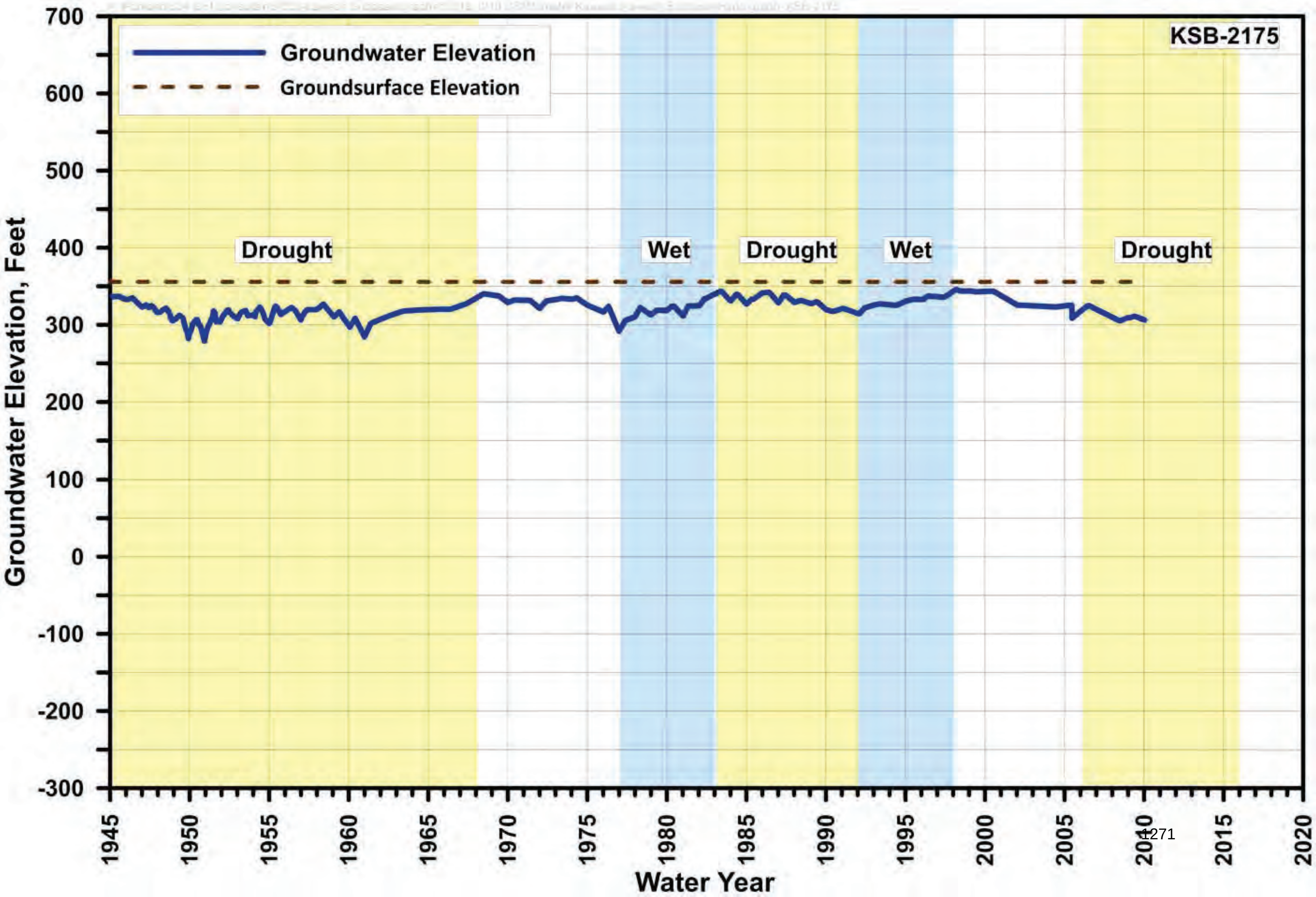
2020


KSB-2175
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
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-300
1945
1950
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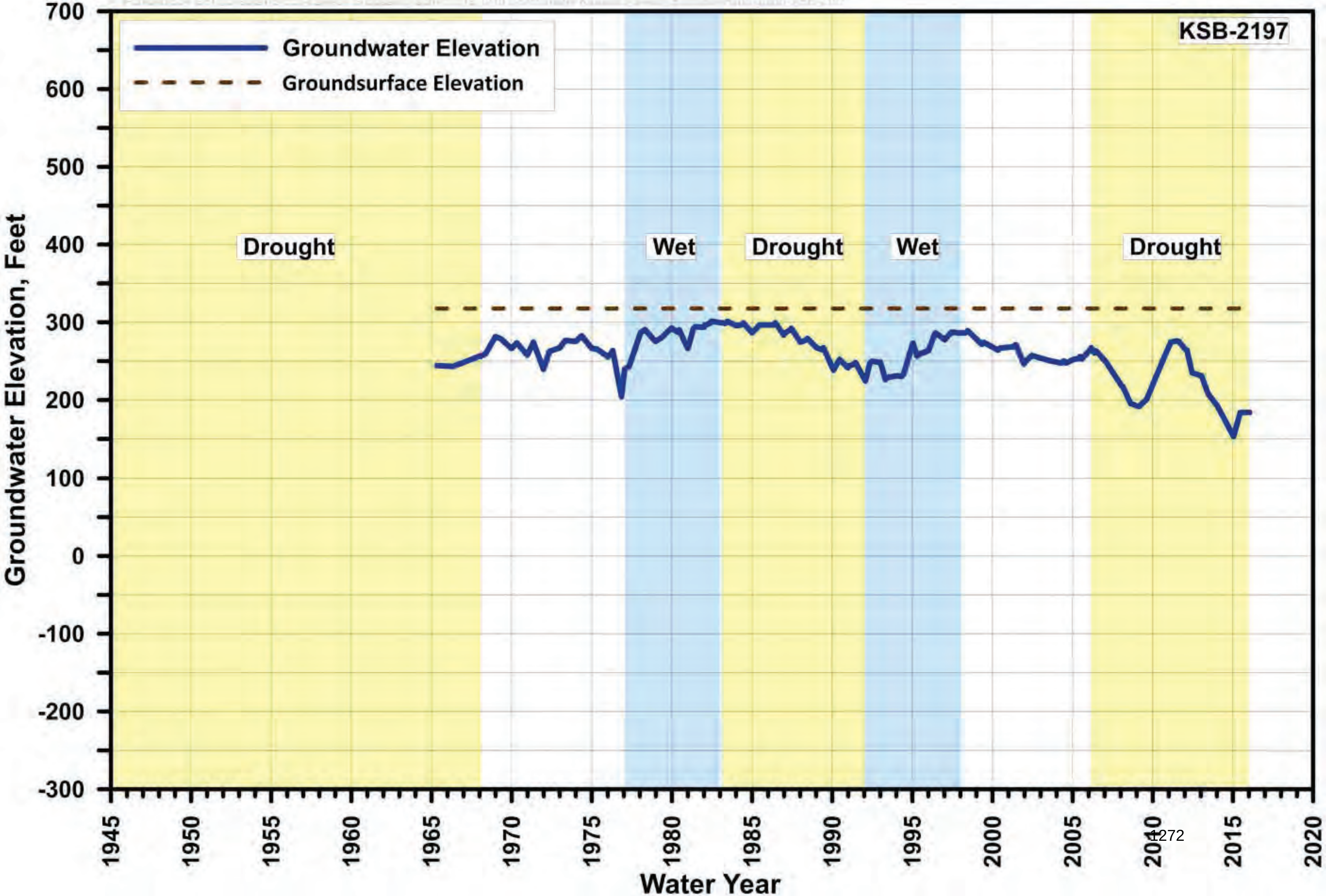
2015
2020
Water Year


KSB-2197
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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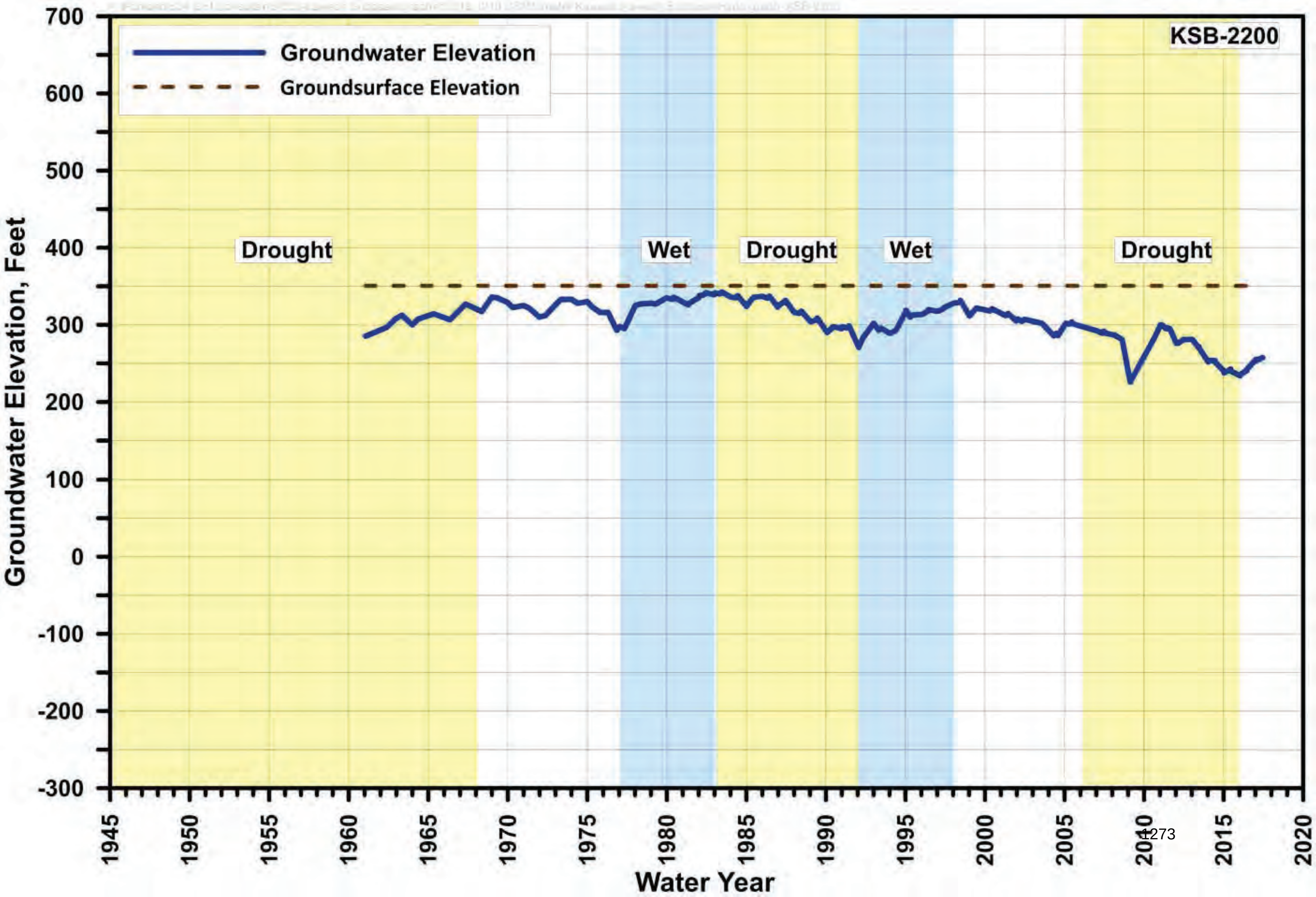
2010
2015
2020
Water Year



KSB-2200
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
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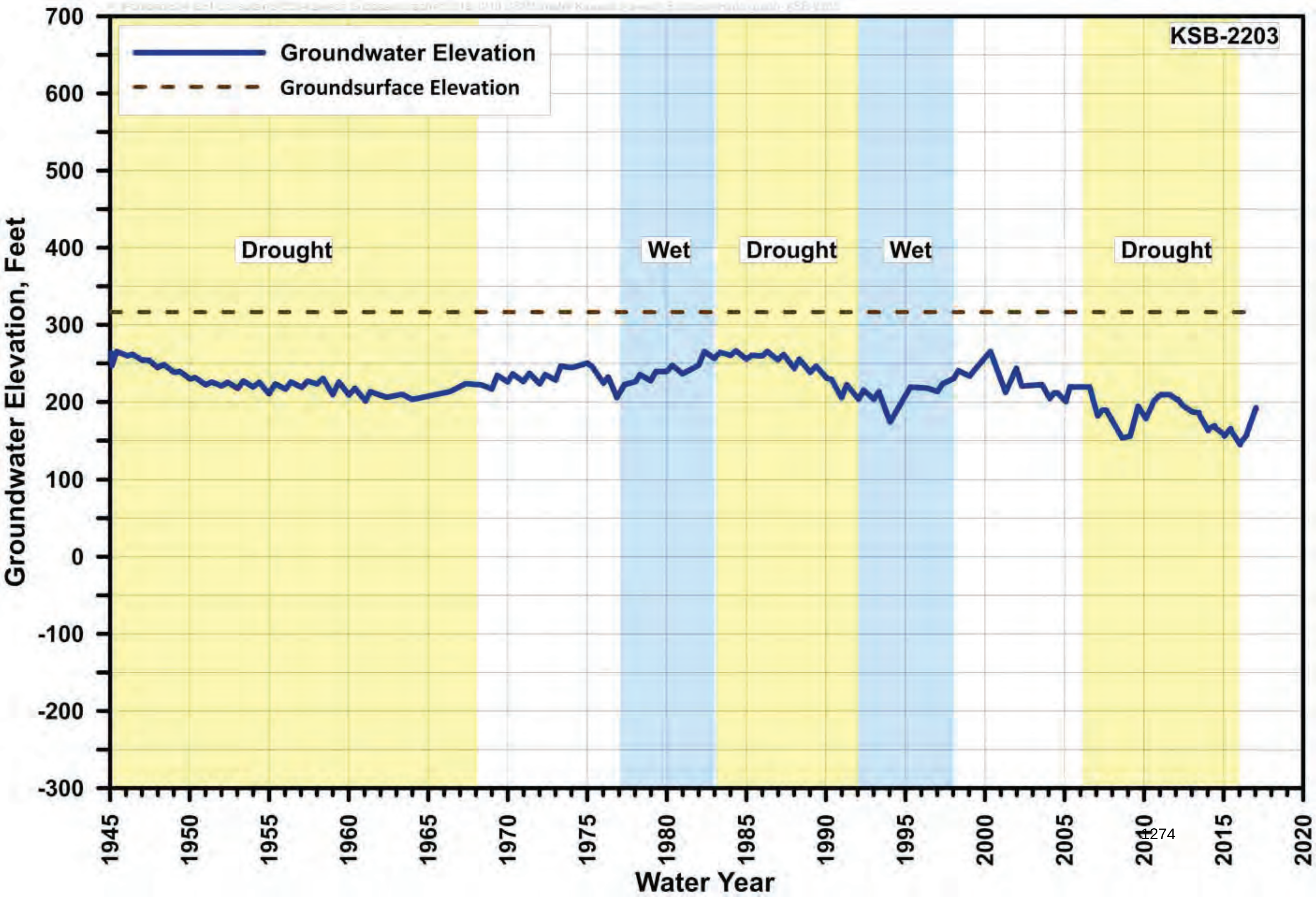
2015
2020
Water Year


KSB-2203
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
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1945
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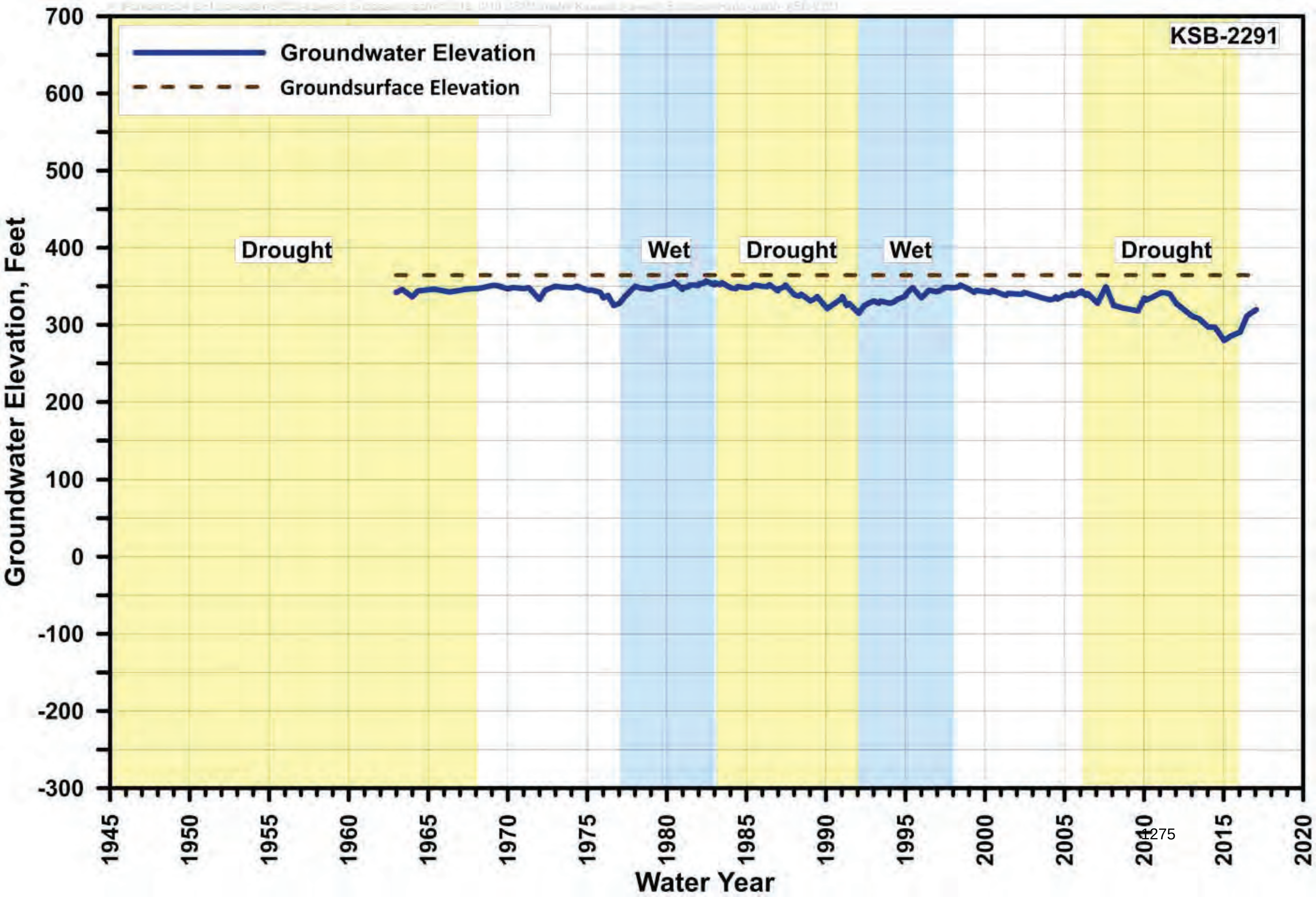
2015
2020
Water Year


KSB-2291
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
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200
100
0
-100
-200
-300
1945
1950
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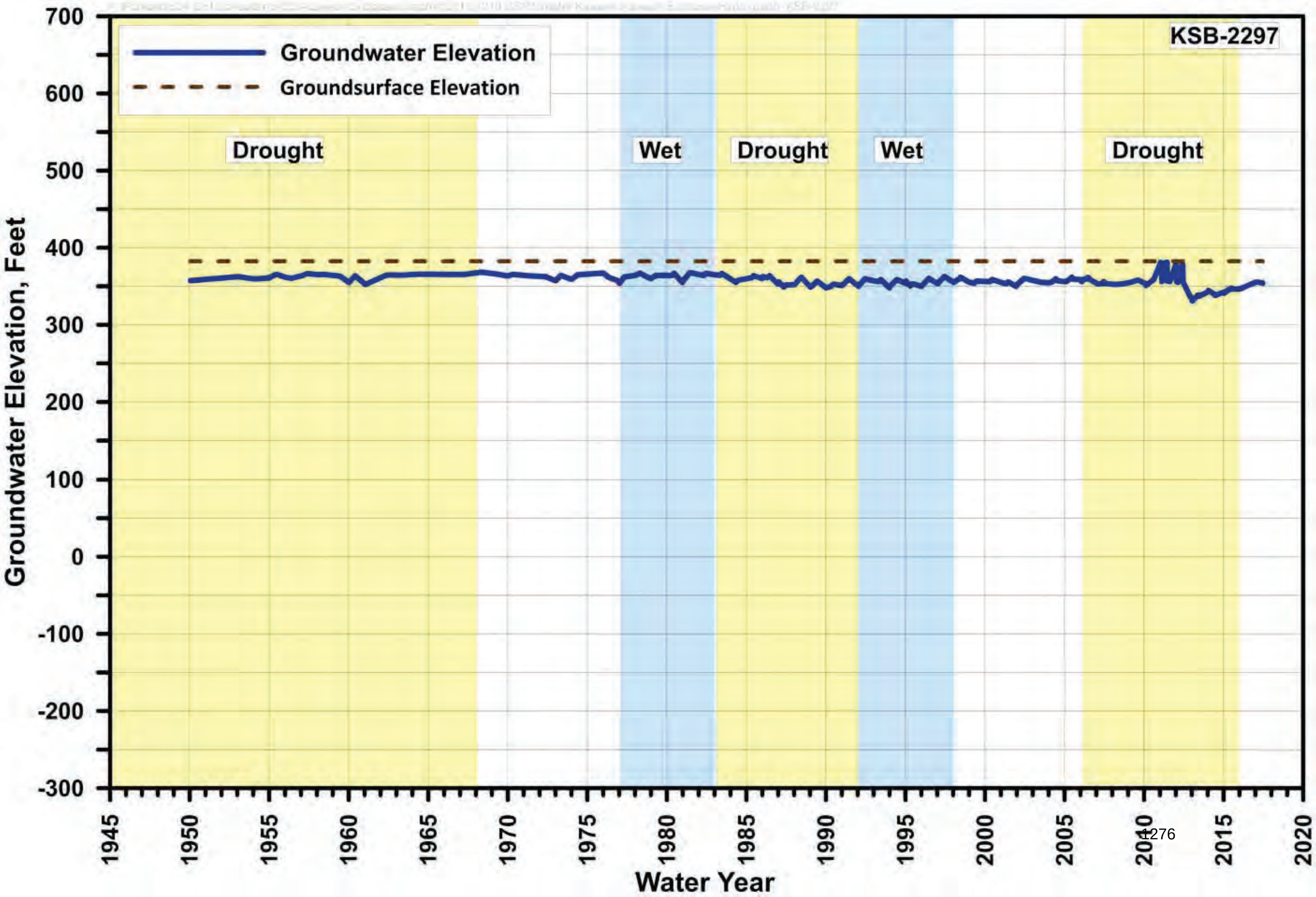
2015
2020
Water Year



KSB-2297
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
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-100
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1945
1950
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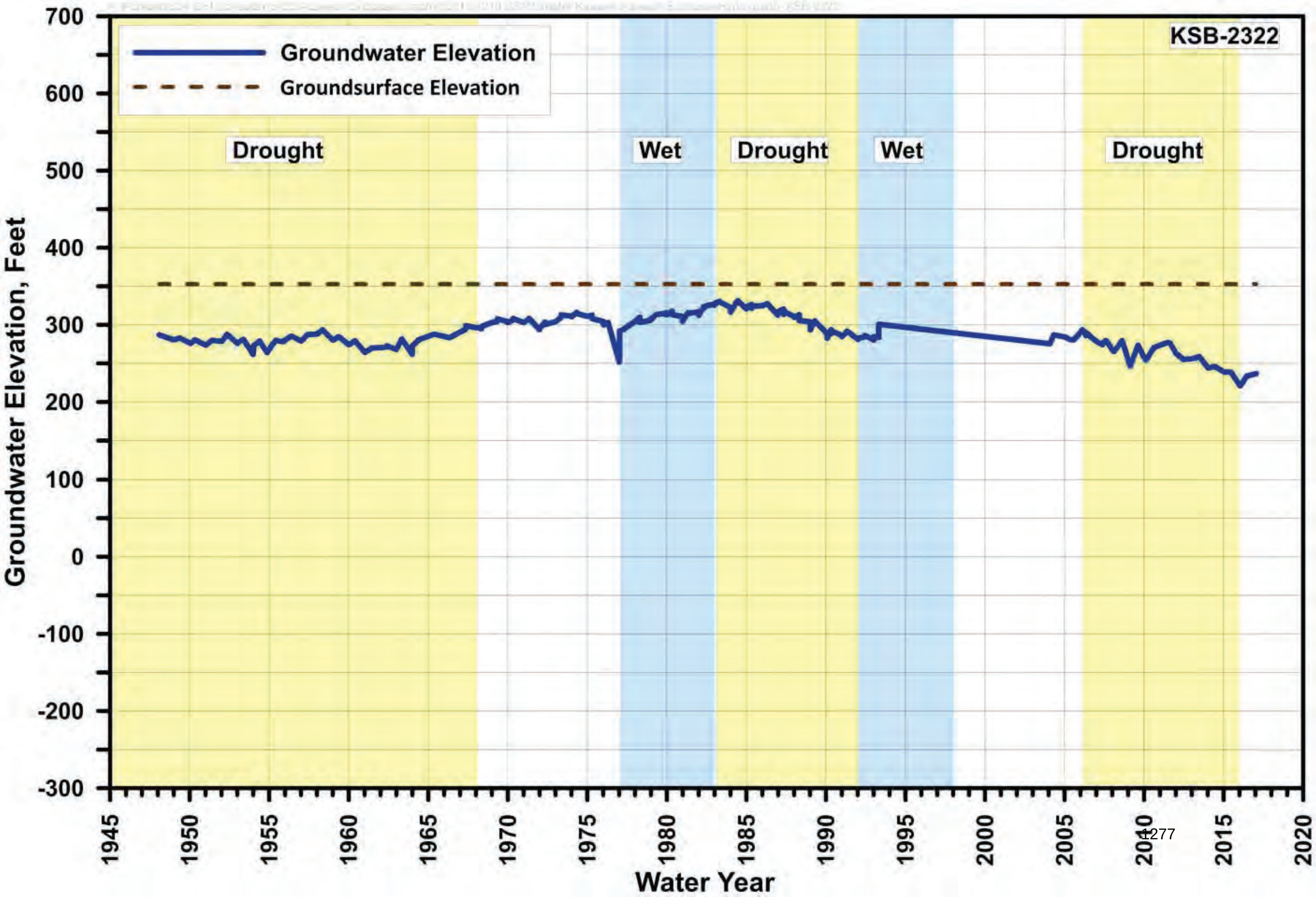
2020
Water Year


KSB-2322
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
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-100
-200
-300
1945
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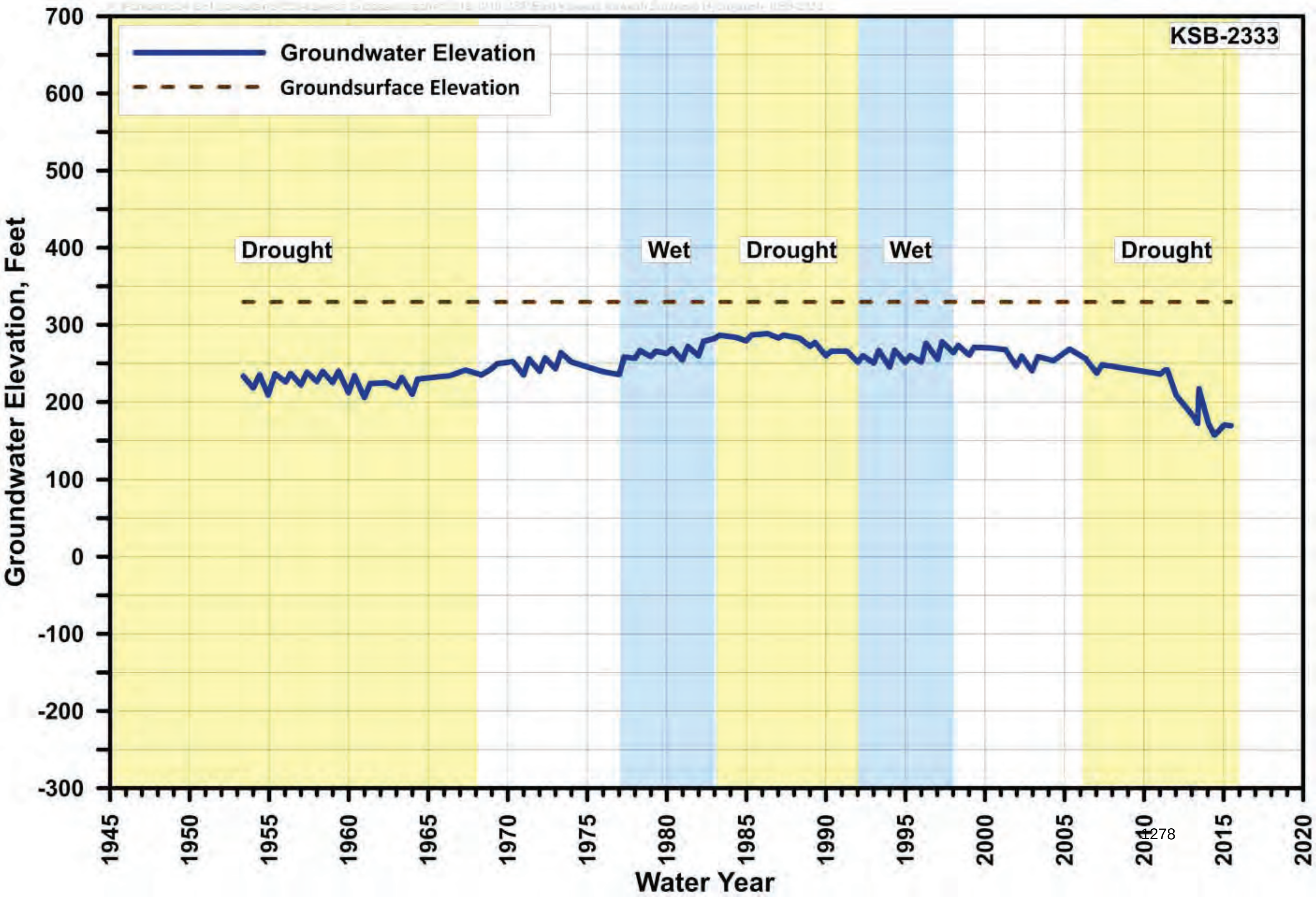

KSB-2333
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
Water Year
700
600
500
400
300
200
100
0
-100
-200
-300
1945
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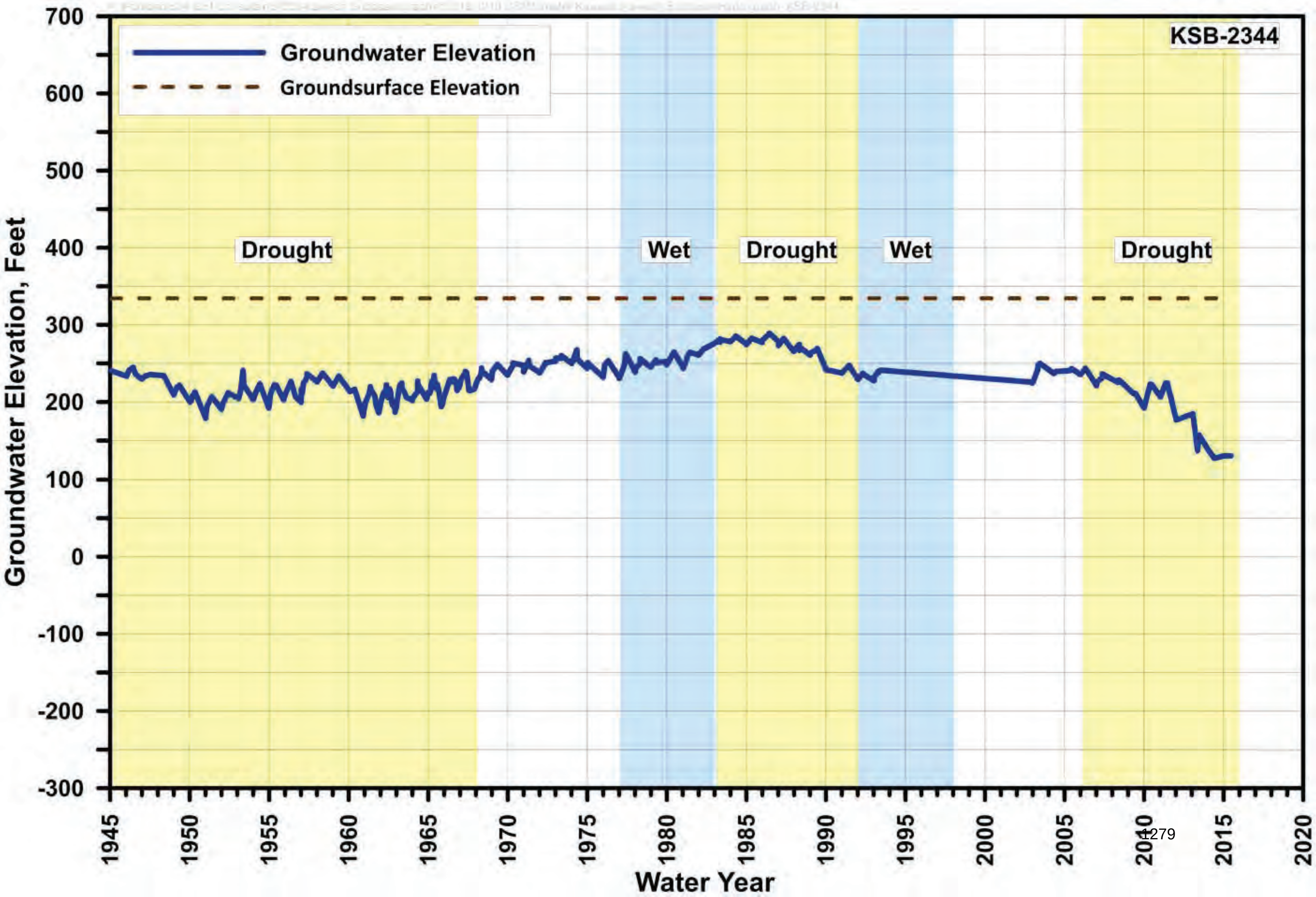
KSB-2344
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
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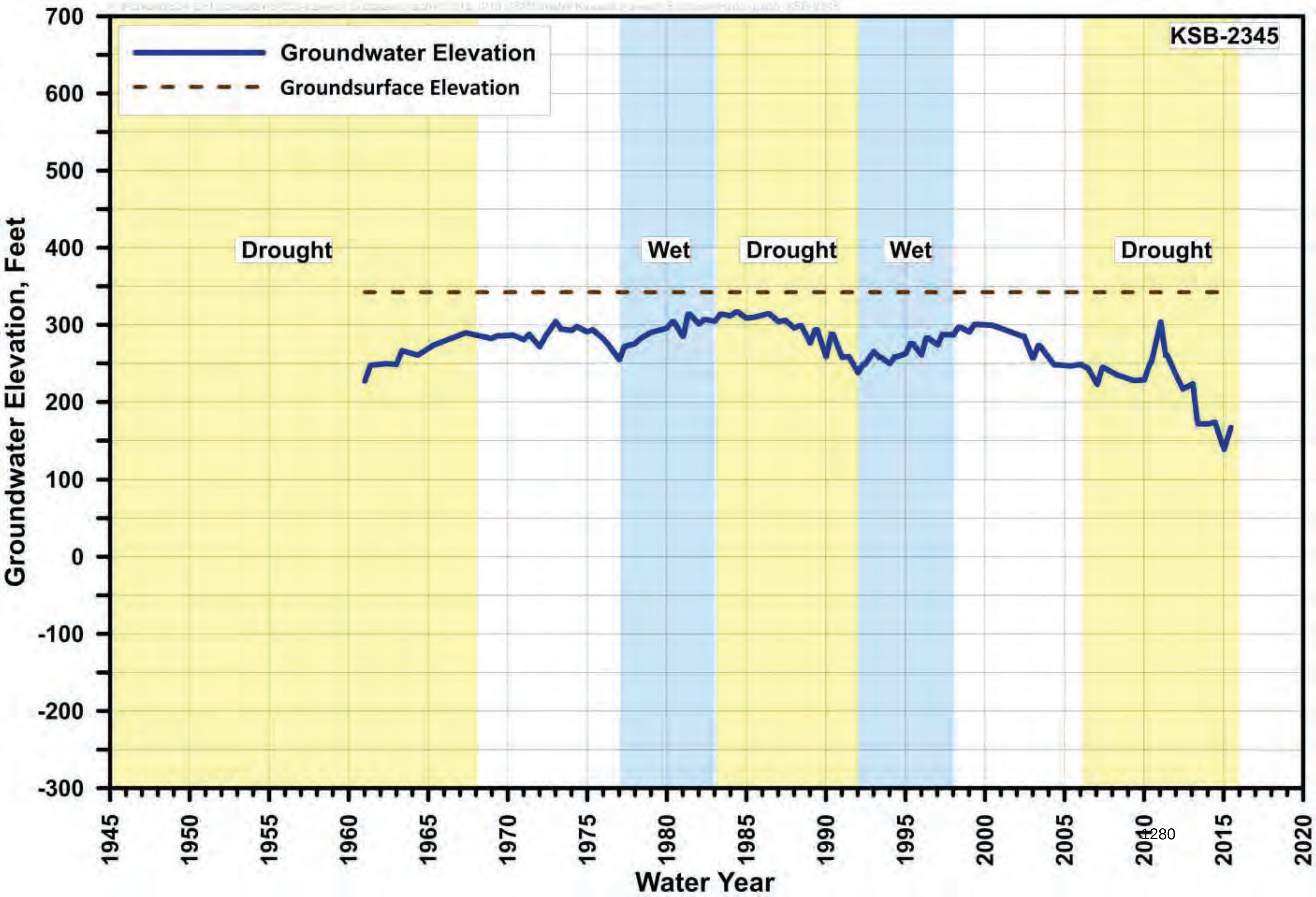
2015
2020
Water Year


KSB-2345
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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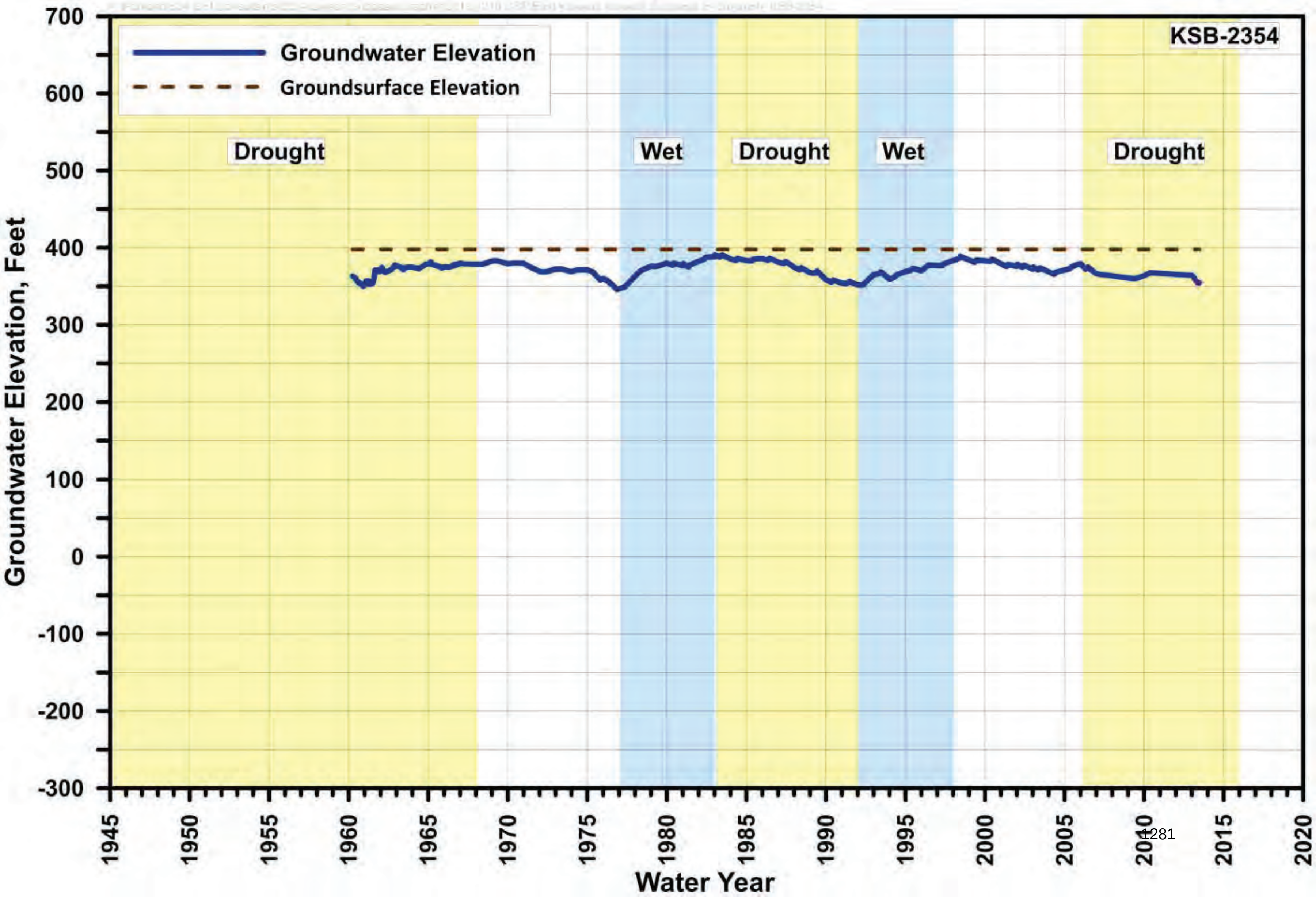
2015
2020
Water Year



KSB-2354
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
0
-100
-200
-300
1945
1950
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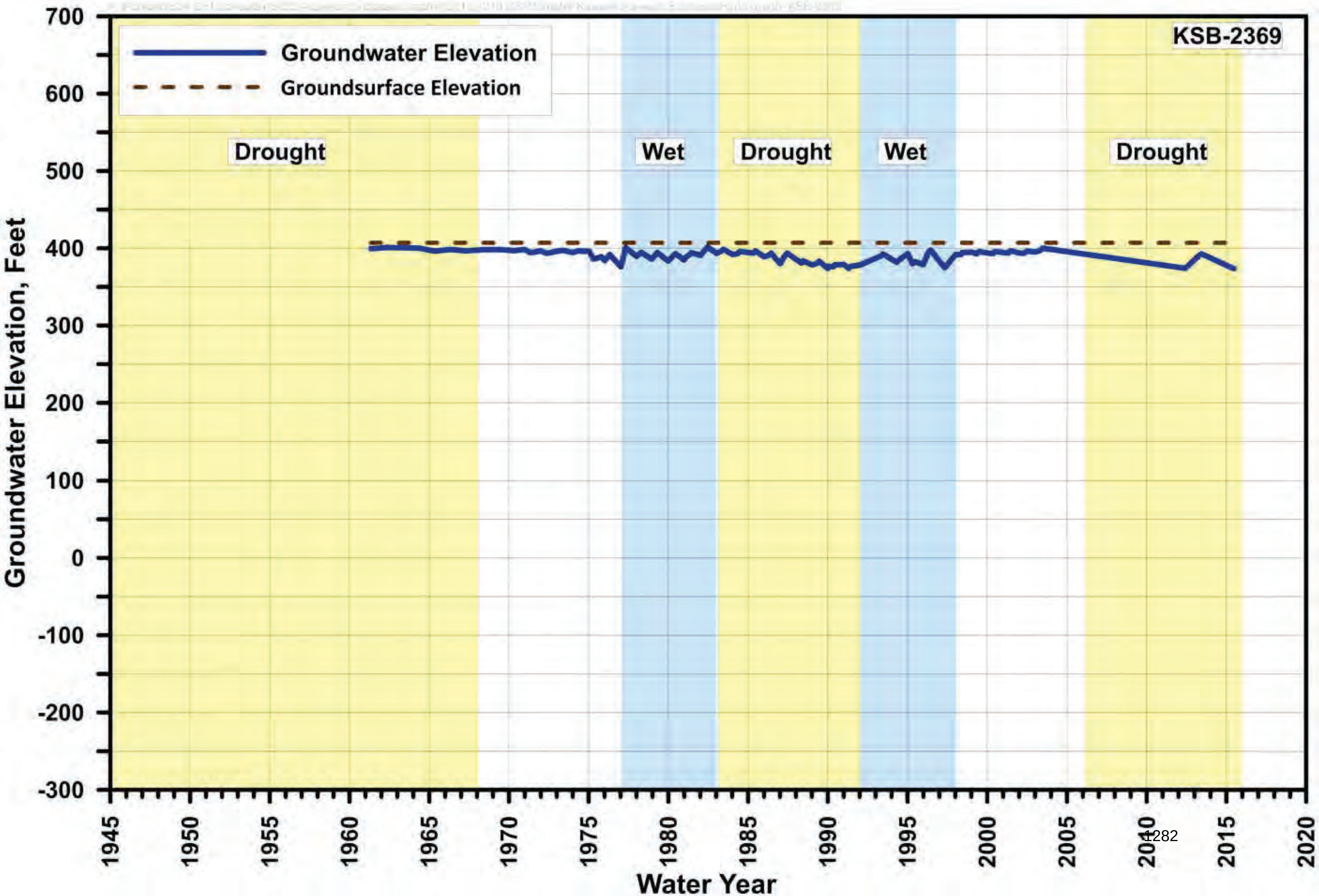
2015
2020
Water Year



KSB-2369
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
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-100
-200
-300
1945
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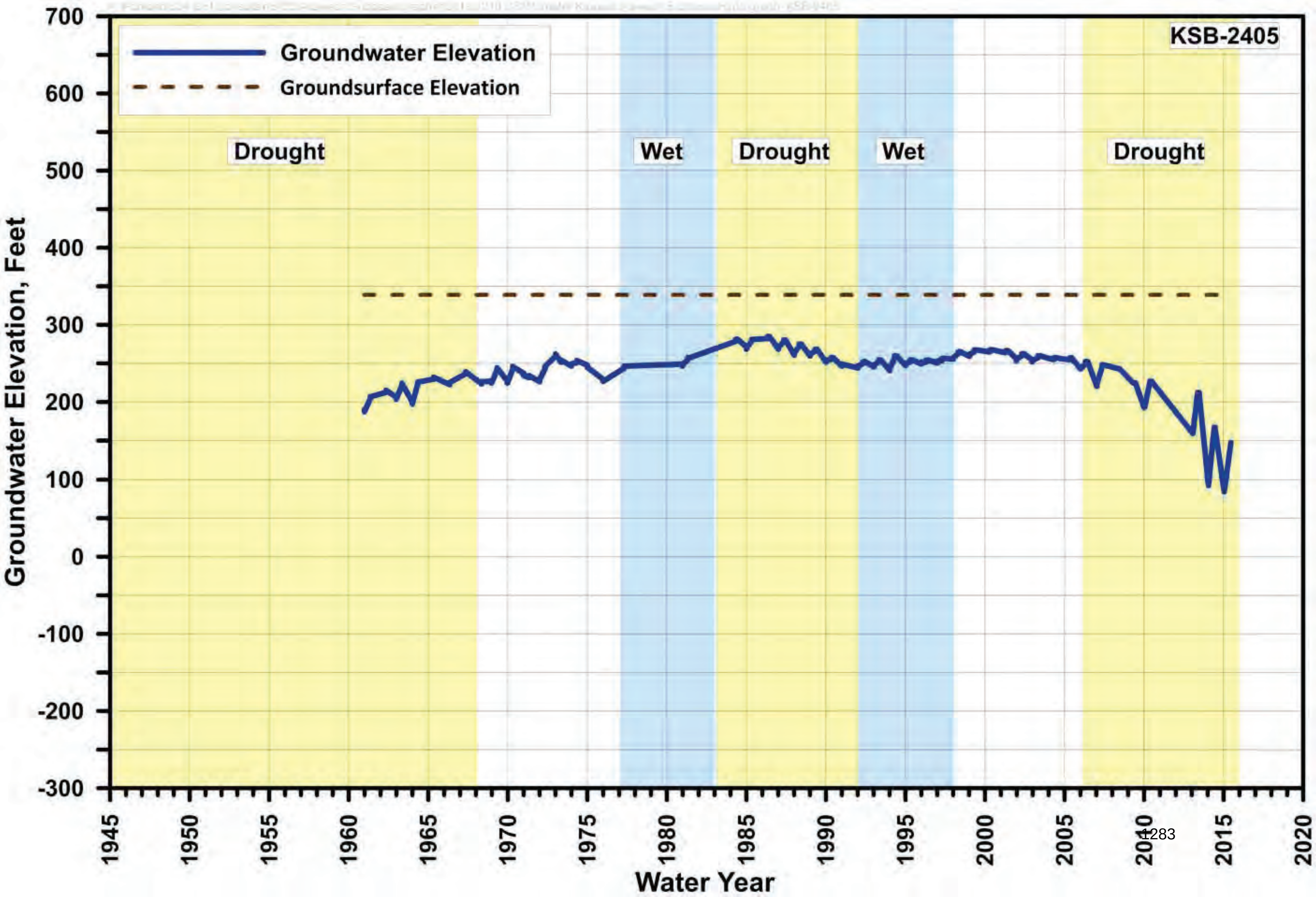
2020
Water Year


KSB-2405
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
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100
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-100
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-300
1945
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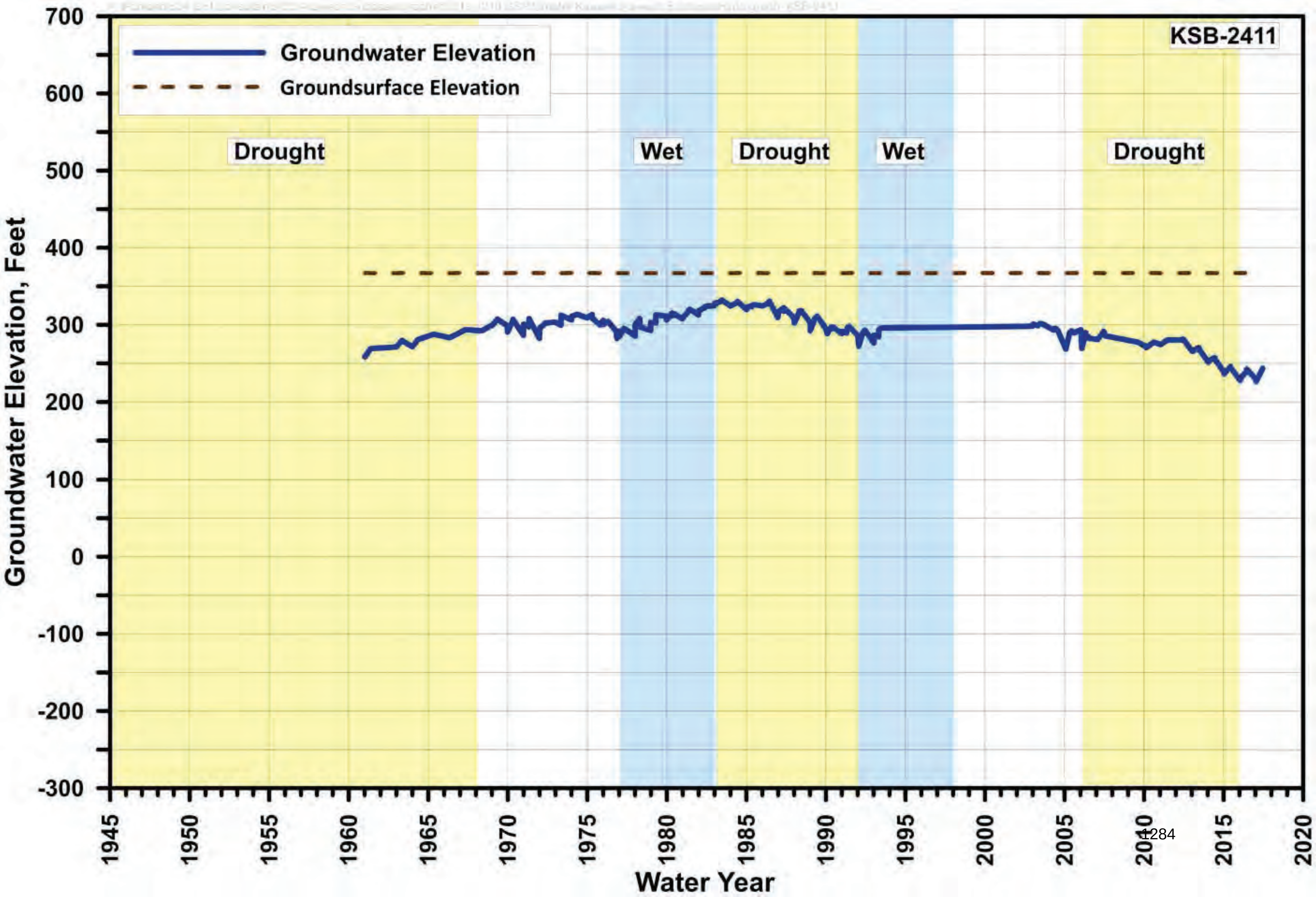
2020
Water Year


KSB-2411
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
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-100
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-300
1945
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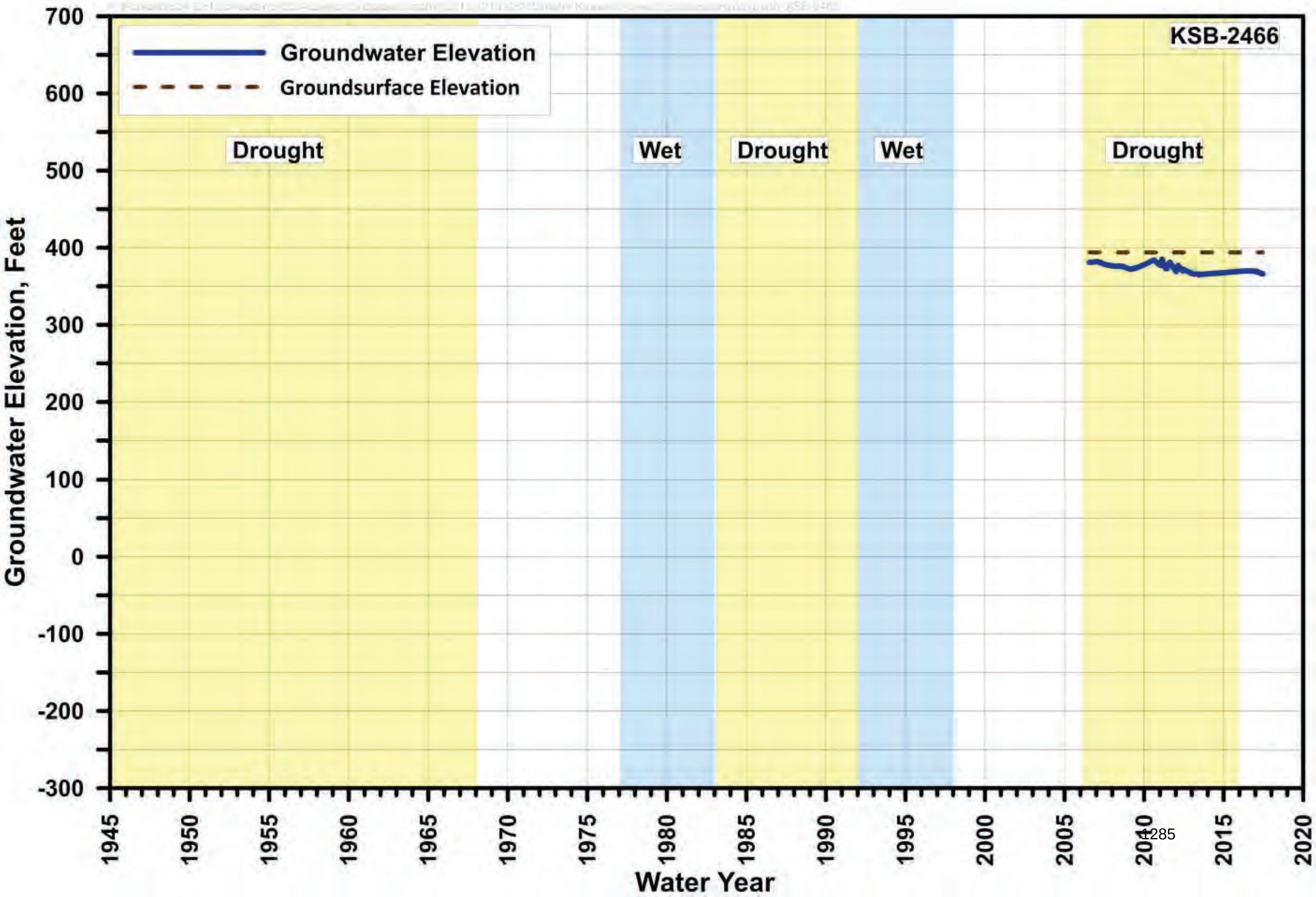
2020
Water Year



KSB-2466
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
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300
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100
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-100
-200
-300
1945
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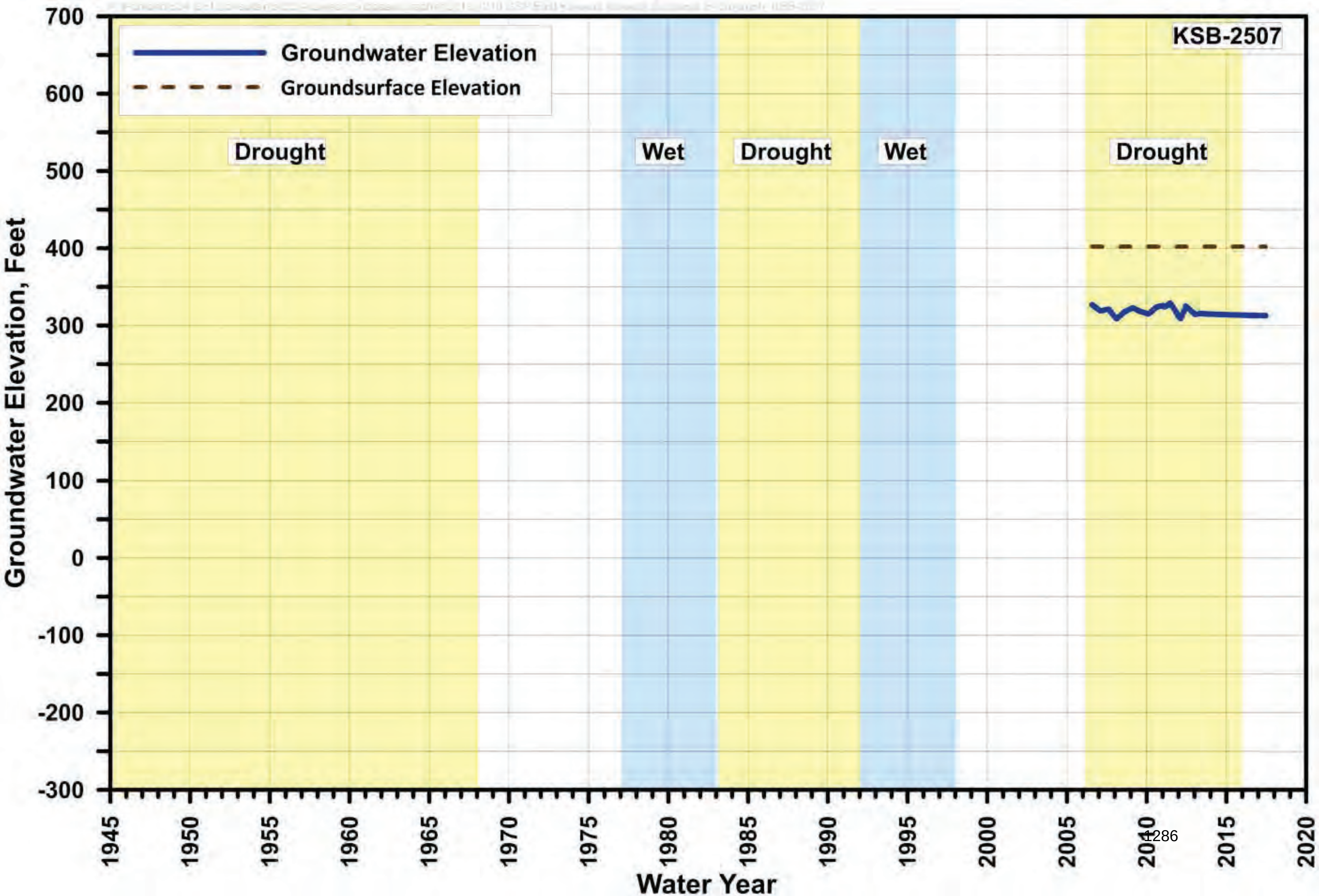
2015
2020
Water Year



KSB-2507
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
500
400
300
200
100
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-100
-200
-300
1945
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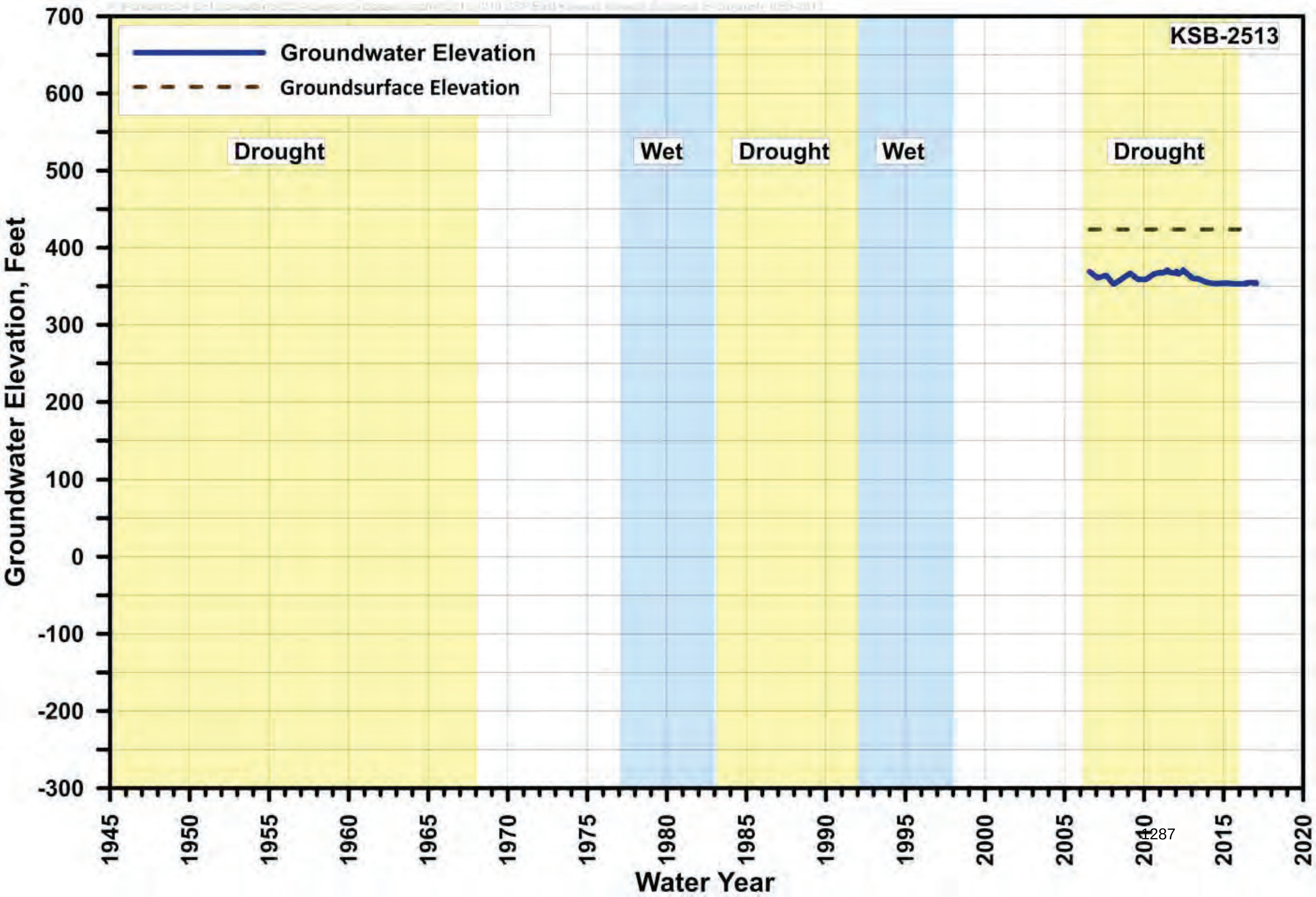
2020
Water Year


KSB-2513
Groundwater Elevation
Groundsurface Elevation
Drought
Wet
Drought
Wet
Drought
Groundwater Elevation, Feet
700
600
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400
300
200
100
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-100
-200
-300
1945
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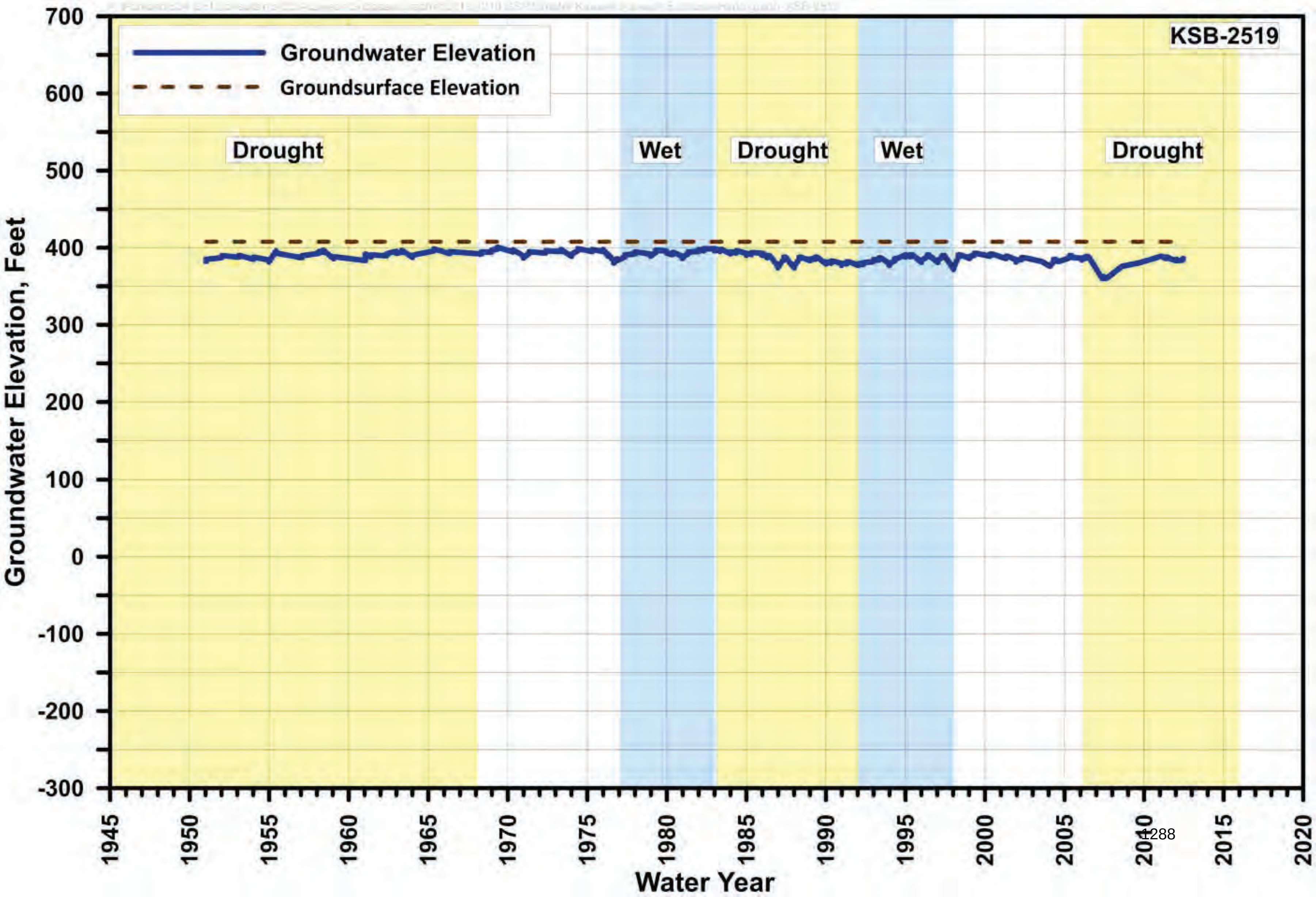
2020
Water Year


KSB-2519
Groundwater Elevation
Groundsurface Elevation
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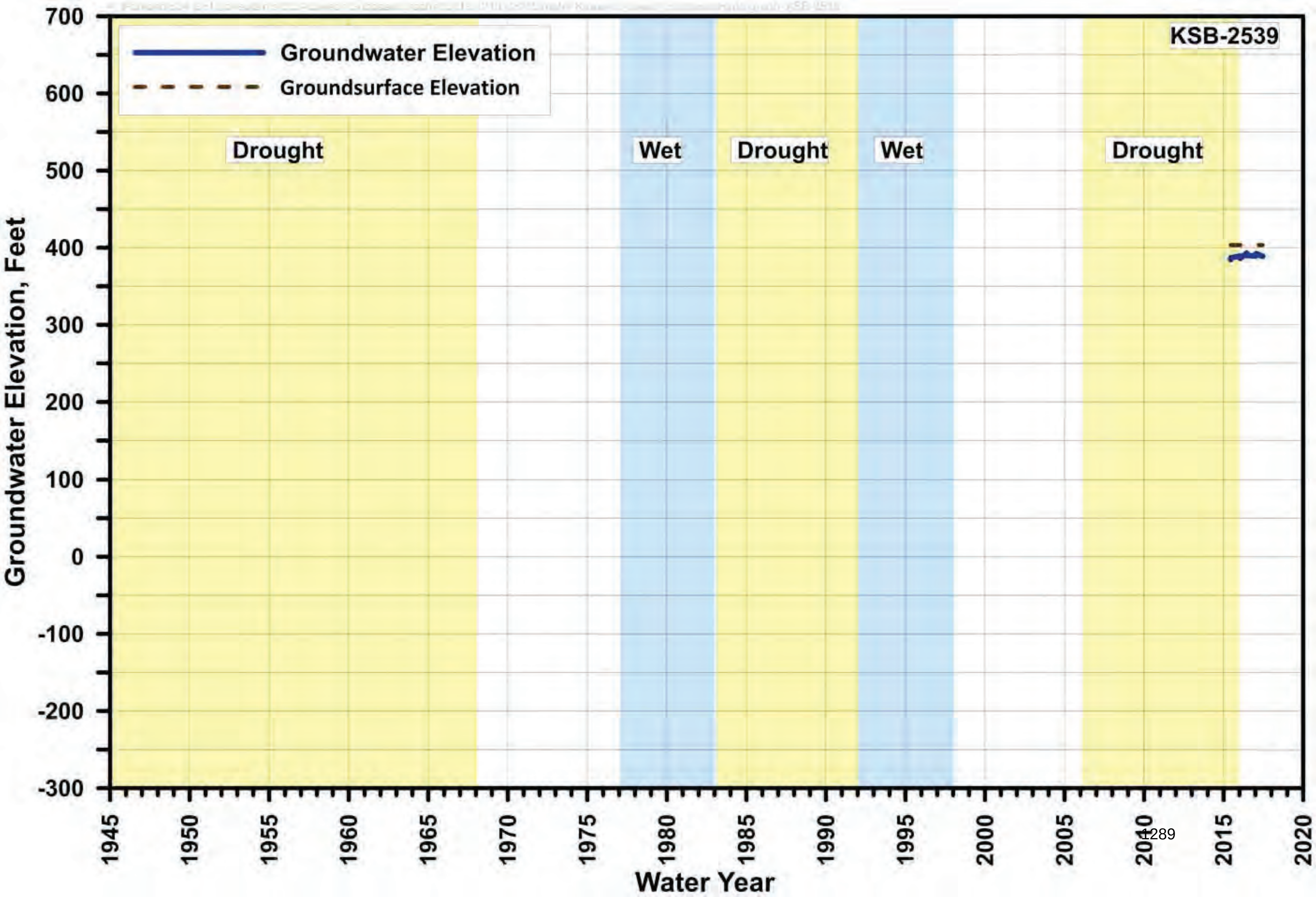
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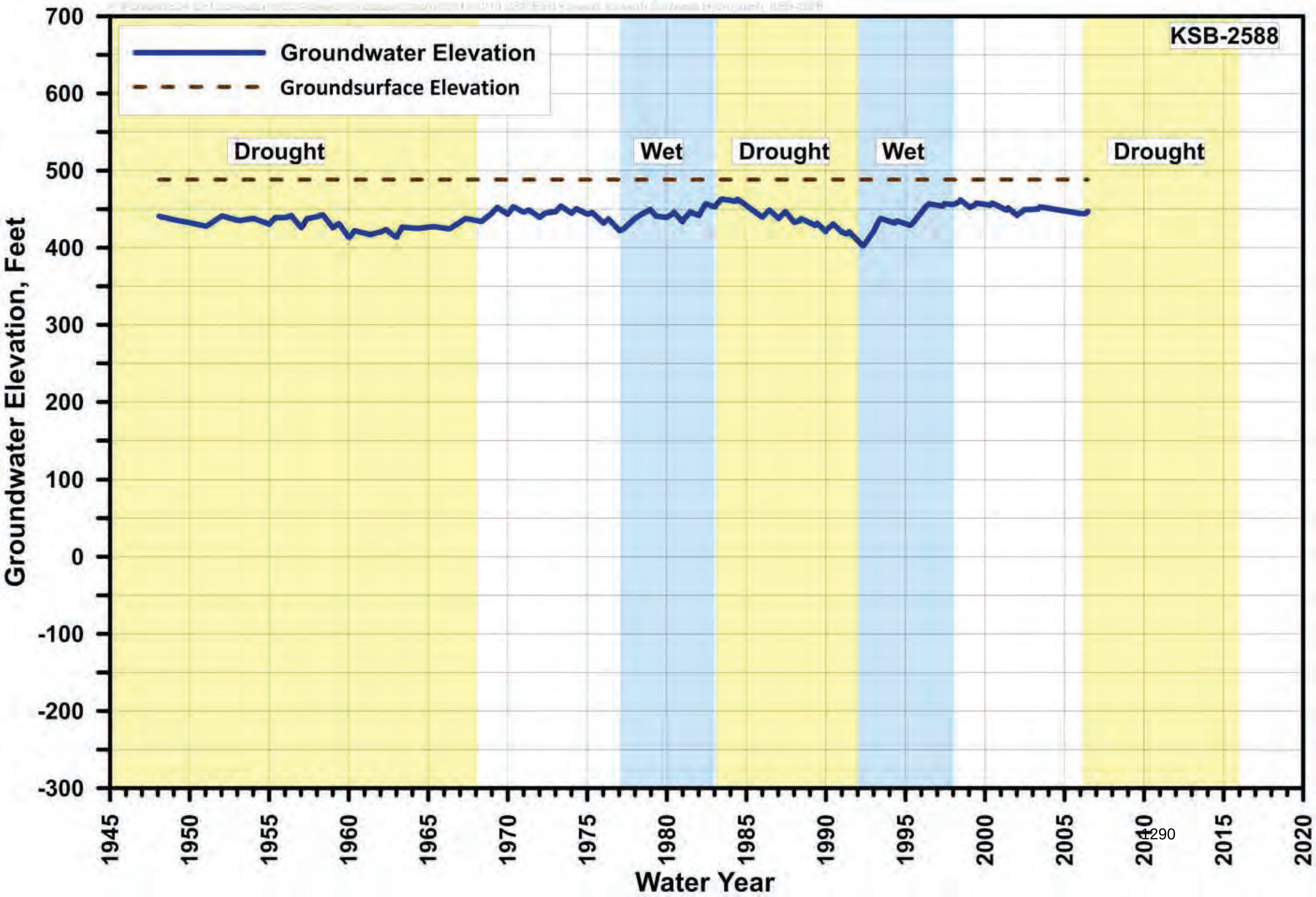
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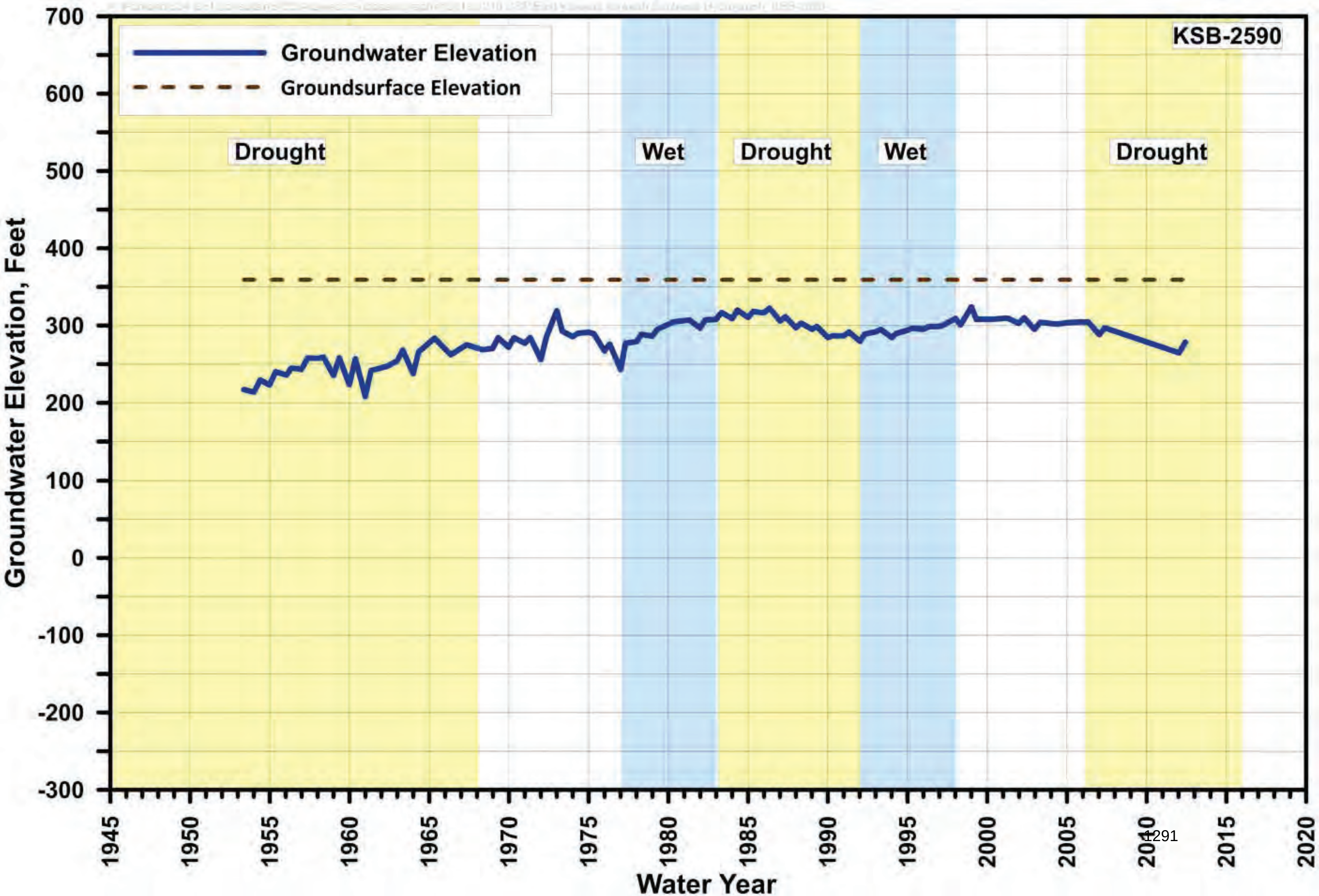
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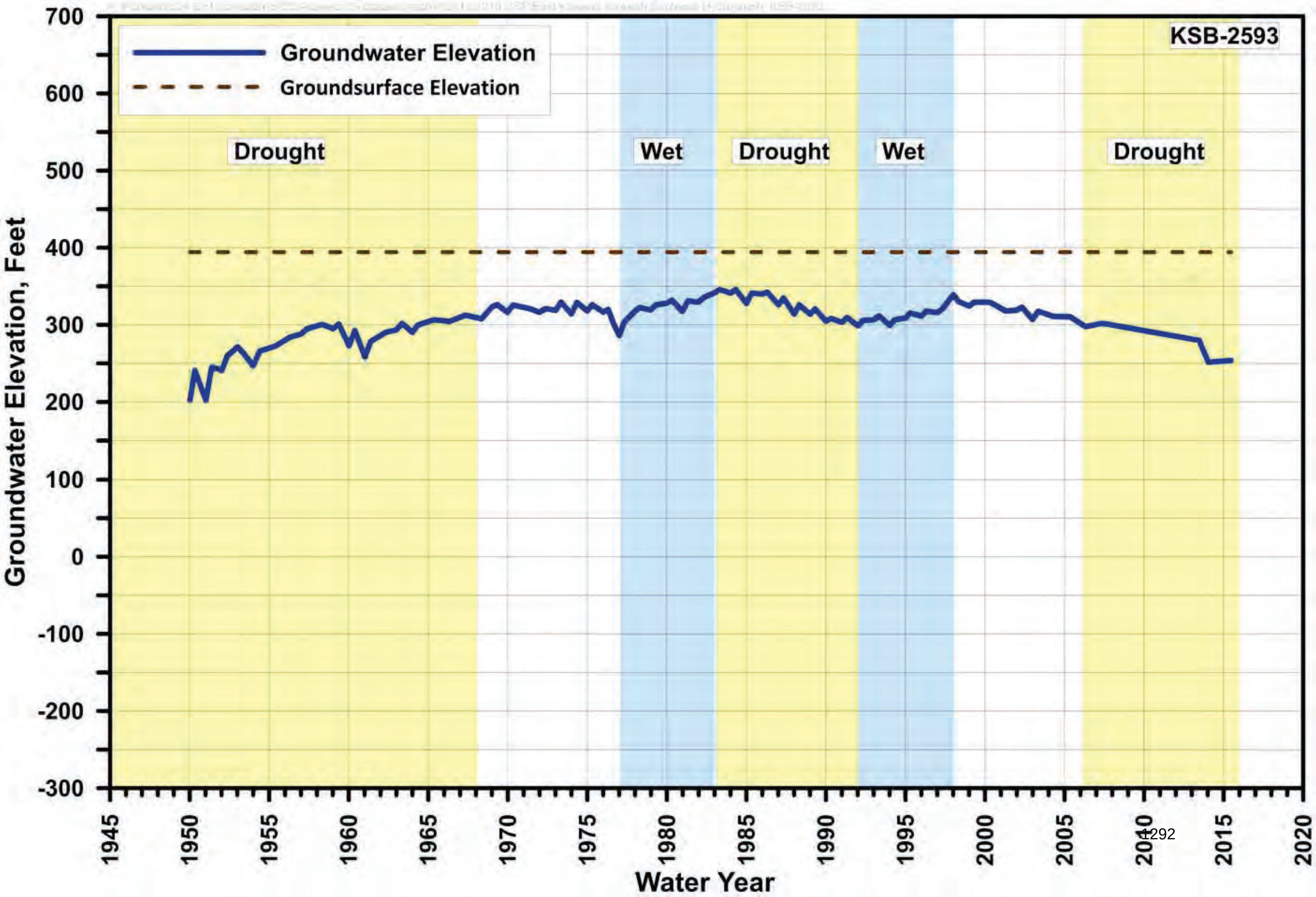

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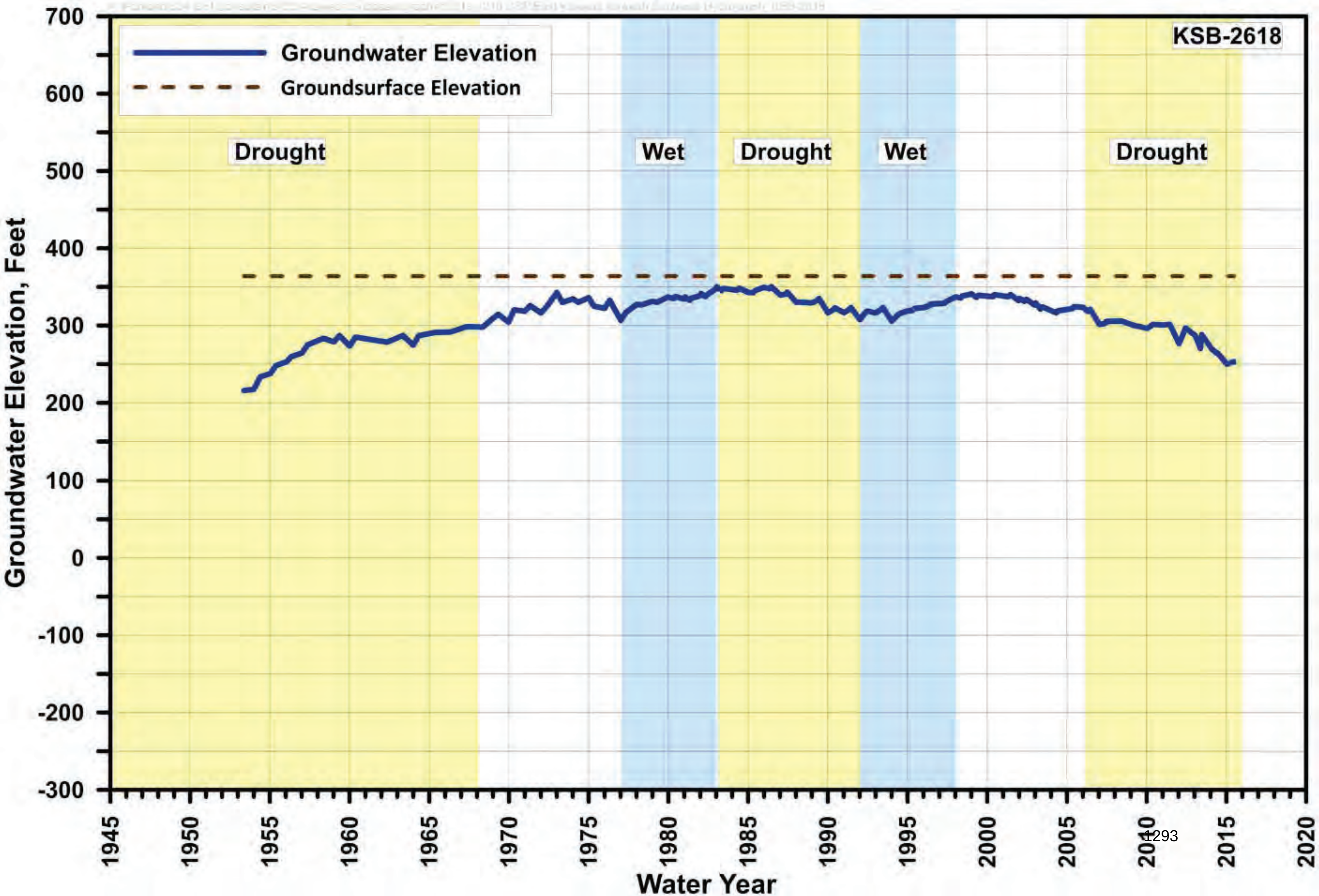

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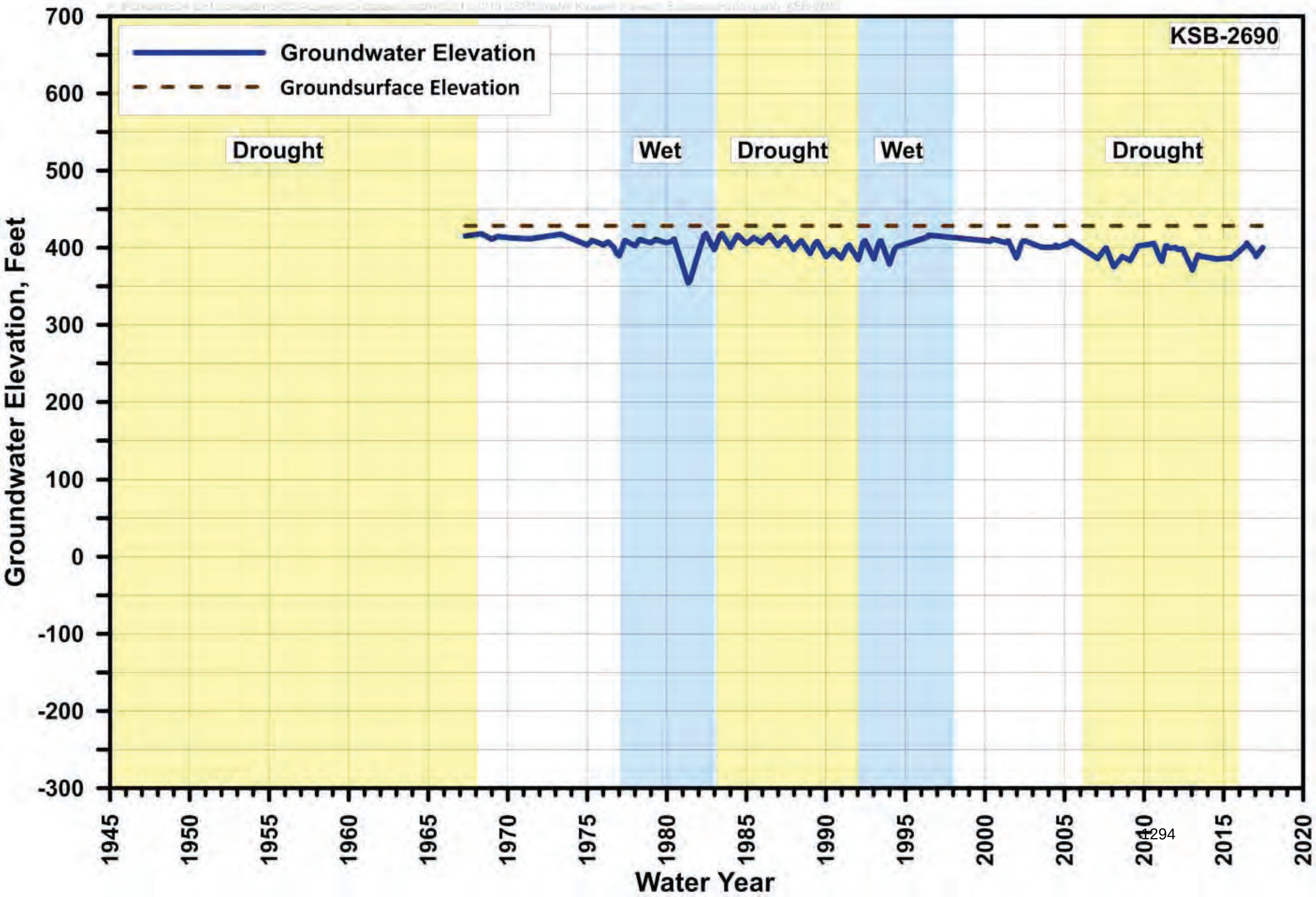
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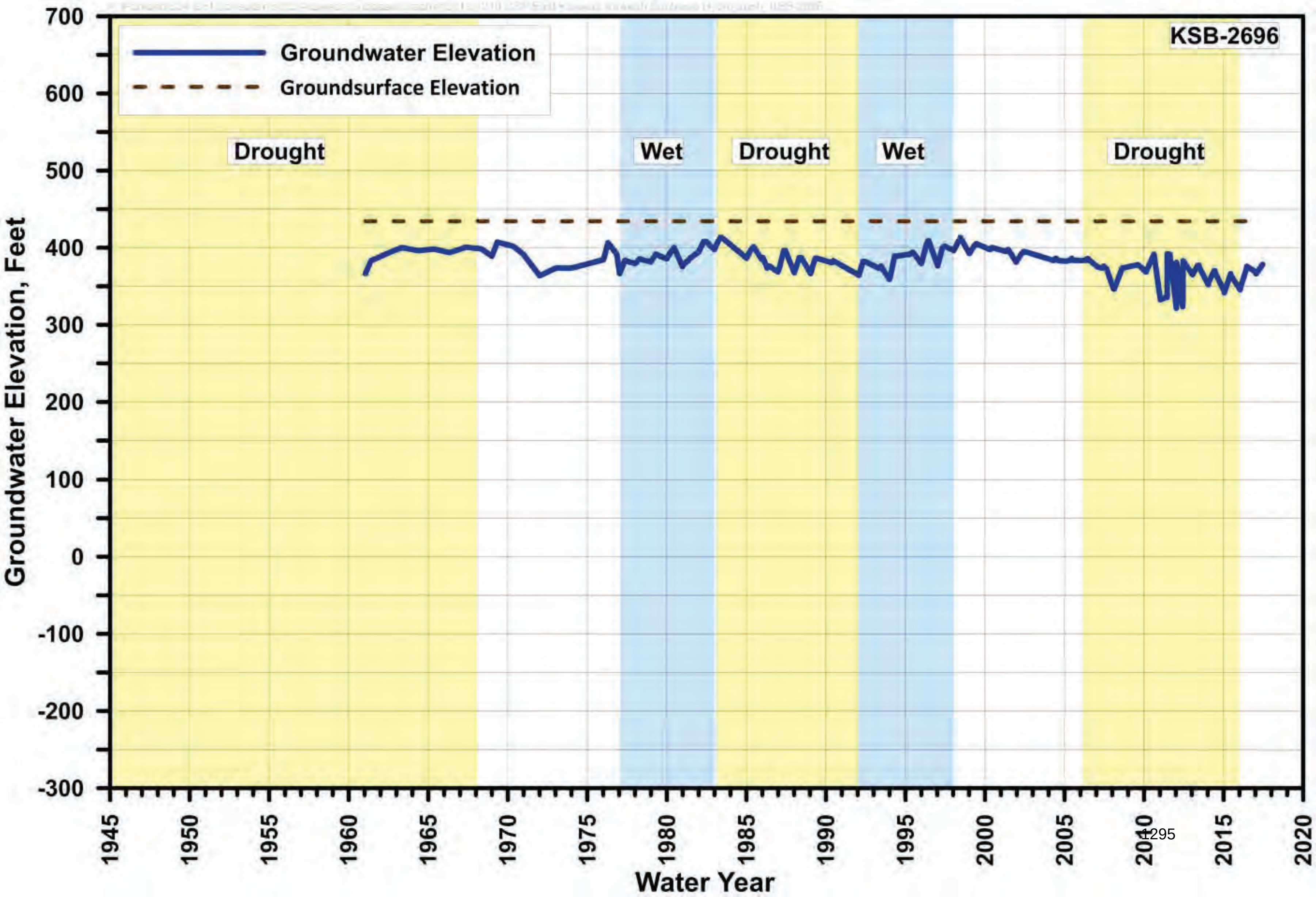

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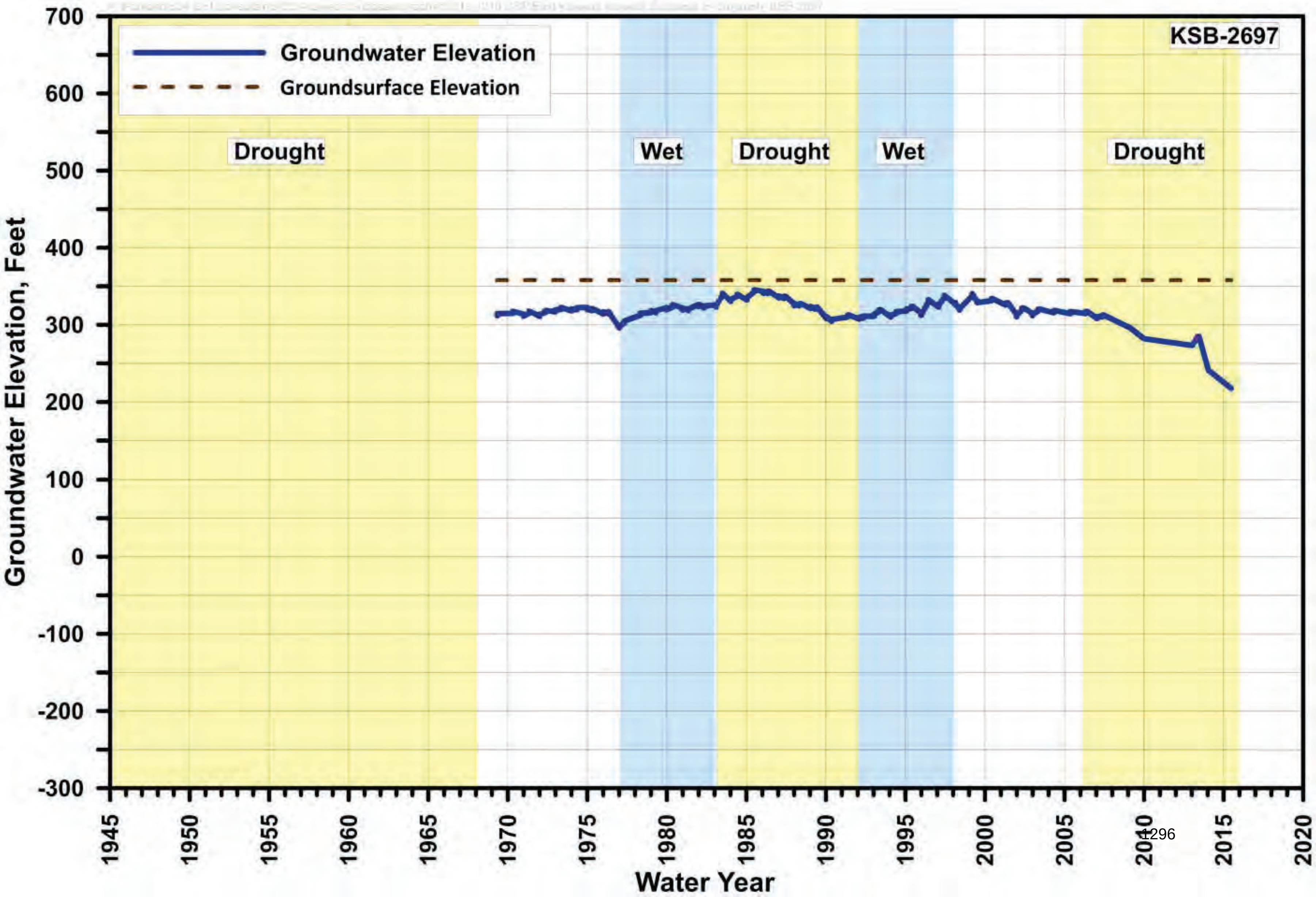
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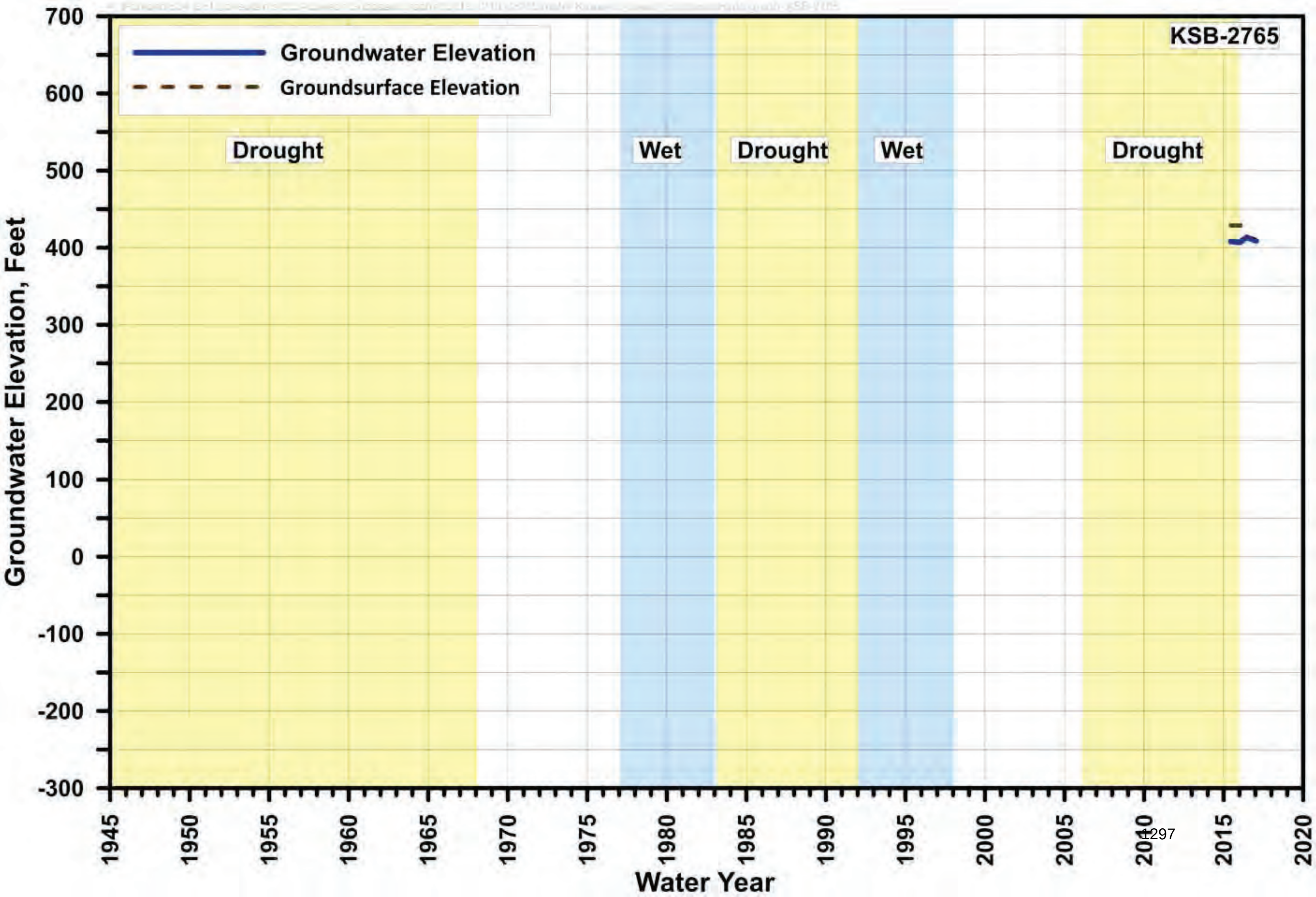

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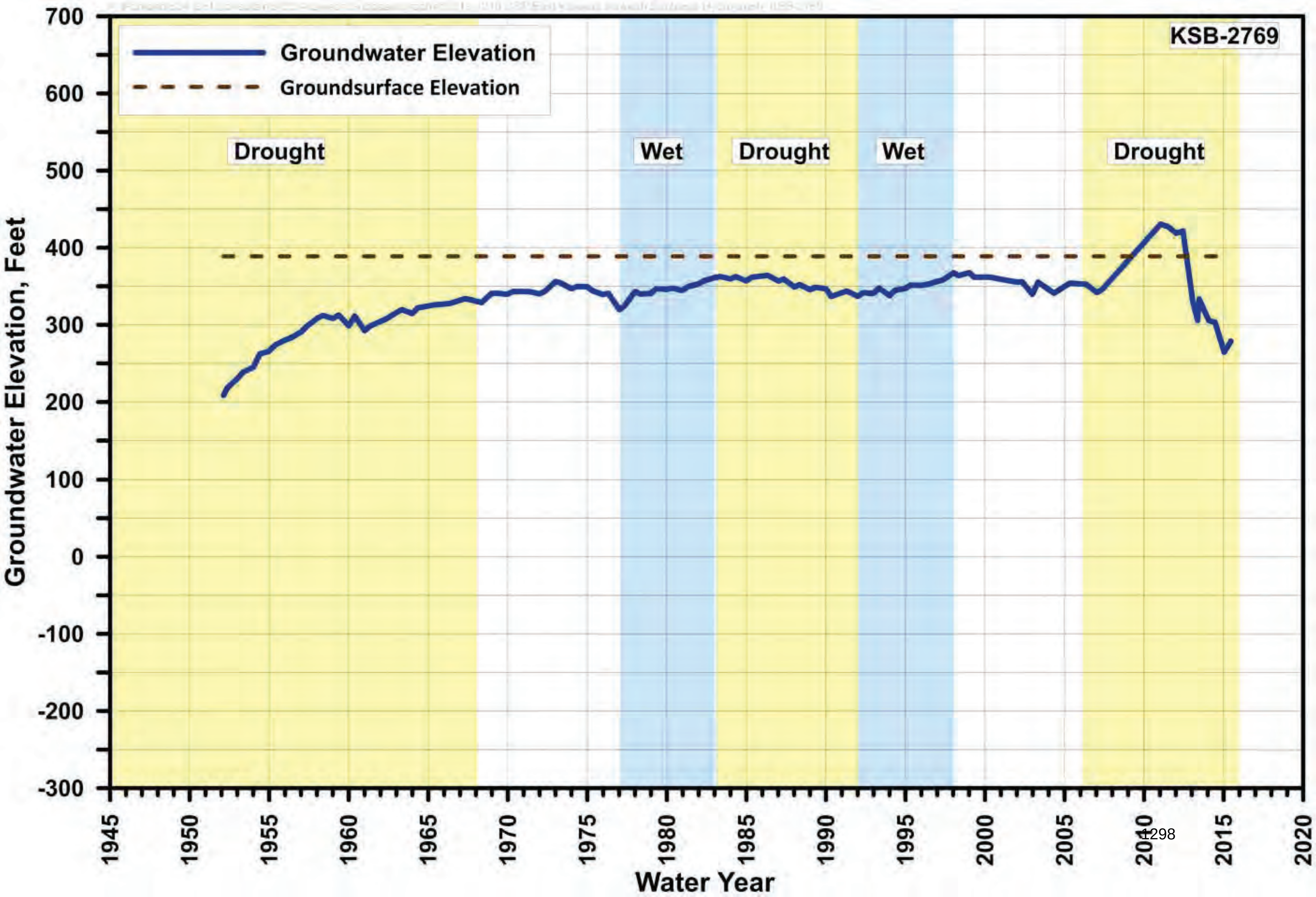
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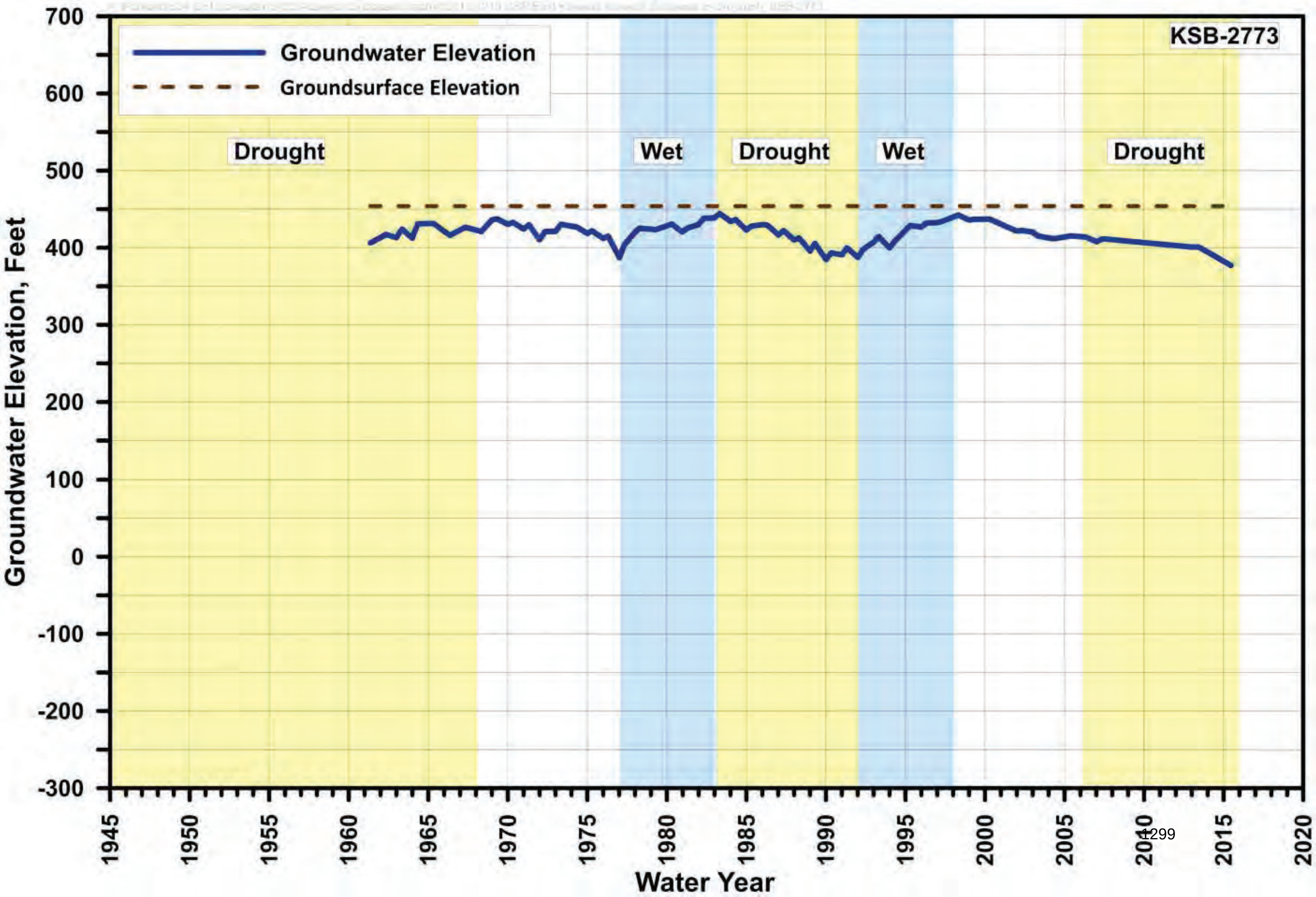

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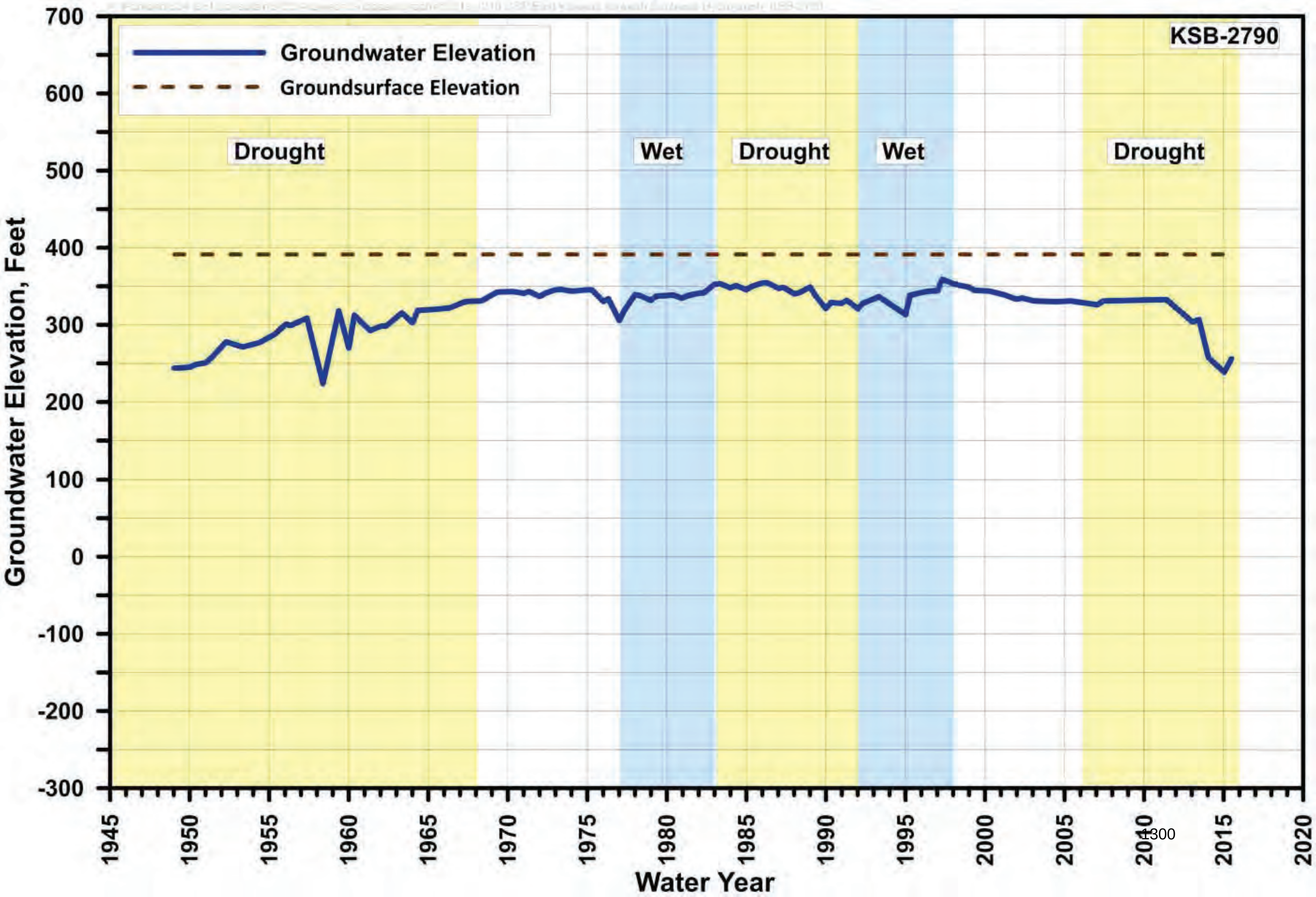

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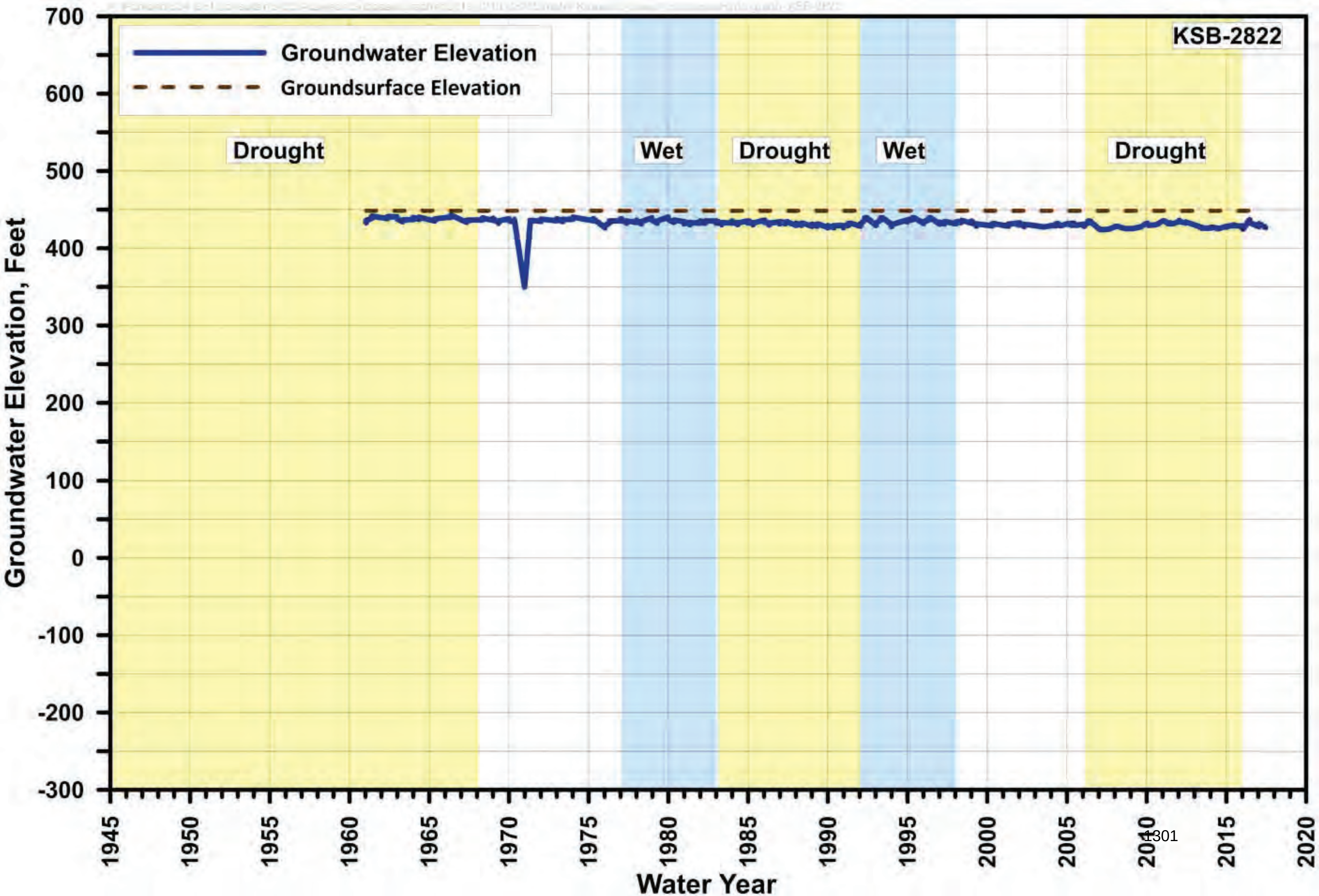
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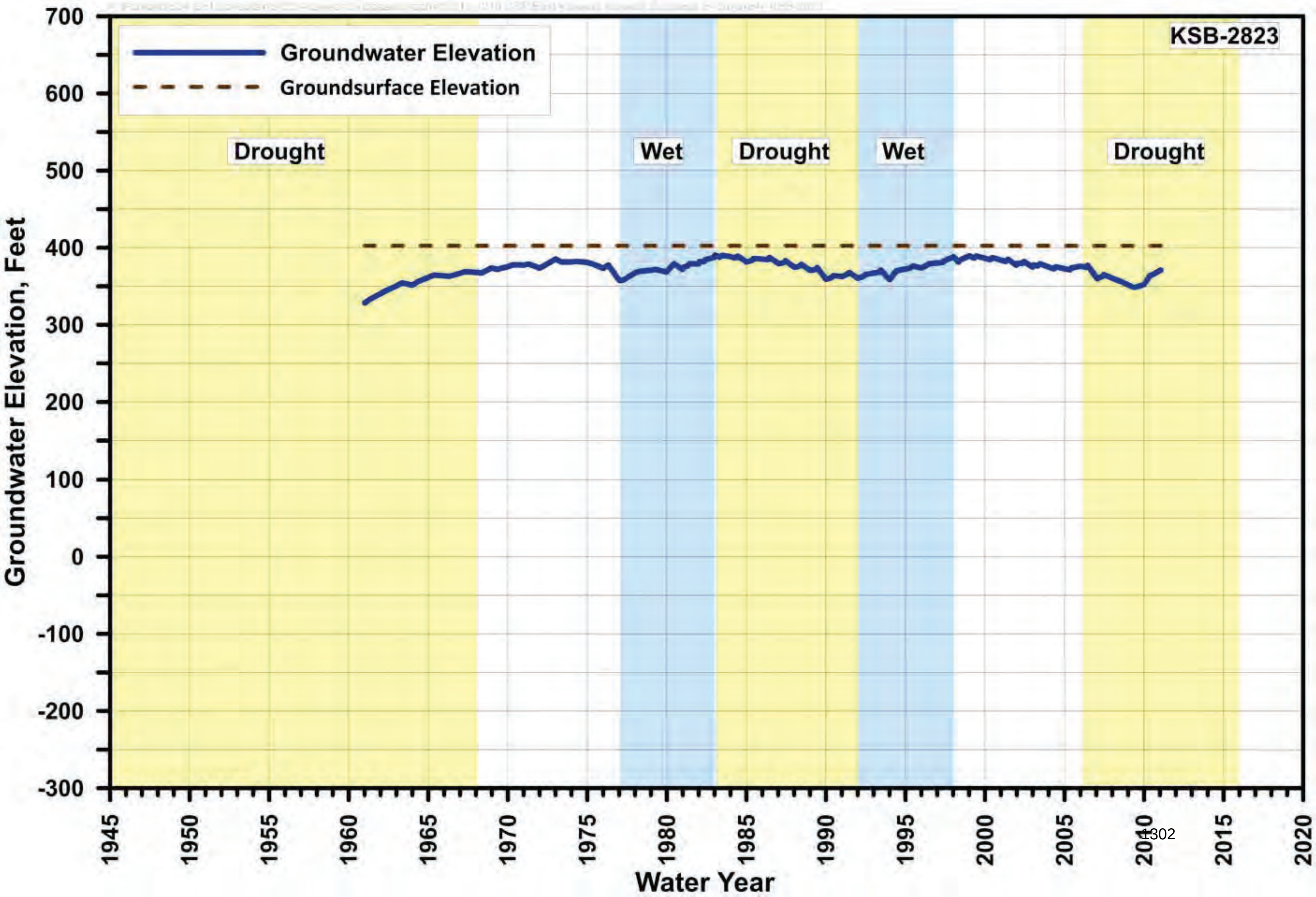

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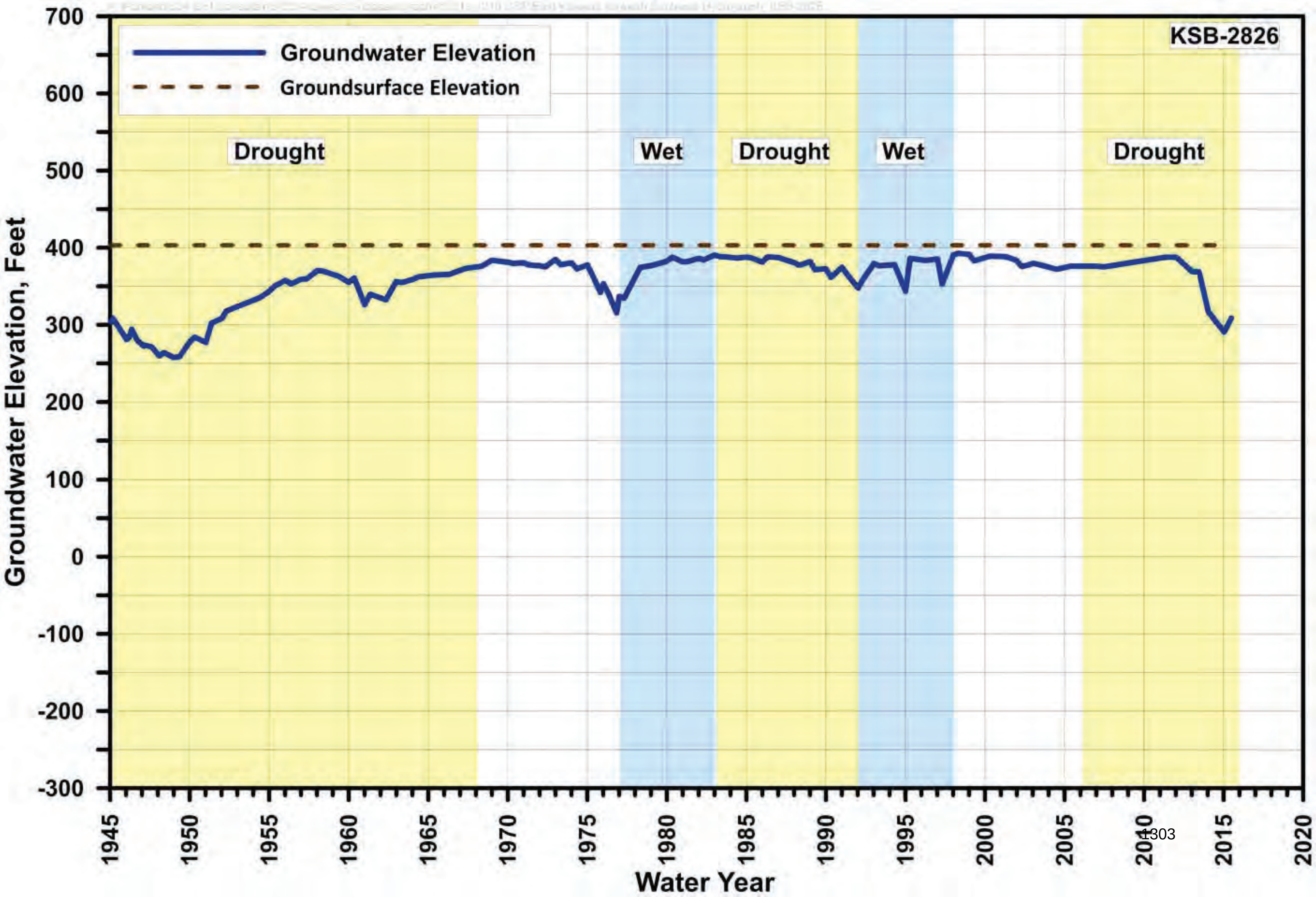

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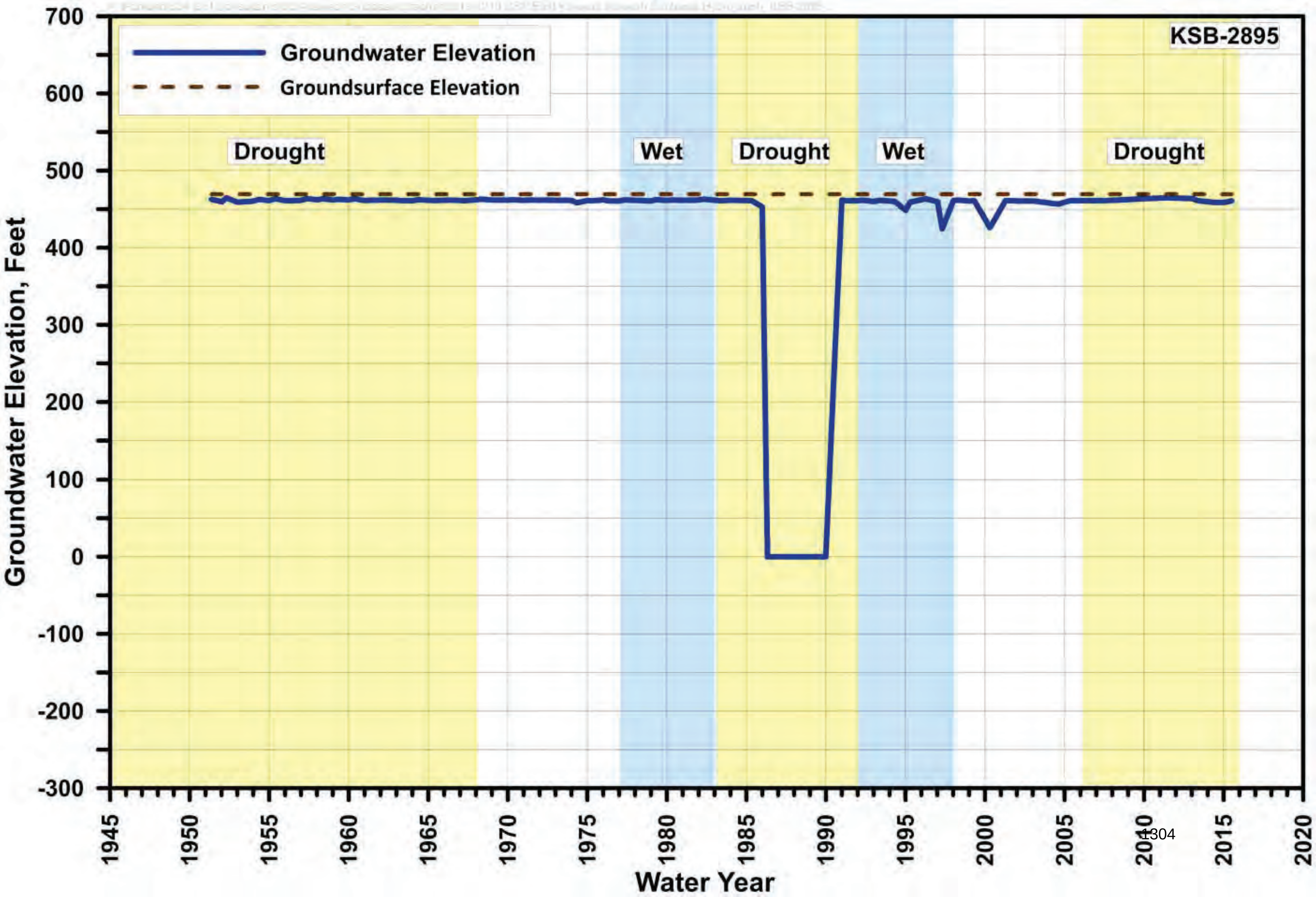

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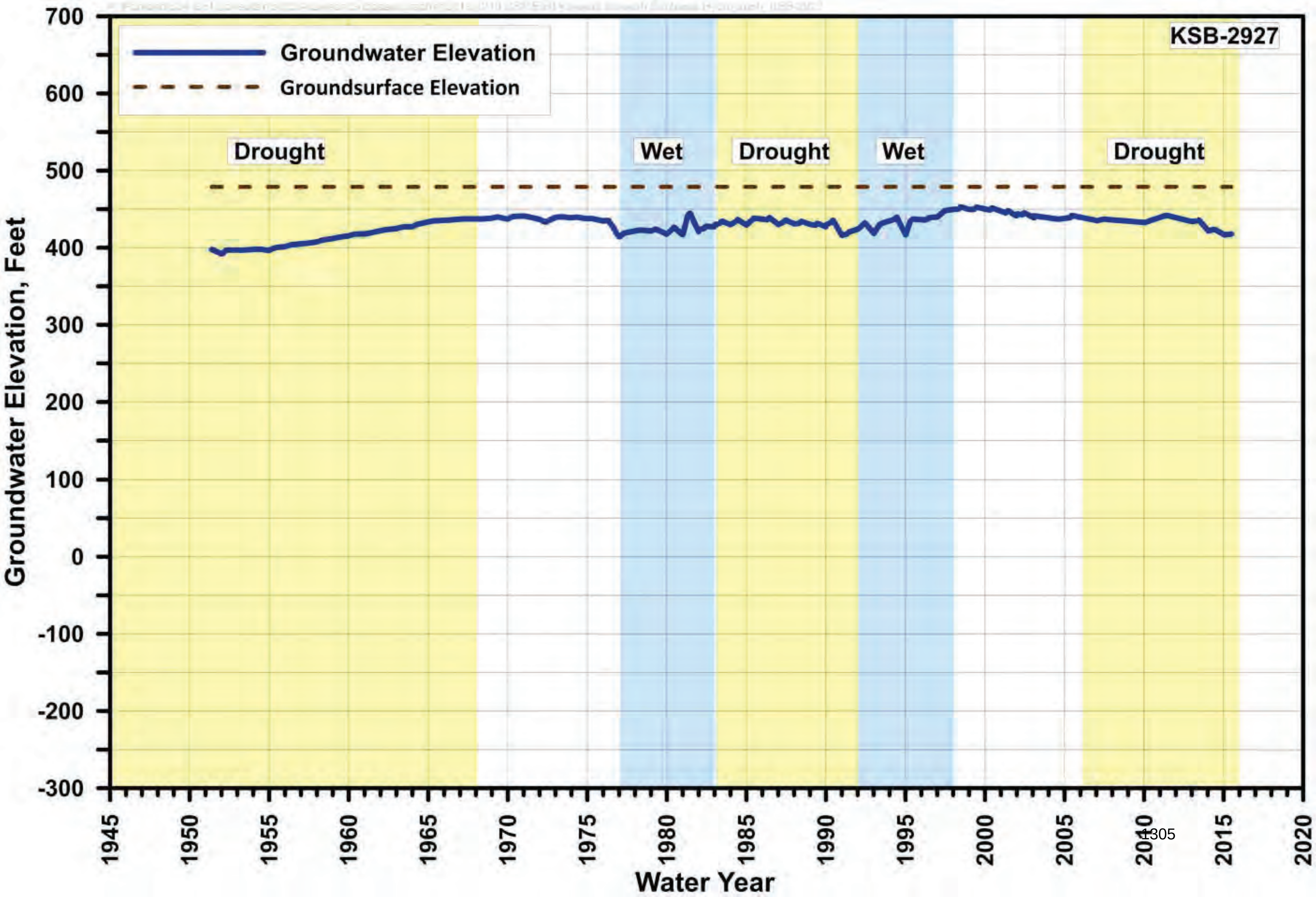

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# Appendix C

## Davids Engineering Evapotranspiration and Applied Water Estimates

## Technical Memorandum

*Specialists in Agricultural Water Management*
*Serving Stewards of Western Water since 1993*

# Technical Memorandum

**To:** GEI Consultants

**From:** Davids Engineering

**Date:** November 30, 2018

**Subject:** **Kaweah Subbasin Development of Evapotranspiration and Applied Water Estimates Using Remote Sensing**

## 1 Summary


The purpose of this effort is to develop time series estimates of agricultural water demands for the Kaweah Subbasin from 1999 through 2017. This effort updates a similar analysis previously completed for the Kaweah Delta Water Conservation District (KDWCD) from 1999 through 2016 to include the areas currently not included in the KDWCD area but lying within the Kaweah Subbasin and to extend the estimates through 2017.

The consumptive use of water (i.e., evapotranspiration) is the primary destination of infiltrated precipitation and applied irrigation water within the Kaweah Subbasin. Quantification of consumptive use was achieved by performing daily calculations of evapotranspiration (ET) for individual fields from October 1998 through December 2017. ET was separated into its evaporation (E) and transpiration (T) components. Transpiration was quantified using a remote sensing approach where Landsat satellite images acquired from USGS were used to calculate the Normalized Difference Vegetation Index (NDVI), which was subsequently translated to a basal crop coefficient and combined with referent ET to calculate transpiration over time.

A spatial coverage of field boundaries was developed for the Kaweah Subbasin, and individual field polygons were assigned cropping and irrigation method information over time based on available data. Field boundaries were delineated by combining polygon coverages in GIS format from the United States Department of Agriculture (USDA) and the California Department of Water Resources (DWR). The area encompassed by the field boundary GIS coverage includes the Kaweah Subbasin and the area immediately surrounding but outside of the subbasin.

Crop ET was calculated based on a combination of remote sensing data and simulation of irrigation events in a daily root zone water balance model. Due to the remote sensing approach crop ET estimates are relatively insensitive to crop type and irrigation method so detailed, accurate assignment of crop types and irrigation methods to each field is not critical to developing relatively reliable estimates of crop ET. Crop types and irrigation method were assigned to each field based on a combination of data from DWR and USDA. The amount of green vegetation present over time was estimated for each field polygon based on NDVI, which is calculated using a combination of red and near infrared reflectances as measured using multispectral satellite sensors onboard Landsat satellites. Following the preparation of NDVI imagery spanning the analysis period all images were quality controlled to remove pixels affected by clouds.

Mean daily NDVI values for each field were converted to basal crop coefficients based on cropping information from the 2007 Tulare County crop survey, combined with an analysis of actual evapotranspiration ($ET_a$) by crop conducted using the Surface Energy Balance Algorithm for Land (SEBAL®) for 2007 (Bastiaanssen et al., 2005; SNA, 2009). Daily precipitation was estimated based on assembly and review of data from the PRISM Climate Group at Oregon State University[1]. Daily reference evapotranspiration ($ET_o$) was estimated based on information from California Irrigation Management Information System (CIMIS) weather stations. Root zone parameters that influence the amount of available soil moisture storage were estimated based on crops and soils present in the Kaweah Subbasin.

A summary for the 1999 to 2017 analysis period of the annual ET of applied water ($ET_{AW}$), $ET_c$ (synonymous with $ET_a$), applied water (AW), deep percolation of applied water ($DP_{AW}$) and deep percolation of precipitation ($DP_{pr}$) estimates based on the root zone water balance model is given in the Results section.

Application of remote sensing combined with daily root zone water balance modeling (RS-RZ model) provides an improved methodology for estimation of surface interactions with the groundwater system including net groundwater depletion through estimation of ET of applied water and other fluxes.

# 2 Introduction

The purpose of this effort is to develop time series estimates of agricultural water demands for the Kaweah Subbasin from 1999 through 2017. Demand was estimated quantitatively at the field scale using a daily root zone water balance model and aggregated to monthly time steps. It is anticipated that these estimates will be used to support development of an integrated hydrologic model for the Kaweah Subbasin and water budget development for one or more Groundwater Sustainability Plans (GSPs). Crop evapotranspiration (ET), the primary driver of agricultural water demand, was estimated based on a combination of remote sensing and simulation of irrigation events using the water balance model.

This effort updates a similar analysis previously completed for the Kaweah Delta Water Conservation District (KDWCD) from 1999 through 2016 to include the areas currently not included in the KDWCD area but lying within the Kaweah Subbasin. In addition to adding the additional areas within the Kaweah subbasin, this analysis extends the estimates through the end of the 2017 calendar year.

# 3 Methodology

## *3.1 Daily Root Zone Simulation Model*

A conceptual diagram of the various surface layer fluxes of water into and out of the crop root zone is provided in Figure 3.1. The consumptive use of water (i.e., evapotranspiration or ET) is the primary destination of infiltrated precipitation and applied irrigation water within the Kaweah Subbasin. Quantification of consumptive use was achieved by performing daily calculations of ET for individual fields from October 1998 through December 2017. Evapotranspiration was separated into its evaporation (E) and transpiration (T) components. Additionally, each component was separated into the amount of E or T derived from precipitation or applied water.

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[1] http://prism.oregonstate.edu/

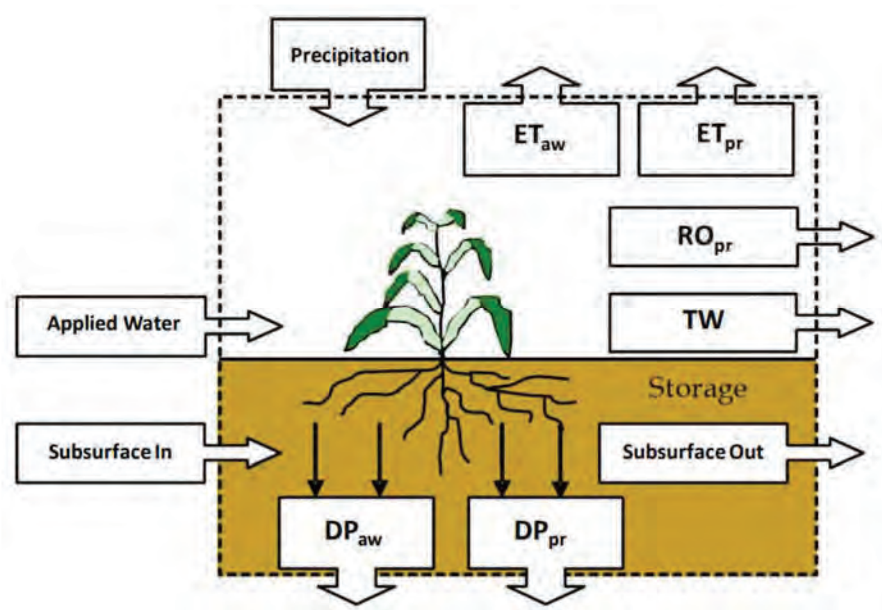


**Figure 3.1. Conceptualization of Fluxes of Water Into and Out of the Crop Root Zone**

Transpiration was quantified using a remote sensing approach whereby Landsat satellite images acquired from USGS were used to calculate the Normalized Difference Vegetation Index (NDVI), a measure of the amount of green vegetation present. NDVI values were calculated and interpolated for each field over time. NDVI values were then converted to transpiration coefficients that were used to calculate transpiration over time by multiplying daily NDVI by daily reference evapotranspiration ($ET_o$). Evaporation was quantified by performing a surface layer water balance for the soil based on the dual crop coefficient approach described in FAO Irrigation and Drainage Paper 56 (Allen et al. 1998). On a daily basis, evaporation was calculated based on the most recent wetting event (precipitation or irrigation) and the evaporative demand for the day ($ET_o$). This methodology is described in greater detail by Davids Engineering (Davids Engineering 2013).

## 3.2 Development of Field Boundaries

A spatial coverage of field boundaries was developed for the Kaweah Subbasin, and individual field polygons were assigned cropping and irrigation method information. For each field polygon, daily water balance calculations were performed for the 1999 to 2017 analysis period, and irrigation events were simulated to estimate the amount of water applied to meet crop irrigation demands. This section describes the development of the field polygon coverage and assignment of cropping and irrigation method attributes.

### 3.2.1 Development of Field Boundaries

Field boundaries were delineated by combining publicly available polygon coverages in GIS format from the United States Department of Agriculture (USDA) and the California Department of Water Resources (DWR). For the original KDWCD study area, common land unit (CLU) coverages developed by the USDA Farm Services Administration (FSA) on a county by county basis were combined to develop the base field coverage. Gaps exist in the CLU field coverages for fields not participating in USDA farm programs. These gaps were filled by overlaying the FSA CLU data with field polygons from DWR land use surveys for Kings and Tulare counties.

For the expanded study area encompassing the full Kaweah Subbasin, the original field boundaries were retained, and additional fields were added based on DWR's 2014 statewide spatial cropping dataset.

The area encompassed by the field boundary GIS coverage includes the Kaweah Subbasin and the area immediately surrounding, but outside of, the subbasin. Fields outside of the subbasin were included to provide a more robust dataset for model calibration and validation. Ultimately, results specific to the subbasin as a whole include only those fields with their centroid located within the Kaweah Subbasin.

### *3.3 Assignment of Cropping and Irrigation Method*

As described previously, crop evapotranspiration (ET) was calculated based on a combination of remote sensing data and simulation of irrigation events in a daily root zone water balance model. A result of the remote sensing approach is that crop transpiration was estimated with little influence from the assigned crop type for each field. Additionally, crop transpiration is the dominant component of ET, meaning that ET estimates are likewise largely independent of the assigned crop type.

Crop evapotranspiration is driven to some extent by the characteristics of the irrigation method and its management, including the area wetted during each irrigation event and the frequency of irrigation. Surface irrigation methods typically wet more of the soil surface than micro-irrigation methods; however, surface irrigated fields are typically irrigated less frequently than their micro-irrigated counterparts. As a result, evaporation rates can be similar among surface and micro-irrigated fields and estimates of evaporation are likewise somewhat independent of the assigned irrigation method. Parameters related to irrigation method were assigned based the predominant irrigation method for each crop, as described by recent historical DWR land and water use surveys.

A key result of the relative insensitivity of the crop ET estimates to crop type or irrigation method (due to the remote sensing approach), is that detailed, accurate assignment of crop types and irrigation methods to each field is not critical to developing reliable estimates of crop ET at the field scale and, more importantly, at coarser scales due to the cancellation of errors in individual field estimates as they are aggregated.

Crop types were assigned to each field based on a combination of data from DWR and USDA. DWR data consisted of land use data from 2003 and 2014 for Kings County and from 1999, 2007, and 2014 for Tulare County. USDA data consisted of Cropland Data Layer coverages for 2008 to 2013 and 2015 to 2016. The source of land use data for each year is summarized in Table 3.1.

**Table 3.1. Land Use Sources by County and Year.**

| County | Year(s) | Source |
|---|---|---|
| Kings | 1999-2007 | DWR (2003) |
| | 2008-2013 | CDL |
| | 2014 | DWR (2014) |
| | 2015-2017 | CDL* |
| Tulare | 1999-2002 | DWR (1999) |
| | 2003-2007 | DWR (2007) |
| | 2008-2013 | CDL |
| | 2014 | DWR (2014) |
| | 2015-2017 | CDL* |

* CDL data for 2016 was used for 2017

## 3.4 NDVI Analysis

The amount of green vegetation present over time was estimated for each field polygon based on the Normalized Difference Vegetation Index (NDVI), which is calculated using a combination of red and near infrared reflectances, as measured using multispectral satellite sensors onboard Landsat satellites. NDVI can vary from -1 to 1 and is typically varies from approximately 0.15 to 0.2 for bare soil to 0.8 for green vegetation with full cover. Negative NDVI values typically represent water surfaces.

### 3.4.1 Image Selection

Landsat images are preferred due to their relatively high spatial resolution (30-meter pixels, approx. 0.2 acres in size). A total of 682 raw satellite images were selected and converted to NDVI spanning the period from September 1998 to January 2018. Of the images selected, 230 were from the Landsat 5 satellite, 350 were from the Landsat 7 satellite (first available in 2001), and 102 were from the Landsat 8 satellite (first available in 2013). These images were used to process and download surface reflectance (SR) NDVI from the USGS Earth Resources Observation and Science (EROS) Center Science Processing Architecture (ESPA)[2].

An example time series of NDVI imagery for 2010 for the Kaweah Delta Water Conservation District (KDWCD) is shown in Figure 3.1 in Davids Engineering (2013). In the figure, areas with little or no green vegetation present are shown in brown, and areas with green vegetation are shown in green.

There was sufficient cloud-free Landsat imagery available that no cloud gap filling as in Davids Engineering (2013) was necessary. The number of days between image dates ranged from 5 to 56, with an average of 10 days. Generally, there was at least one image selected for each month.

### 3.4.2 Extraction of NDVI Values by Field and Development of Time Series NDVI Results

Following the preparation of NDVI imagery spanning the analysis period, all images were masked using the Quality Assessment Band (BQA) provided by ESPA to remove pixels affected by clouds. Then, mean NDVI was extracted from the imagery for each field for each image date. These NDVI values were then interpolated across the full analysis period from October 1, 1998 to December 31, 2017 to provide a daily time series of mean NDVI values for each field.

[2] USGS ESPA website: https://espa.cr.usgs.gov/

Top of Atmosphere (TOA) NDVI was calculated for several image dates and compared to SR NDVI on the same image dates to establish the following relationship ($R^2$=0.99):

$$(\text{TOA NDVI}) = 0.9224*(\text{SR NDVI}) - 0.0171 \quad [3.1]$$

This regression was applied to all image dates to convert from SR to TOA NDVI to provide consistency with the relationship between NDVI and the transpiration coefficient developed by Davids Engineering (2013) Error! Bookmark not defined..

Landsat 8 bandwidth was adjusted to be consistent with bandwidths from Landsat satellites 5 and 7 using the following empirical relationship:

$$(\text{L7 mean NDVI}) = 0.984*(\text{L8 mean NDVI}) - 0.0421 \quad [3.2]$$

An example of time varying NDVI for individual fields over time is found in Section 3 of Davids Engineering (2013). Interpolated NDVI values for selected fields are provided for the period 1999 through 2010 on an annual basis, from January 1 to December 31 of each year. These figures illustrate the ability of the remote sensing approach to account for both changes in cropping over time and the presence of double- and triple-cropping.

### 3.4.3 Development of Relationships to Estimate Basal Crop Coefficient from NDVI

Basal crop coefficients ($K_{cb}$) describe the ratio of crop transpiration to reference evapotranspiration ($ET_o$) as estimated from a ground-based agronomic weather station. By combining $K_{cb}$, estimated from NDVI, with an evaporation coefficient ($K_e$), it is possible to calculate a combined crop coefficient ($K_c = K_{cb} + K_e$) over time[3]. By multiplying $K_c$ by $ET_o$, crop evapotranspiration ($ET_c$) can be calculated. For this analysis, $ET_o$, $K_{cb}$, $K_e$, and $ET_c$ (synonymous to actual ET, $ET_a$) were estimated for each field on a daily time step from October 1, 1998 to December 31, 2017.

Mean daily NDVI values for each field were converted to basal crop coefficients based on cropping information from the 2007 Tulare County crop survey conducted by DWR, combined with an analysis of actual evapotranspiration ($ET_a$) by crop conducted using the Surface Energy Balance Algorithm for Land (SEBAL®) for 2007 (Bastiaanssen et al., 2005; SNA, 2009). Specifically, a relationship between actual basal crop coefficients estimated using SEBAL and field-scale mean NDVI values developed by Davids Engineering (2013) was applied to calculate daily basal crop coefficients for each field over time[4].

## *3.5 Precipitation*

Daily precipitation was estimated based on assembly and review of data from the PRISM Climate Group at Oregon State University[5]. Specifically, each field was assigned estimated precipitation from the 4km PRISM grid cell within which its centroid fell. The update generally results in modest increases in estimated precipitation within the study area, with greater increases moving from west to east due to orographic effects.



[3] The estimation of Ke is based on a daily 2-stage evaporation model presented in FAO Irrigation and Drainage Paper No. 56 (Allen et al. 1998).

[4] This relationship is developed based on comparison of the combined crop coefficient to NDVI for individual fields, but represents only the transpiration component of ET. Thus, the relationship developed predicts the basal crop coefficient, Kcb.

[5] http://prism.oregonstate.edu/

Annual precipitation totals, averaged over the study area for water years 1999 to 2017, are shown in Figure 3.1. Water year precipitation over the study period varied from 4.1 inches in 2014 to 16.1 inches in 2011, with an annual average of 9.1 inches.

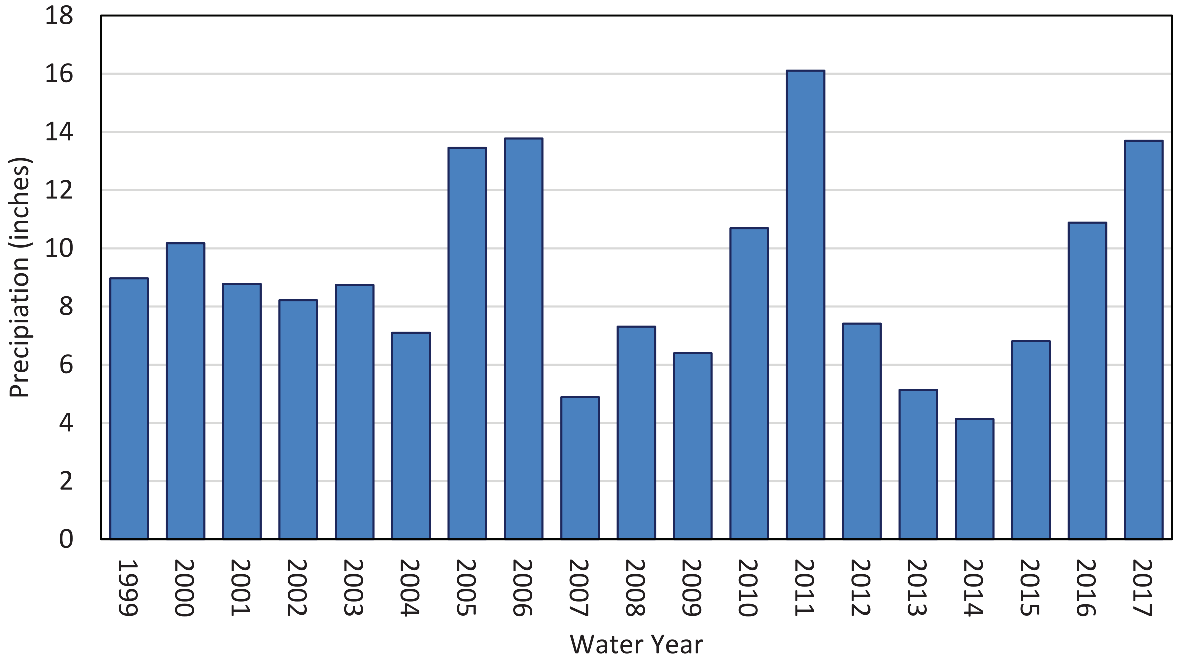


**Figure 3.2. Annual Precipitation Totals**

## *3.6 Estimation of Daily Reference Evapotranspiration*

Daily reference evapotranspiration ($ET_o$) was estimated based on information from California Irrigation Management Information System (CIMIS) weather stations. $ET_o$ provides a means of estimating actual crop evapotranspiration over time for each field. Based on review of nearby weather stations with data available during the period of analysis, the Porterville station (169) was selected based on it being relatively close to the Kaweah Subbasin, at a similar elevation to the Kaweah Subbasin, having relatively good fetch, and having available data for the majority of the analysis period.

Individual parameters from the available data including incoming solar radiation, air temperature, relative humidity, and wind speed were quality-controlled according to the procedures of Allen et al. (2005). The quality-controlled data were then used to calculate daily $ET_o$ for the available period of record.

CIMIS data for Porterville were not available prior to August 2000. As a result, it was necessary to estimate $ET_o$ for the period from October 1, 1998 to August 1, 2000. $ET_o$ for Porterville was estimated by developing a linear regression to estimate Porterville $ET_o$ using quality-controlled data from the Stratford CIMIS station for the period of overlapping data availability.

## *3.7 Estimation of Root Zone Water Balance Parameters*

Root zone parameters that influence the amount of available soil moisture storage were estimated based on crops and soils present in the Kaweah Subbasin. Crop parameters of interest include root depth, NRCS curve number[6], and management allowable depletion (MAD). Root depth was estimated by crop group based on published values and a representative mix of individual crops within each crop group for the Kaweah Subbasin. Curve numbers were estimated based on values published in the NRCS National Engineering Handbook, which provides estimates based on crop type and condition. MAD values by crop were estimated based on values published in FAO Irrigation and Drainage Paper No. 56 (Allen et al., 1998).

Soil hydraulic parameters of interest include field capacity (% by vol.), wilting point (% by vol.), saturated hydraulic conductivity (ft/day), total porosity (% by vol.), and the pore size distribution index (λ, dimensionless). These parameters were estimated by first determining the depth-weighted average soil texture (sand, silt, clay, etc.) based on available NRCS soil surveys. Then, the hydraulic parameters were estimated using hydraulic pedotransfer functions developed by Saxton and Rawls (2006). Next, hydraulic parameters were adjusted within reasonable physical ranges for each soil texture so that the modeled time required for water to drain by gravity from saturation to field capacity agreed with typically accepted agronomic values. Unsaturated hydraulic conductivity (e.g. deep percolation) within the root zone was modeled based on the equation developed by Campbell (1974) for unsaturated flow.

# 4 Results

## *4.1 Crop Evapotranspiration*

Estimated annual crop evapotranspiration volumes for fields with their centroid within the Kaweah Subbasin are shown in Figure 4.1. Estimated volumes of ET derived from applied water (ETaw) and precipitation (ETpr) are shown in thousands of acre-feet (taf). Annual ETaw ranged from 721 taf to 916 taf, with an average of 817 taf. Annual ETpr ranged from 87 taf to 260 taf, with an average of 174 taf. Total crop ET ranged from 899 taf to 1,056 taf, with an average of 991 taf.

[6] The curve number runoff estimation method developed the Natural Resources Conservation Service (NRCS) was used to estimate runoff from precipitation in the model. For additional information, see NRCS NEH Chapter 2 (NRCS, 1993).

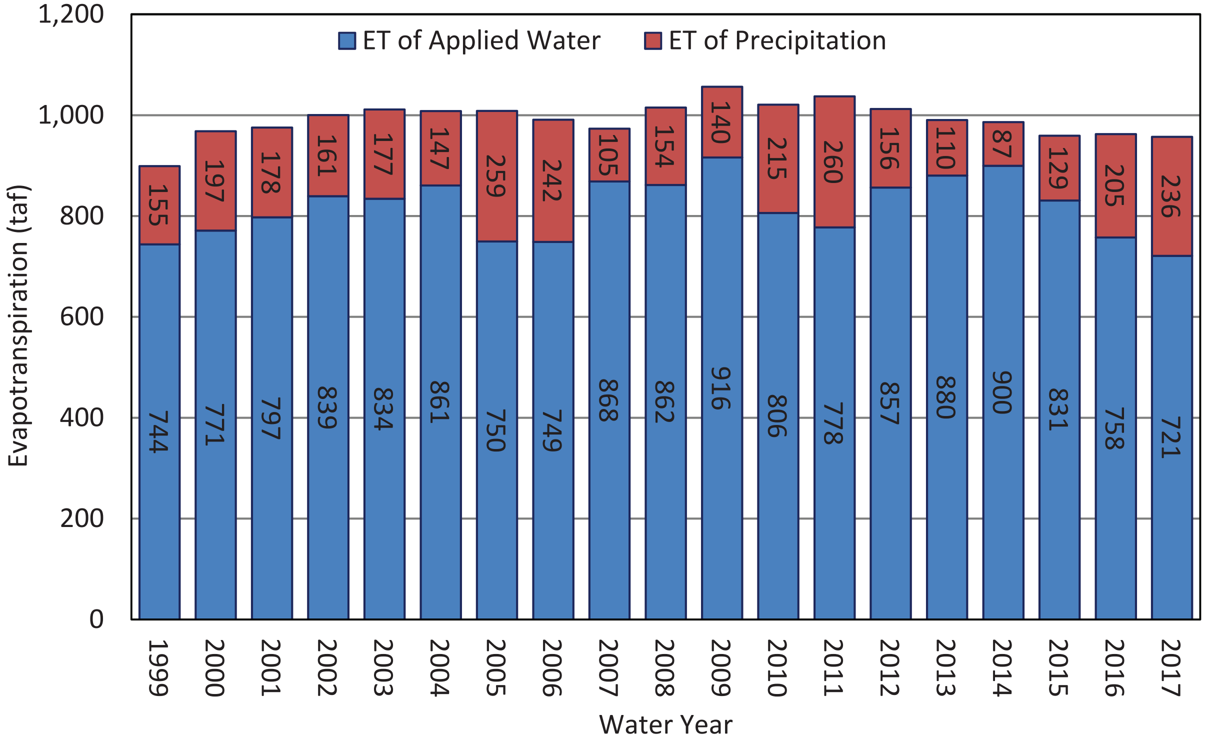


**Figure 4.1. Kaweah Subasin Crop ET by Water Year**

## *4.2 Irrigation Demands*

Annual estimated irrigation demands for fields with their centroid within the Kaweah Subbasin are shown in Figure 4.2 in thousands of acre feet. Annual demands ranged from 948 taf to 1,149 taf, with an average of 1,042 taf.

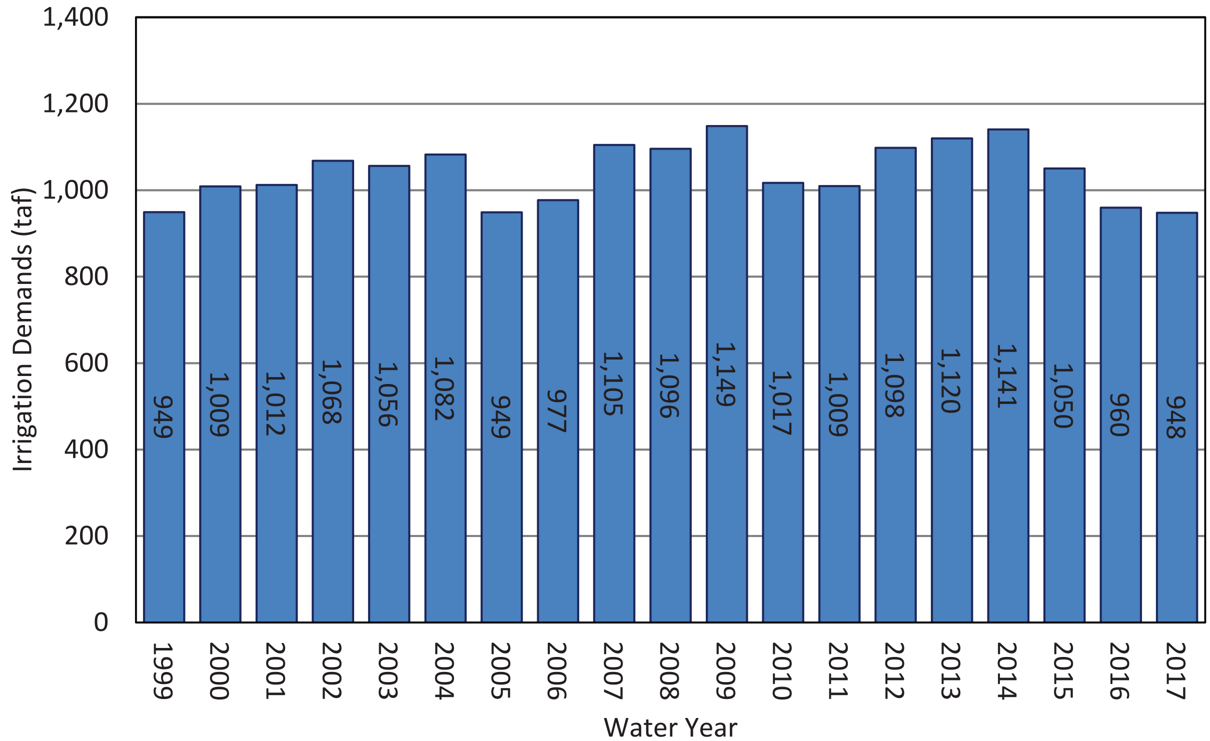


**Figure 4.2. Kaweah Subasin Irrigation Demands by Water Year**

## *4.3 Deep Percolation*

Estimated annual deep percolation volumes for fields with their centroid within the Kaweah Subbasin are shown in Figure 4.3. Estimated volumes of deep percolation derived from applied water (DPaw) and precipitation (DPpr) are shown in thousands of acre-feet. Annual DPaw ranged from 208 taf to 242 taf, with an average of 227 taf. Annual DPpr ranged from 24 taf to 130 taf, with an average of 60 taf. Total deep percolation ranged from 255 taf to 372 taf, with an average of 287 taf.

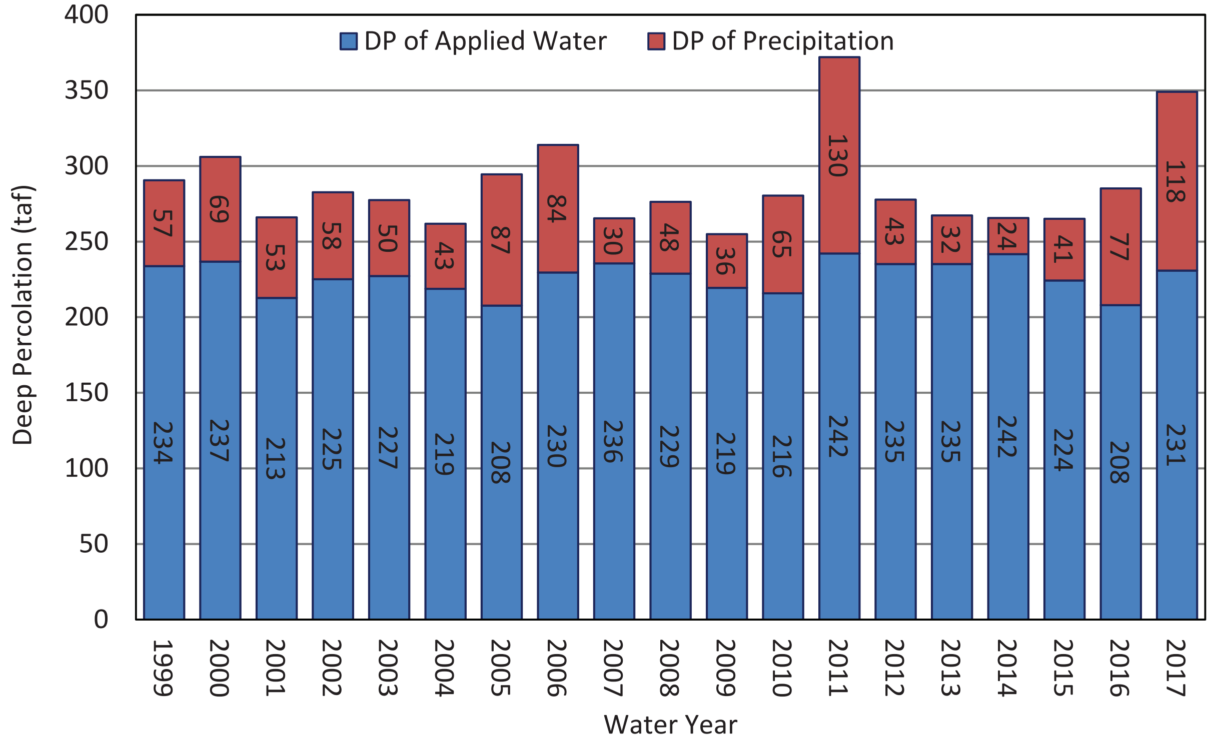


**Figure 4.3. Kaweah Subasin Deep Percolation by Water Year**

### *4.4 Annual Evapotranspiration by Crop for 2014*

Estimated annual average evapotranspiration by crop is shown in Figure 4.4, along with the estimated acreage for each crop. Figure 4.4 shows the estimated average total ET by crop in inches in 2014. Average ET ranges from 7 inches for miscellaneous grain and hay to 49 inches for walnuts. The primary crops are corn, citrus, alfalfa and walnuts, representing 82, 60,40, and 31 thousand acres, respectively.

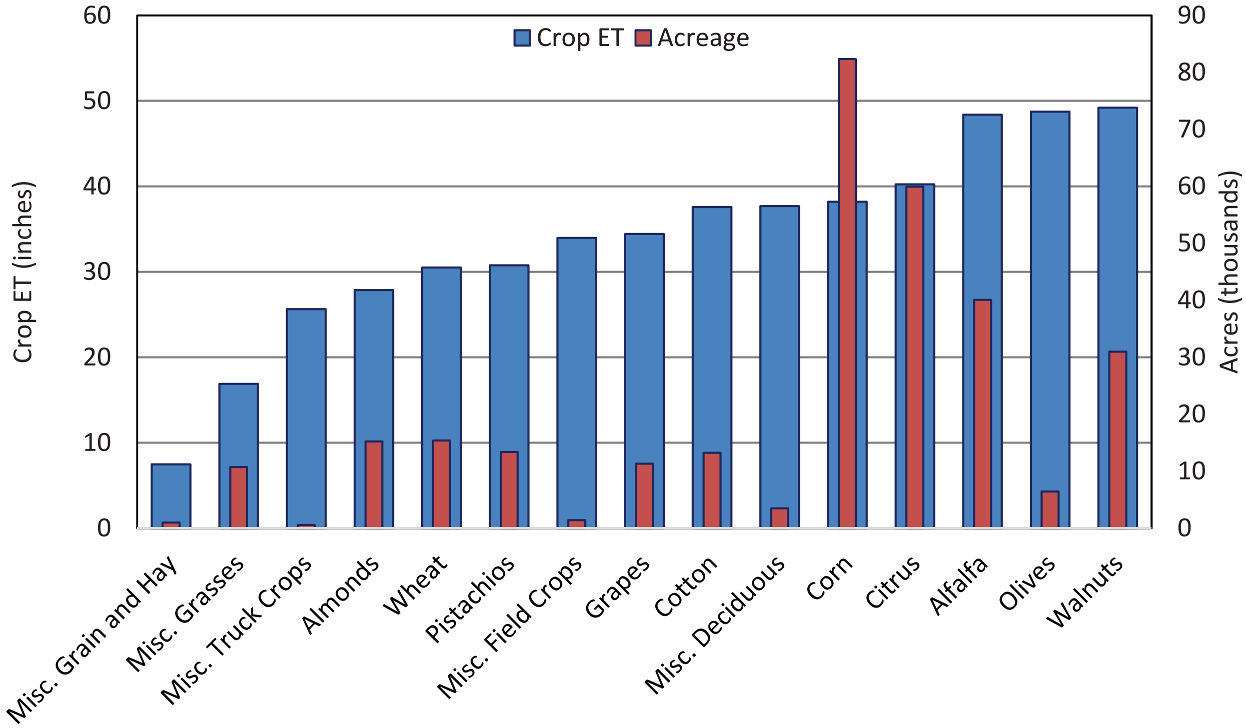


**Figure 4.4. Kaweah Subasin 2014 Average ET by Crop and Crop Acreage**

Additional monthly plots of $ET_{oF}$, $ET_a$ and AW by crop for 2014 can be found in the appendix.

# 5 References

Allen, R.G, L.S. Pereira, D. Raes, and M. Smith. 1998. Crop Evapotranspiration - Guidelines for Computing Crop Water Requirements. FAO Irrigation and Drainage Paper 56. FAO. Rome, Italy.

Davids Engineering. 2013. Time Series Evapotranspiration and Applied Water Estimates from Remote Sensing. Kaweah Delta Water Conservation District. http://www.kdwcd.com/wp-content/uploads/2018/07/KDWCD-NDVI-ET-Analysis-FINAL-REPORT-March-2013.pdf

NRCS. 1993. Chapter 2 - Watershed Project Evaluation Procedures. National Engineering Handbook Part 630, Hydrology.

Saxton, K.E. and W.J. Rawls. 2006. Soil Water Characteristic Estimates by Texture and Organic Matter for Hydrologic Solutions. Soil Sci. Soc. Am. J. 70:1569–1578.

# 6 Appendix

This appendix includes the following figures:

- Average monthly crop water use coefficients or “fraction of reference ET” (EToF) by crop, along with error bars depicting the standard deviation among fields.
- Average monthly crop ET by crop, along with error bars depicting the standard deviation among fields.
- Average monthly applied water by crop, along with error bars depicting the standard deviation among fields.

## *EToF 2014*

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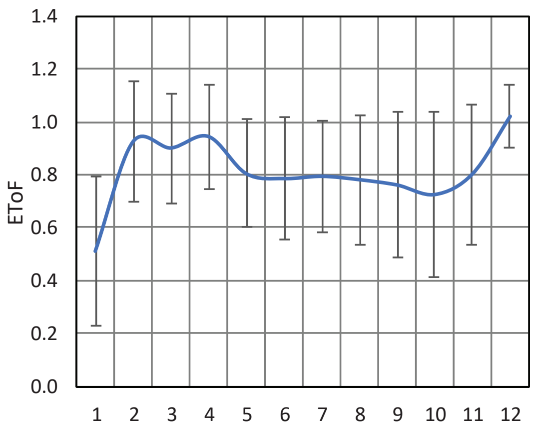


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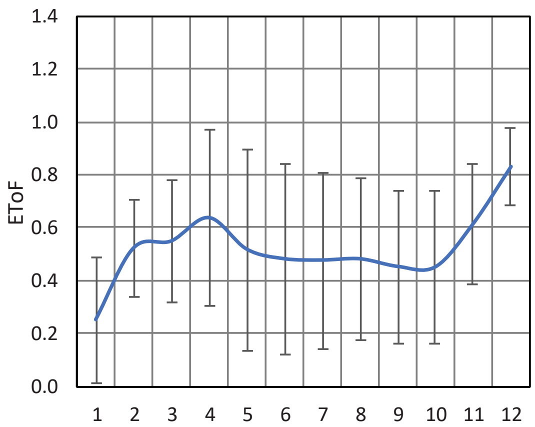


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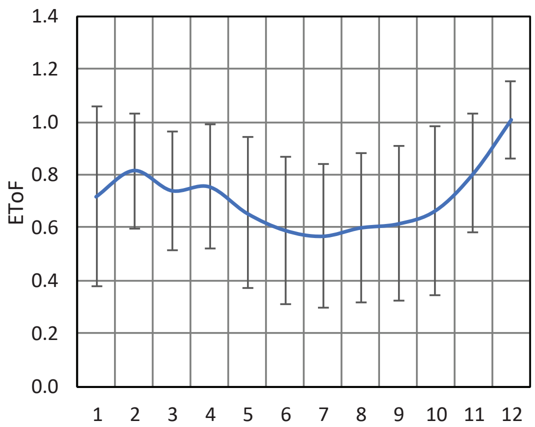


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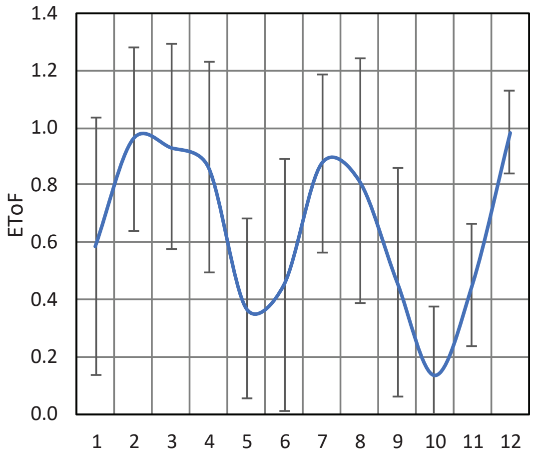
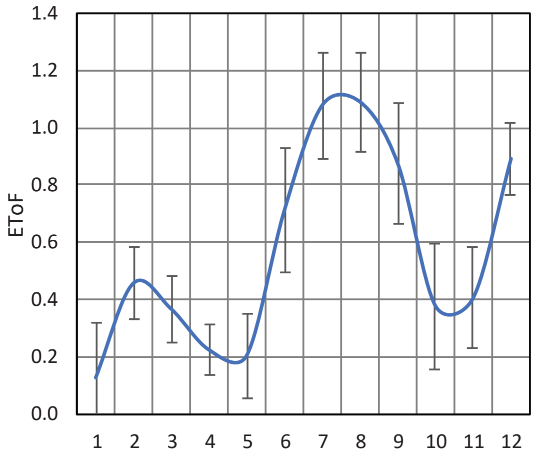
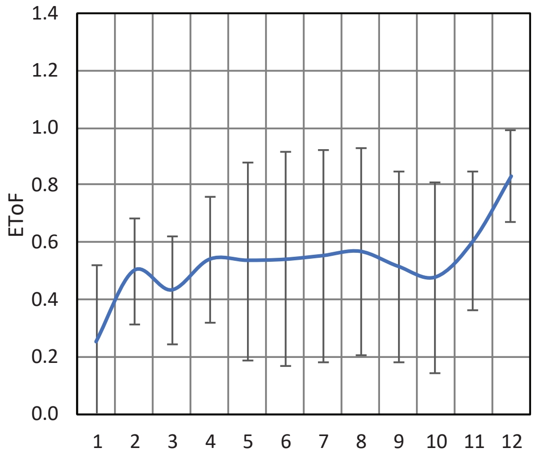



Cotton




Grapes



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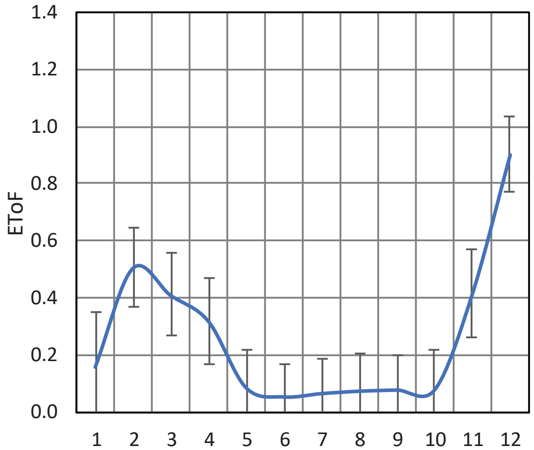


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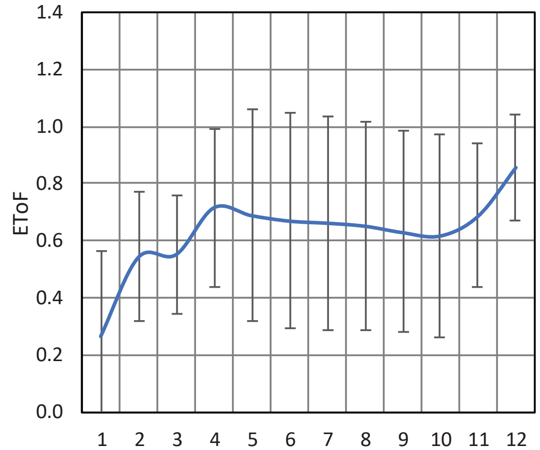


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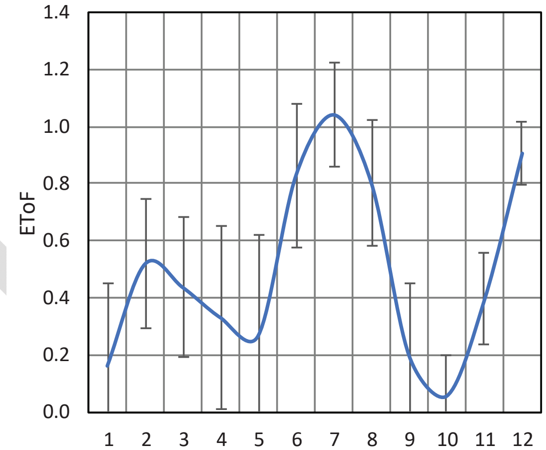


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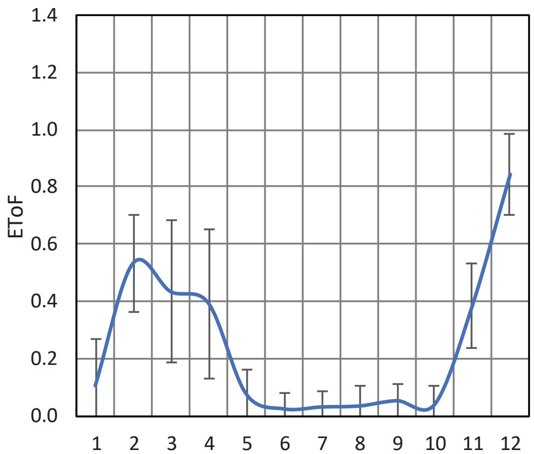


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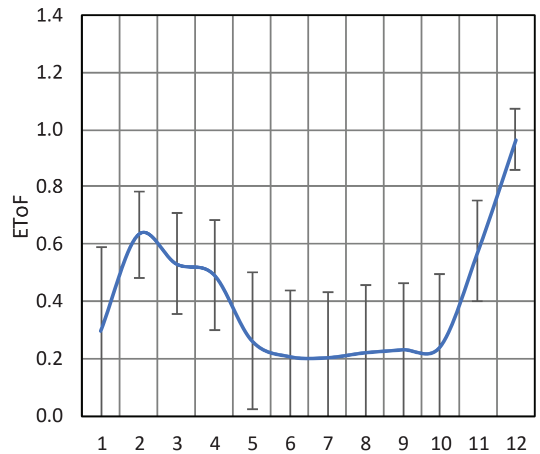


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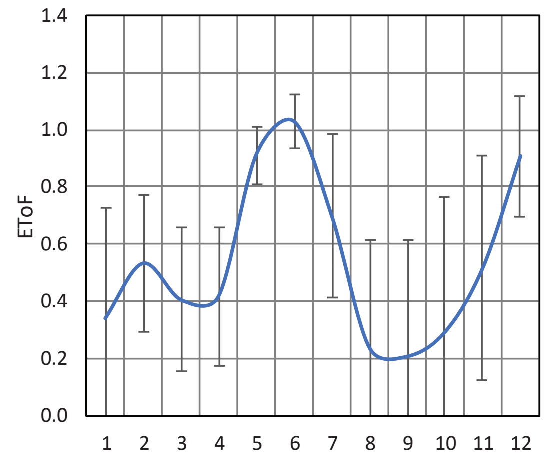

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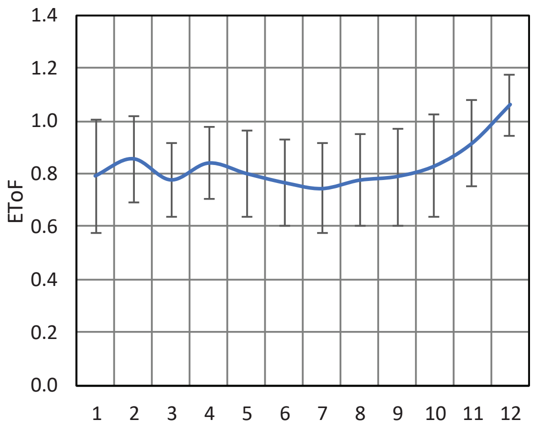


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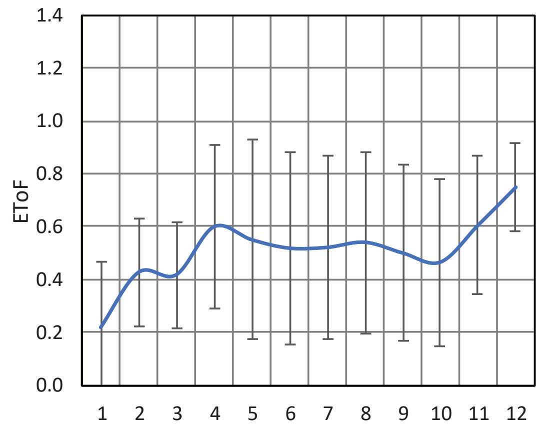


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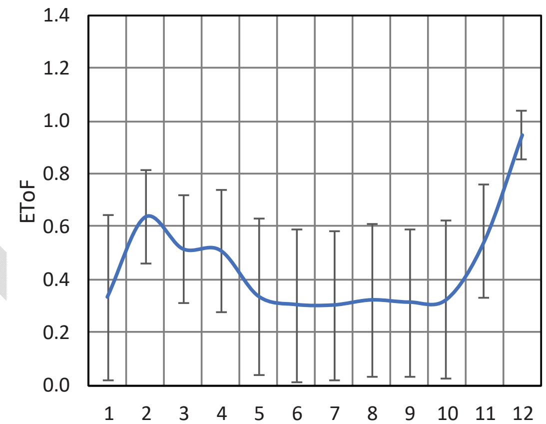


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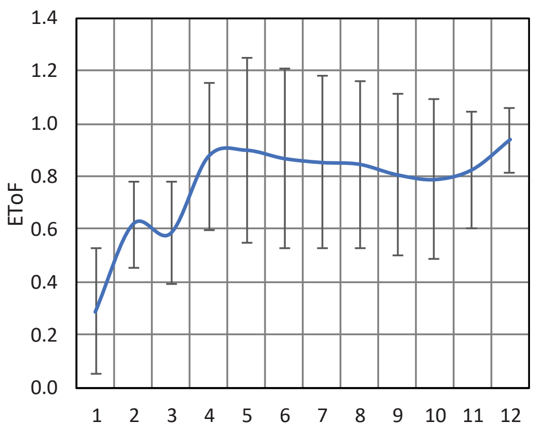


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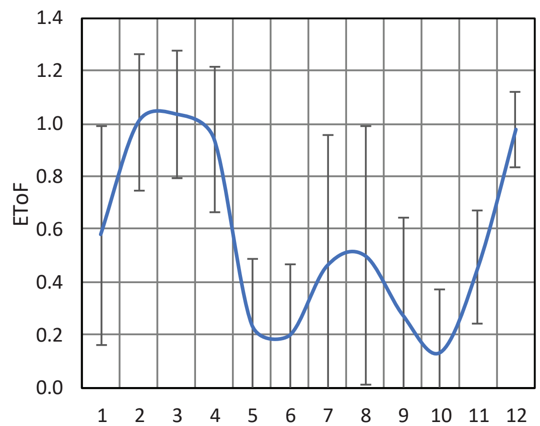

## *ETc 2014*

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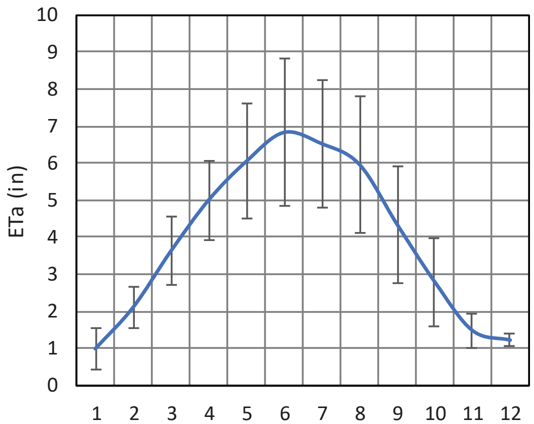


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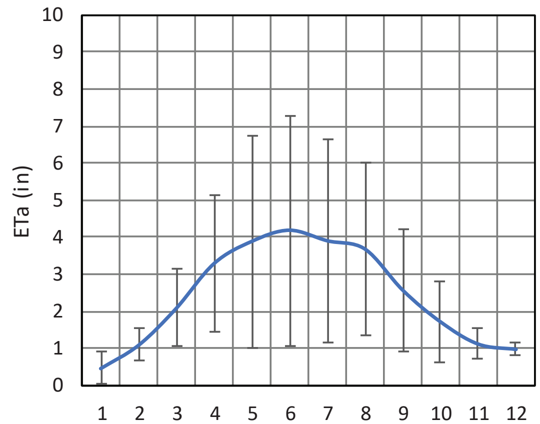


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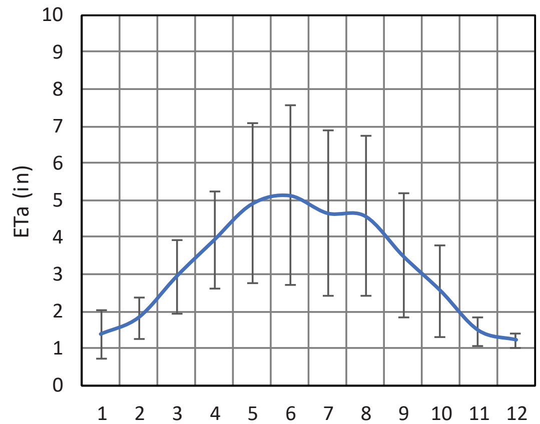


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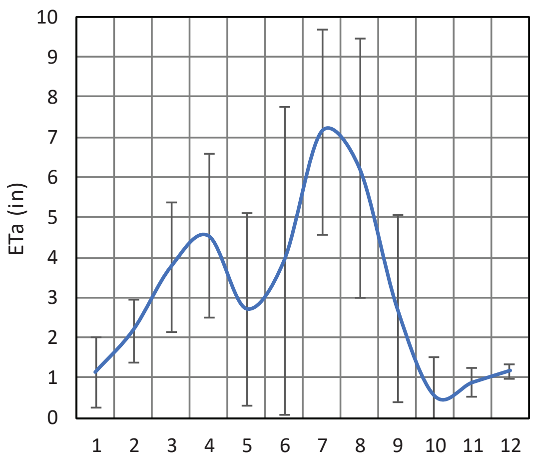


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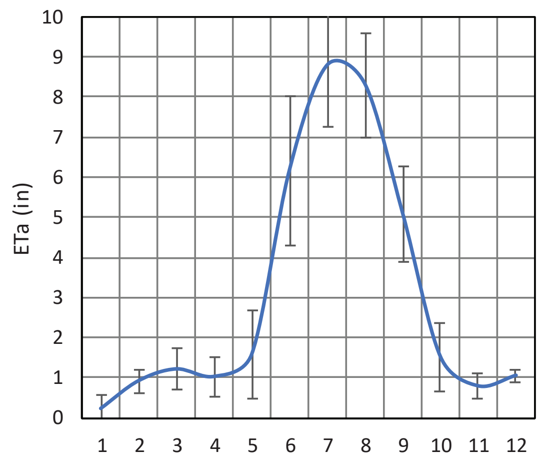


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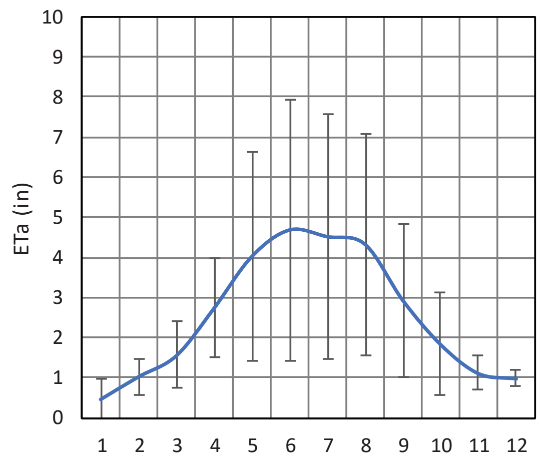

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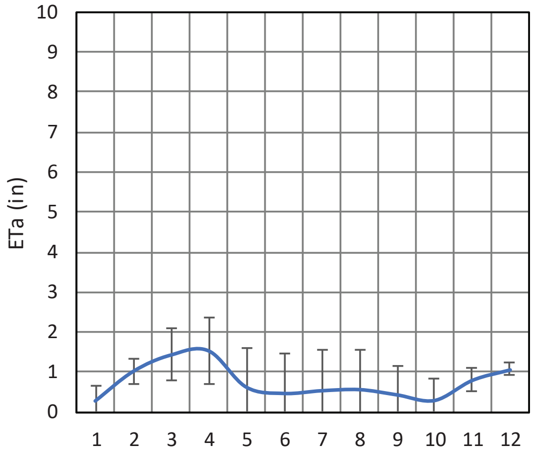


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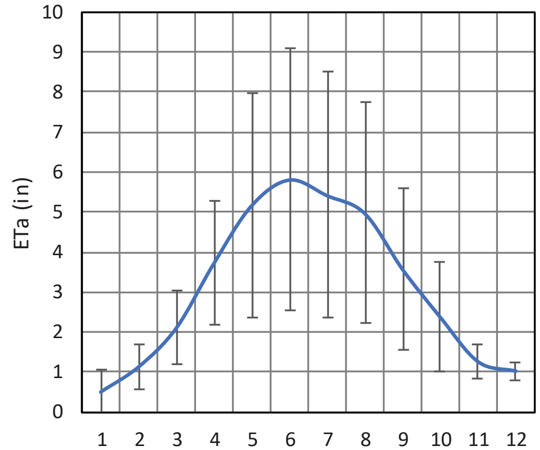


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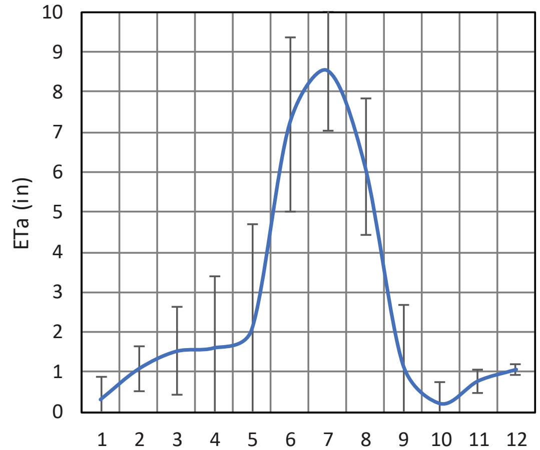


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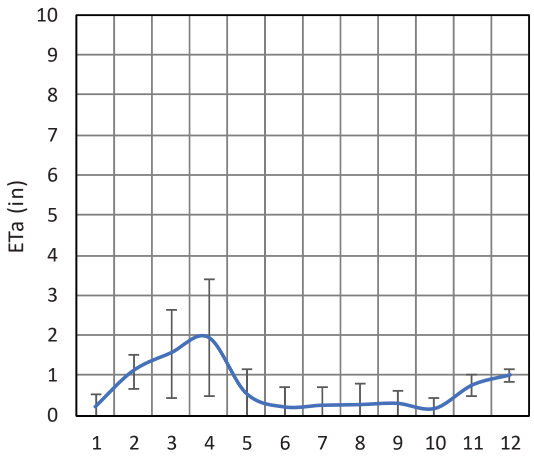


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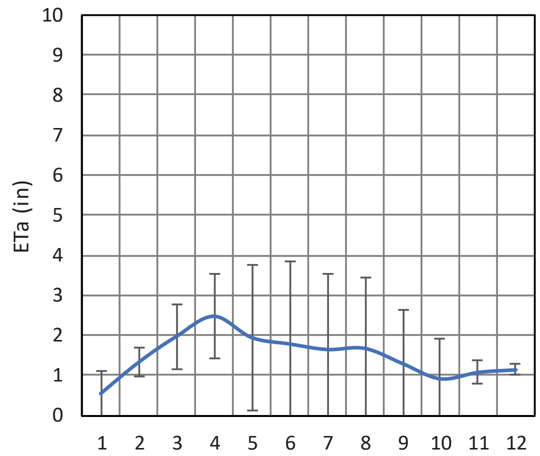


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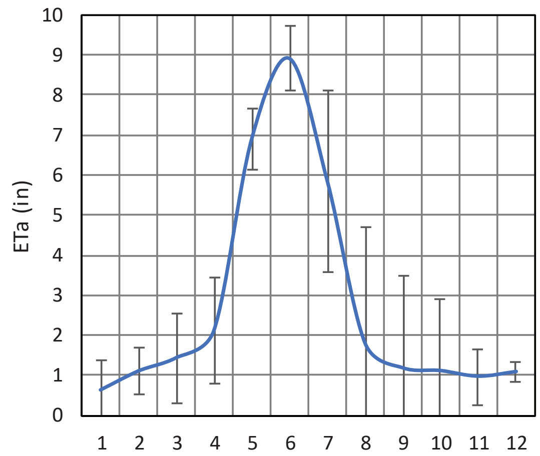

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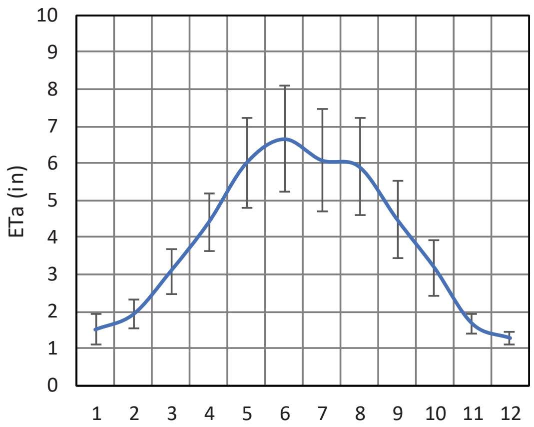


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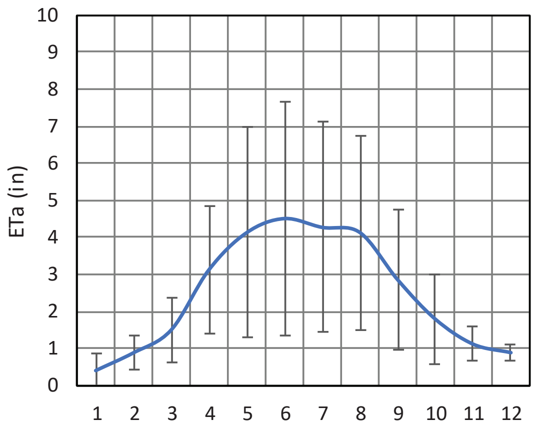


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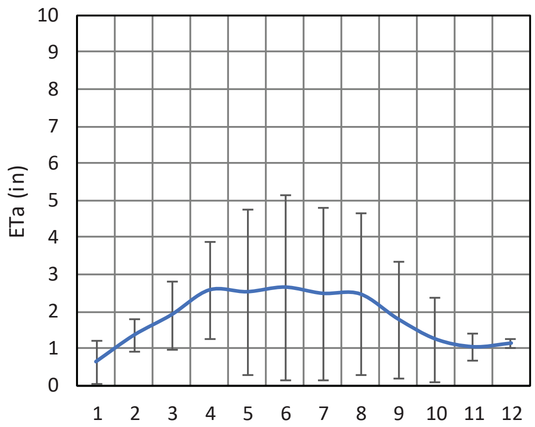


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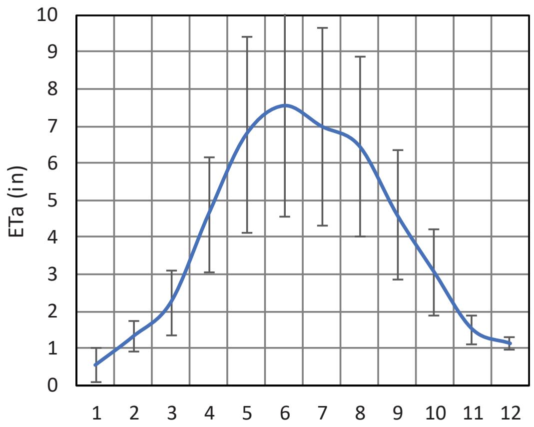


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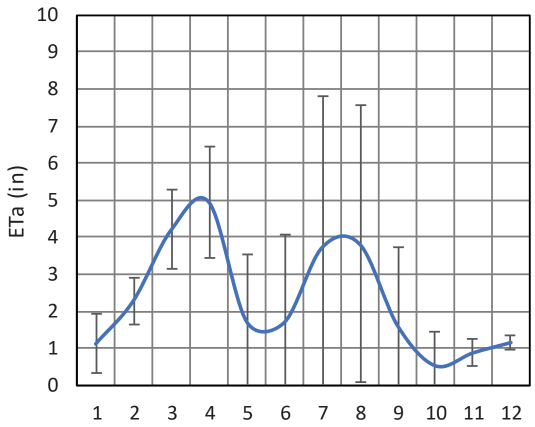

## *AW 2014*

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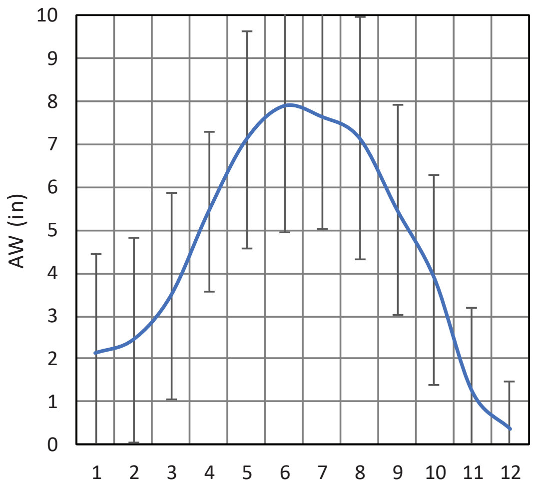


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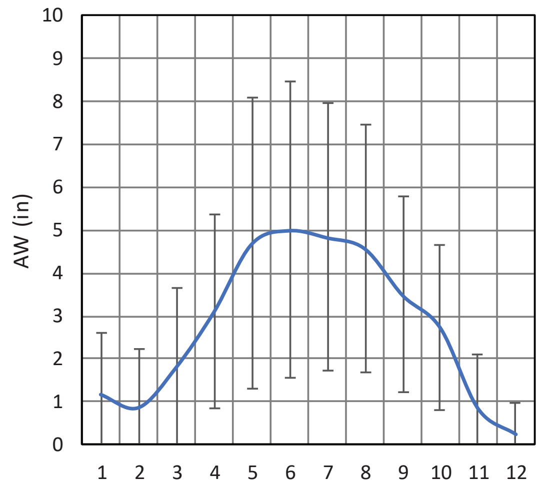


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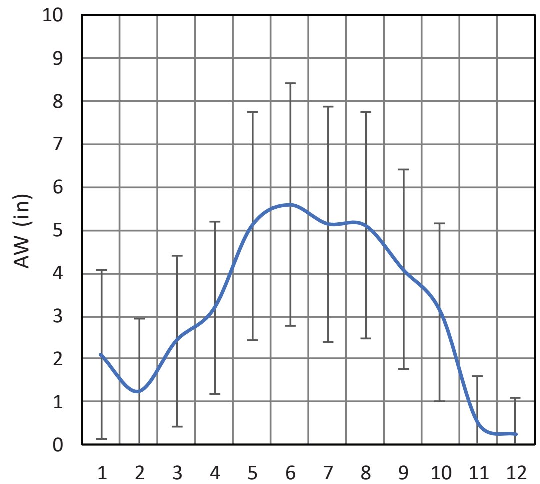


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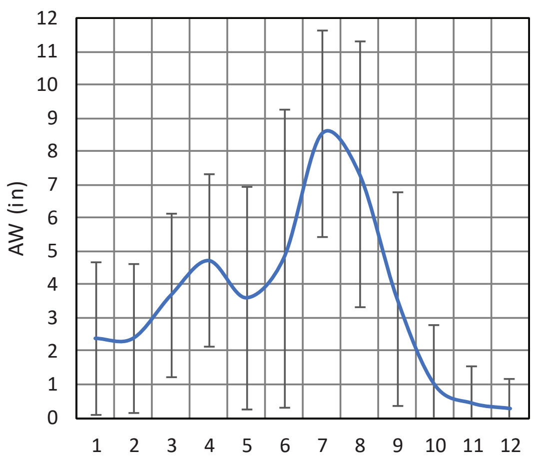


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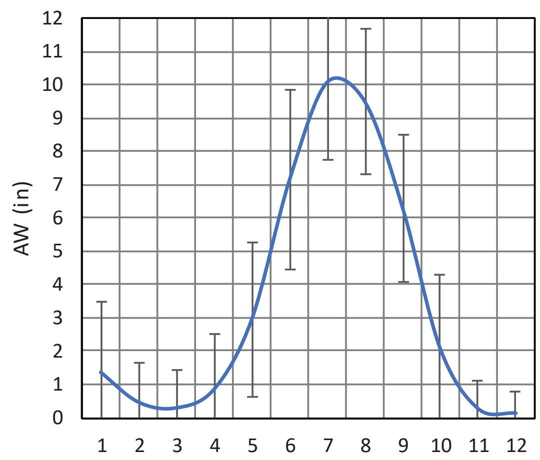


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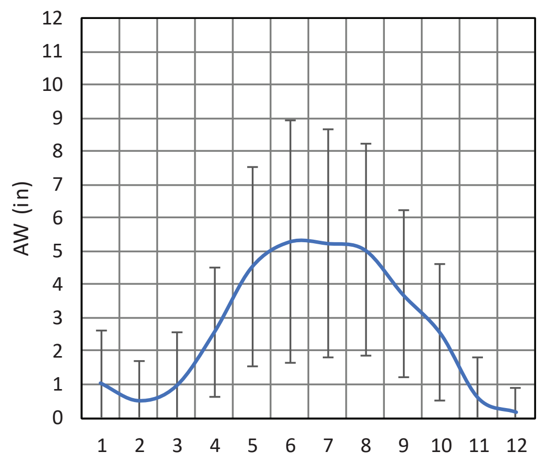

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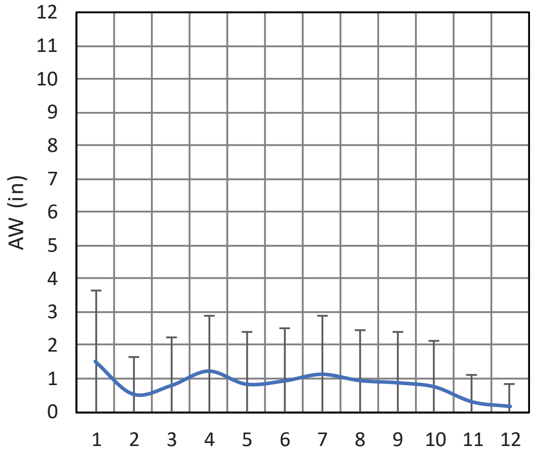


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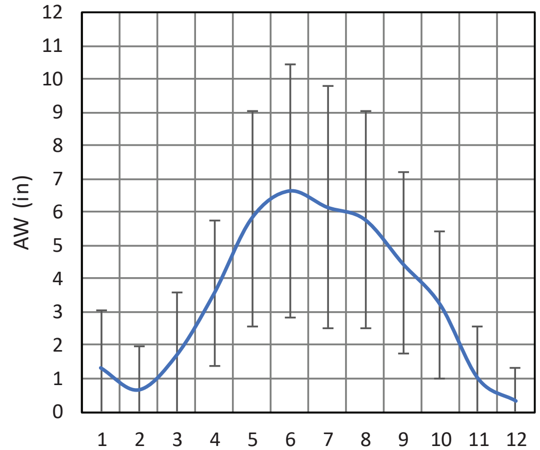


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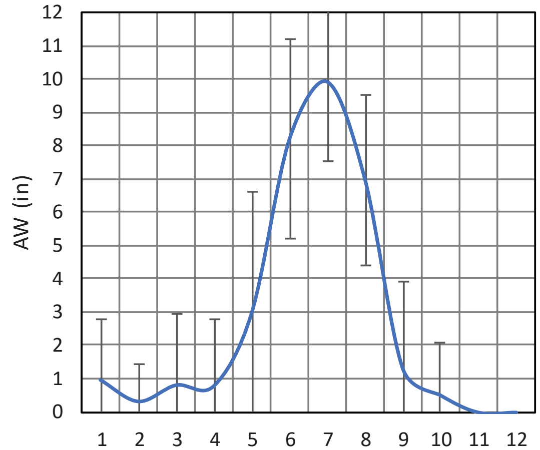


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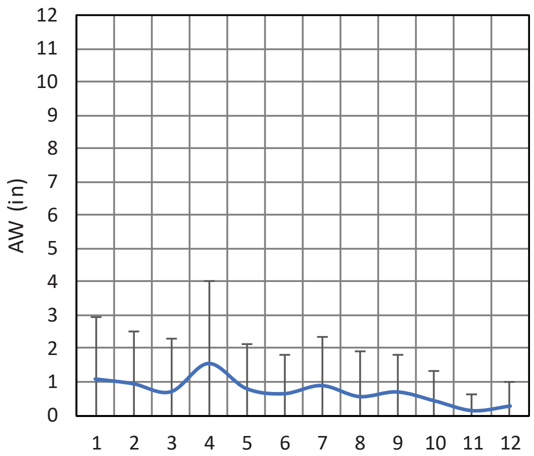


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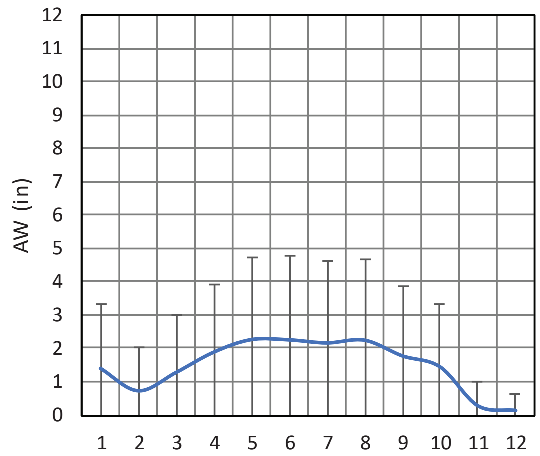


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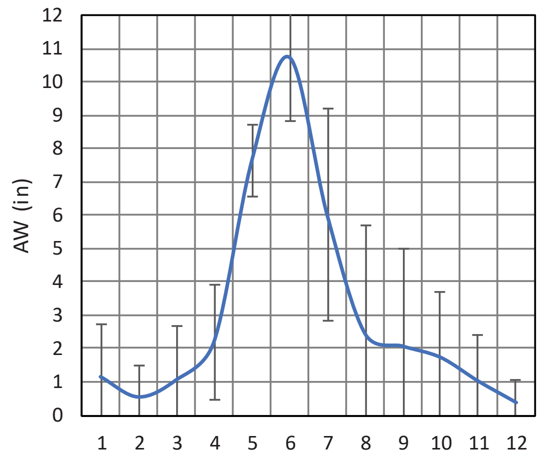

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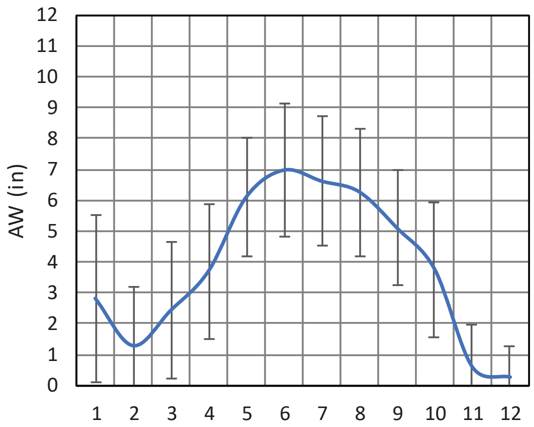


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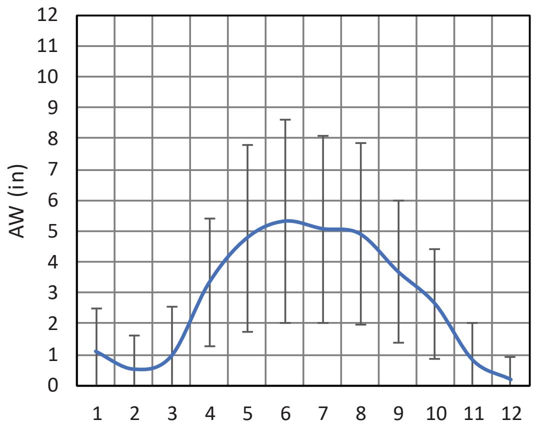


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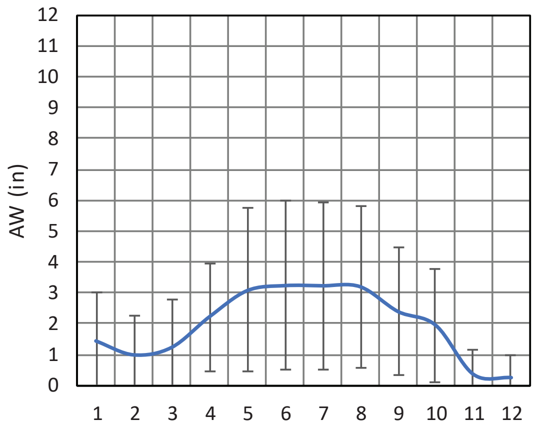


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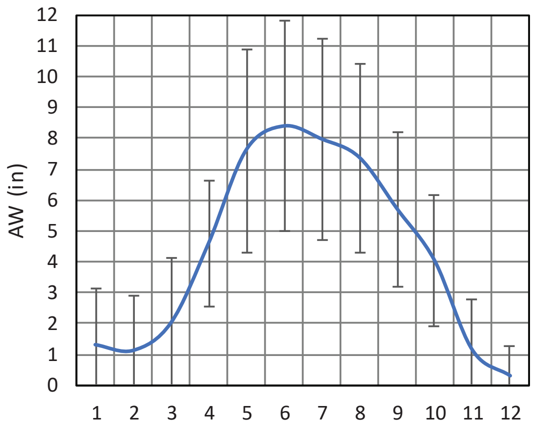


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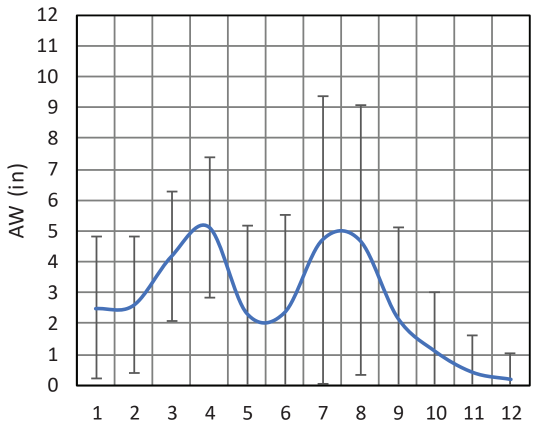

# Appendix D

## Friant Water Authority

## Future Water Supply Study

Friant
WATER AUTHORITY

# Technical Memorandum

## Estimate of Future Friant Division Supplies for use in Groundwater Sustainability Plans, California

# CONTENTS



# FIGURES



# TABLES

# ACRONYMS

| | |
|---|---|
| CFS | cubic feet per second |
| CVP | Central Valley Project |
| CWC | California Water Commission |
| DEW | Drier/Extreme Warming |
| DWR | California Department of Water Resources |
| GSA | Groundwater Sustainability Agency |
| Friant | Friant Water Authority |
| Friant Contractors | Friant Division long-term contract holders |
| PEIS/R | Program Environmental Impact Statement/Report |
| Reclamation | U.S. Department of the Interior, Bureau of Reclamation |
| RWA | Recovered Water Account |
| SGMA | Sustainable Groundwater Management Act |
| SJRRP | San Joaquin River Restoration Program |
| SJRRS | San Joaquin River Restoration Settlement |
| SWP | State Water Project |
| TAF | thousand acre-feet |
| TM | Technical Memorandum |
| WMW | Wetter, Moderate Warming |
| WSIP | Water Supply Investment Program |

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# BACKGROUND

The Friant Water Authority (Friant) was approached by several Groundwater Sustainability Agencies (GSAs) for information about future water supply availability from the Central Valley Project (CVP) Friant Division. Those GSAs include the following, who were subsequently engaged during the development of analysis to meet their request:

- Mid-Kaweah GSA, represented by Paul Hendrix
- White Wolf Sub-basin GSA, represented by Jeevan Muhar
- Kern Groundwater Authority, represented by Terry Erlewine

This Technical Memorandum (TM) was prepared for use by those GSAs and others, in accordance with the expectations set by the Friant Board of Directors in their 2016 Strategic Plan to provide “accurate and up-to-date data needed to manage water supplies through modeling and data collection.”

This TM presents five scenarios that were intended to represent a range of potential water supply conditions for the Friant Division through the end of the century, all of which were assembled from existing studies that were recently conducted using the CalSim-II computer model. These scenarios were assembled from pre-existing model runs and analysis and have been compiled and reviewed by Friant for use or consideration in plans developed by GSAs that receive Friant Contract surface water deliveries. The selected scenarios are summarized below and organized by their identification name in the accompanying “Summary_FutureFriantSupplies_Final” spreadsheet file.

1. **Model Run 2015.c (‘‘2015.c’’)** was designed to represent current conditions, where implementation of the San Joaquin River Restoration Settlement (SJRRS) is limited by downstream capacity limitations and the climate and hydrology are assumed to be most similar to historical hydrologic conditions.

2. **‘‘2030.c’’** was designed to represent near future climate conditions centered around 2030 and uses California Department of Water Resources (DWR’s) central tendency climate projection. This scenario assumes implementation of the SJRRS, as described in the Reclamation’s Funding Constrained Framework for Implementing the SJRRS (SJRRP, 2018).

3. **‘‘2070.c’’** was designed to represent far-future climate conditions centered around 2070 and uses DWR’s central tendency climate projection. This scenario assumes implementation of the SJRRS, as described in the Reclamation’s Funding Constrained Framework for Implementing the SJRRS (SJRRP, 2018).

4. **‘‘DEW.c’’** was included in this TM for completeness, as it represents an extreme climate condition (being: Drier/Extreme Warming, “DEW”) that was produced by DWR for planning studies. The DEW scenario was developed by DWR as a means of bracketing the range of potential future climate conditions by 2070, which are highly uncertain. This scenario was modeled with implementation of the SJRRS, as described in the Reclamation’s Funding Constrained Framework for Implementing the SJRRS (SJRRP, 2018).

5. **‘‘WMW.c’’** was included in this TM for completeness, as it represents an extreme climate condition (being: Wetter/Moderate Warming, “WMW”) that was produced by DWR for planning studies. The WMW scenario was developed by DWR as a means of bracketing the range of potential future climate conditions by 2070, which are highly uncertain. This scenario was modeled with implementation of the SJRRS, as described in the Reclamation’s Funding Constrained Framework for Implementing the SJRRS (SJRRP, 2018).

For questions, clarifications, or suggestions that will improve this TM or its application with the implementation of the Sustainable Groundwater Management Act (SGMA) for planning purposes, please contact Jeff Payne, Director of Water Policy at jpayne@friantwater.org

# STUDY SETTING

The Friant Division includes storage for waters of the San Joaquin River at Friant Dam (Millerton Lake), as well as conveyance and delivery facilities through the Friant-Kern and Madera canals that deliver water to 32 Friant Division long-term contract holders (Friant Contractors) and other water users. Figure 1 shows the location of the Friant Contractors in the San Joaquin Valley. Friant Contractors all have access to waters of the San Joaquin River through their contracts with Reclamation. However, most Friant Contractors have other supplies that include groundwater and surface water supplies that are local to their geography.

Combined, the facilities of the Friant Division span over 180 miles, crossing seven rivers, and conveying water between 16 GSAs as shown in Figure 2. All the basins connected by the Friant Division and its facilities are considered by DWR to be “critically overdrafted” and therefore are each a “high priority” for the implementation of SGMA. Table 1 lists the Friant Contractors with lands overlapping a GSA and 2014 Friant Contractor irrigated lands. A Friant Contractor may appear in more than one GSA. The 2014 irrigated acreage was obtained from remote sensing from DWR (DWR, 2017). Friant Division M&I contractors were assumed to have no agricultural demand. Kaweah-Delta Water Conservation District agricultural demands were not estimated in this analysis. Any agricultural demand within City of Fresno is represented as part of the Fresno Irrigation District.


*Figure 1: Location of Friant Contractors in the San Joaquin Valley*

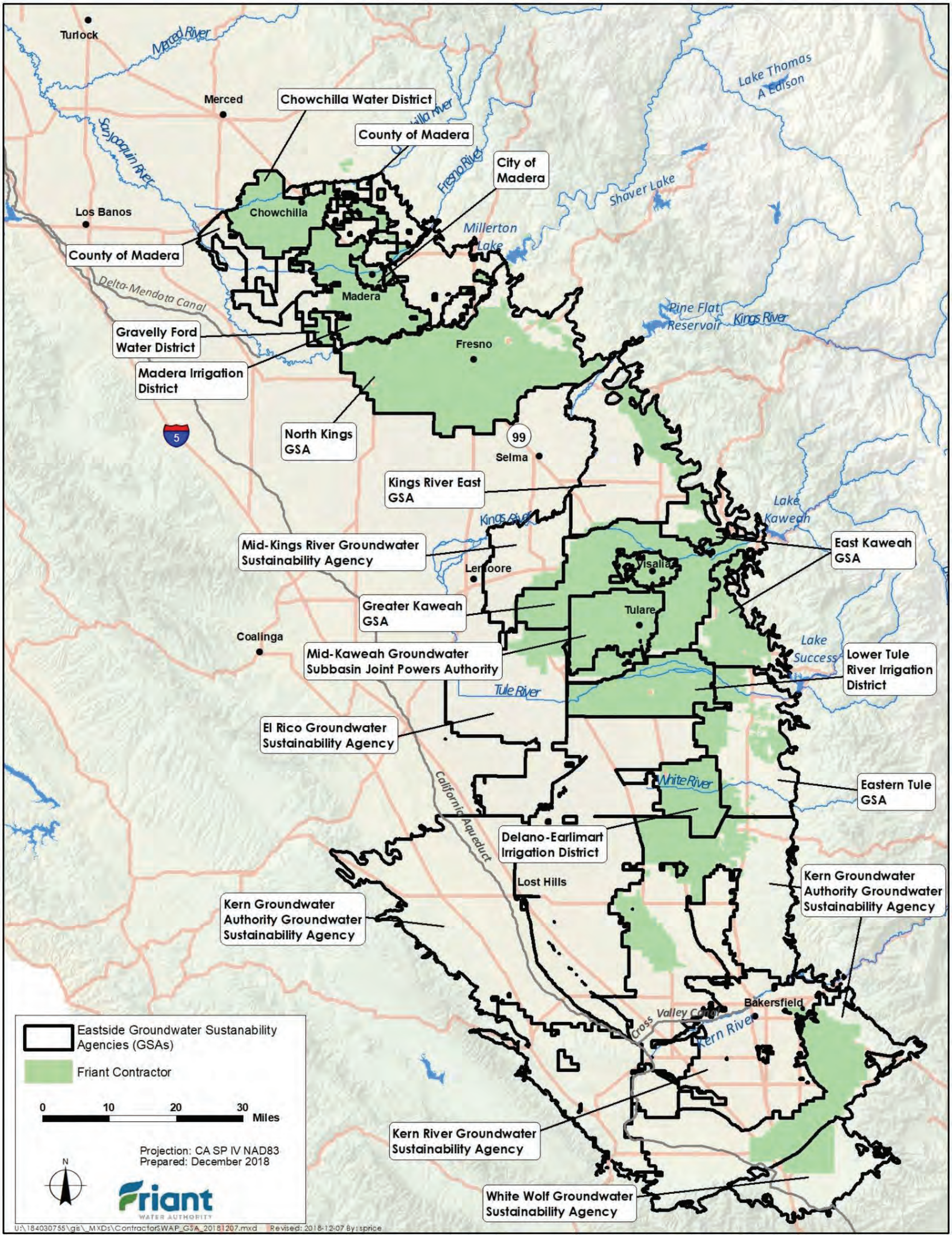



*Figure 2: Location of Friant Contractors relative to GSAs*

**Table 1. Friant Contractors and Estimated Irrigated Acreage relative to GSAs (DWR, 2017)**

| GROUNDWATER SUSTAINABILITY AGENCY | FRIANT CONTRACTOR[1] | FRIANT CONTRACTOR IRRIGATED LAND[2] (ACRES) |
|---|---|---|
| Chowchilla Water District | Chowchilla Water District | 67,170 |
| City of Madera | Madera Irrigation District | 910 |
| County of Madera | Chowchilla Water District | 30 |
| | Madera Irrigation District | 90 |
| Gravelly Ford Water District | Gravelly Ford Water District | 7,490 |
| Madera Irrigation District | Madera Irrigation District | 100,360 |
| North Kings GSA | Fresno Irrigation District[3] | 128,330 |
| | Garfield Water District | 1,160 |
| | International Water District | 540 |
| Kings River East GSA | Hills Valley Irrigation District | 2,830 |
| | Orange Cove Irrigation District | 24,360 |
| | Tri-Valley Water District | 1,040 |
| Mid-Kings River GSA | Kaweah Delta Water Conservation District[2] | NE |
| East Kaweah GSA | Exeter Irrigation District | 10,580 |
| | Ivanhoe Irrigation District | 9,630 |
| | Lewis Creek Water District | 1,010 |
| | Lindmore Irrigation District | 22,760 |
| | Lindsay - Strathmore Irrigation District | 10,880 |
| | Lower Tule River Irrigation District | 80 |
| | Stone Corral Irrigation District | 5,980 |
| Greater Kaweah GSA | Exeter Irrigation District | 500 |
| | Ivanhoe Irrigation District | 30 |
| | Kaweah Delta Water Conservation District[4] | NE |
| | Tulare Irrigation District | 60 |
| Mid-Kaweah Groundwater Subbasin Joint Powers Authority | Tulare Irrigation District | 58,160 |
| El Rico GSA | Kaweah Delta Water Conservation District[4] | NE |
| Lower Tule River Irrigation District | Lower Tule River Irrigation District | 80,480 |
| | Porterville Irrigation District | 70 |
| Eastern Tule GSA | Kern - Tulare Water District | 8,480 |
| | Porterville Irrigation District | 12,470 |
| | Saucelito Irrigation District | 18,060 |
| | Tea Pot Dome Water District | 3,090 |
| | Terra Bella Irrigation District | 9,110 |
| Delano - Earlimart Irrigation District | Delano - Earlimart Irrigation District | 49,960 |
| Kern Groundwater Authority GSA | Arvin - Edison Water Storage District | 84,280 |
| | Kern-Tulare Water District | 14,500 |
| | Shafter - Wasco Irrigation District | 30,190 |
| | Southern San Joaquin Municipal Utility District | 45,190 |
| Kern River GSA | Arvin - Edison Water Storage District | 190 |
| White Wolf GSA | Arvin - Edison Water Storage District | 20,830 |

Key:
GSA = Groundwater Sustainability Agency
NE = Not estimated
Notes:
[1]Only Friant Contractors with agricultural demands shown per GSA, Friant M&I contractors were assumed to have no agricultural demand.
[2] Irrigated lands rounded to nearest 10 acres
[3]Any agricultural lands within City of Fresno is represented as part of the Fresno Irrigation District
[4]Kaweah-Delta Water Conservation District agricultural lands were not estimated

# PREVIOUS STUDIES AND REPORTS

The potential range of future Friant Division water supplies from the San Joaquin River have been studied for several recent efforts. This TM relies on computer models, assumptions, and analysis that were initially developed for and reported by the following:

- San Joaquin River Restoration Settlement, and Program (SJRRS and SJRRP)
  - Settlement Agreement (2006)
  - Program Environmental Impact Statement/Report (PEIS/R; Reclamation, 2009)
- Temperance Flat Reservoir studies, including:
  - Federal Feasibility Study (Reclamation, ongoing)
  - Application to California Proposition 1, Water Storage Investment Program (Temperance Flat Reservoir Authority, 2017)

# FACTORS AFFECTING FRIANT SUPPLIES THROUGH YEAR 2100

Beyond the natural variability of annual precipitation in the headwaters of the San Joaquin River, several drivers are expected to greatly influence the water supplies of the Friant Division over the coming century. These include:

1. **Changes in the climate and hydrology**: These changes include a warming trend that is expected to reduce winter snow accumulation and hasten spring melt and runoff. Five climate conditions are considered in this report.
2. **Implementation of the SJRRS Restoration Goal:** The SJRRS Restoration Goal is currently limited in its implementation but is expected to be fully implemented by 2030, with the completion of river conveyance enhancements below Friant Dam. When completed, the impact of the SJRRS on Friant Contractor supplies will reach the extent anticipated in the SJRRS.
3. **Implementation of the SJRRS Water Management Goal**: The SJRRS Water Management Goal provides for several mechanisms to reduce or avoid water supply impacts on Friant Contractors. The water supply benefits of two SJRRS provisions are quantified in this analysis, being those described in Paragraphs 16(a) (i.e., recapture and recirculation) and 16(b) (i.e., water sold at $10 per acre foot during wet conditions).
   - Paragraph 16(a) is restricted at this time, being limited to the recapture of flows that can be released from Friant Dam. As implementation of the Restoration Goal progresses, so will recapture and recirculation.
   - Paragraph 16(b) is currently underutilized. At the time of the Settlement, a fixed $10 per acre foot price for wet year supplies was expected to stimulate investments in groundwater infiltration facilities. With subsequent water supply challenges imposed by SGMA on the Eastern San Joaquin Valley, the regional appetite for groundwater infiltration has grown dramatically. At this time, Friant Contractors anticipate considerable interest and ability to divert and infiltrate flows that may have spilled from Friant Dam under historical conditions. The upper end of implementation of 16(b) is expected to occur before 2030.

The technical representations of these conditions were taken from previous studies and reports, in the manner described below.

## INVENTORY OF MODEL SIMULATIONS PERFORMED

This report presents simulated operations that account for five climate conditions and the eventual full implementation of SJRRS Restoration and Water Management goals. Table 2 identifies 15 individual modeling runs compiled for this TM, along with the major assumptions for each.

The reader should note that each of the five climate conditions contain three model runs, denoted with a suffix of “a”, “b”, and “c”. To calculate the Restoration Goal for each of these climate conditions, model runs “a” and “b” were conducted to create comparisons that are necessary for explaining effect of SJRRS implementation. Calculation of the Water Management Goal requires a comparison of model runs “a” to model runs “b” and “c” to represent the expected recapture and recirculation for each level of SJRRS implementation. Model runs denoted with “c” are provided for comparative analyses that calculate recapture and recirculation, as well as additional groundwater recharge deliveries during wet conditions.

All simulations were performed using CalSim-II, the State of California’s premiere water supply planning and analysis tool. The primary use of the CalSim model is for estimating water supply exports from the Sacramento-San Joaquin Delta for delivery to CVP and State Water Project (SWP) water users. CalSim-II simulates statewide water supply operations using a continuous 82-year hydrology, traditionally based on the period of historic records beginning October 1921 and running through September 2003.

**Table 2. Fifteen model runs simulated for this Report**

| MODEL RUN | CLIMATE CONDITION | SJRRS SETTLEMENT RESTORATION GOAL | SJRRS SETTLEMENT WATER MANAGEMENT GOAL | BENCHMARK CALSIM-II MODEL USED |
|---|---|---|---|---|
| 2015.a | 2015 Conditions (historical modified for recent changes) | Pre-SJRRS | Pre-SJRRS | DWR Delivery Capability Report, 2015 climate |
| 2015.b | | Limited SJRRS | Limited Access | |
| 2015.c | | | Full Access | |
| 2030.a | Near-Future (DWR 2030 Central Tendency) | Pre-SJRRS | Pre-SJRRS | Water Commission, 2030 climate |
| 2030.b | | Full SJRRS | Limited Access | |
| 2030.c | | | Full Access | |
| 2070.a | Late-Future (DWR 2070 Central Tendency) | Pre-SJRRS | Pre-SJRRS | Water Commission, 2070 climate |
| 2070.b | | Full SJRRS | Limited Access | |
| 2070.c | | | Full Access | |
| DEW.a | Late-Future, 2070 Drier/Extreme Warming | Pre-SJRRS | Pre-SJRRS | Water Commission, 2070 DEW climate |
| DEW.b | | Full SJRRS | Limited Access | |
| DEW.c | | | Full Access | |
| WMW.a | Late-Future, 2070 Wetter/Moderate Warming | Pre-SJRRS | Pre-SJRRS | Water Commission, 2070 WMW climate |
| WMW.b | | Full SJRRS | Limited Access | |
| WMW.c | | | Full Access | |

Key:
DEW = Drier/Extreme Warming
DWR = California Department of Water Resources
SJRRS = San Joaquin River Restoration Settlement
WMW = Wetter/Moderate Warming

# CLIMATE CHANGES EVALUATED

The California Water Commission Water Supply Investment Program (CWC WSIP) developed baseline CalSim-II simulations using several levels of potential climate change to modify input hydrology of the entire system, including the San Joaquin River. These scenarios were developed using the 20 combinations of climate change models and representative concentration pathways recommended by DWR Climate Change Technical Advisory Group as being most appropriate for California water resource planning and analysis. Further details on the specific climate change included in each of the simulations is included in the CWC WSIP Technical Reference (CWC, 2016). The resulting climate change conditions used in this analysis include:

1. **2015 Conditions:** This represents a historical hydrology modified to match climate and sea level conditions for a thirty-year period centered at 1995 (reference climate period 1981 – 2010).
2. **Near-Future 2030 Central Tendency:** This represents a 2030 future hydrology with projected climate and sea level conditions for a thirty-year period centered at 2030 (reference climate period 2016 – 2045).
3. **Late-Future 2070 Central Tendency:** This hydrology represents a 2070 future condition with projected climate and sea level conditions for a thirty-year period centered at 2070 (reference climate period 2056 – 2085).
4. **Late-Future 2070 Drier/Extreme Warming Conditions (DEW):** This hydrology represents a 2070 DEW future condition with projected climate and sea level conditions for a thirty-year period centered at 2070 (reference climate period 2056 – 2085).
5. **Late-Future 2070 Wetter/Moderate Warming Conditions (WMW):** This hydrology represents a 2070 WMW future condition with projected climate and sea level conditions for a thirty-year period centered at 2070 (reference climate period 2056 – 2085).

The seasonal timing of inflow to Millerton Lake is projected to change in response to climate change. Historical inflow to Millerton Lake generally peak during the month of June due to the delayed runoff from a large snow pack. The climate change scenarios for 2030 and 2070 are based on warmer conditions that will produce precipitation events with more rainfall and less snowpack than historically occurred, resulting in peak runoff earlier in the year. Peak runoff into Millerton Lake is projected to occur in May for the 2030 scenario, and in April for the 2070 scenario. Figure 3 shows the general trend of Millerton Lake inflow change due to climate change.

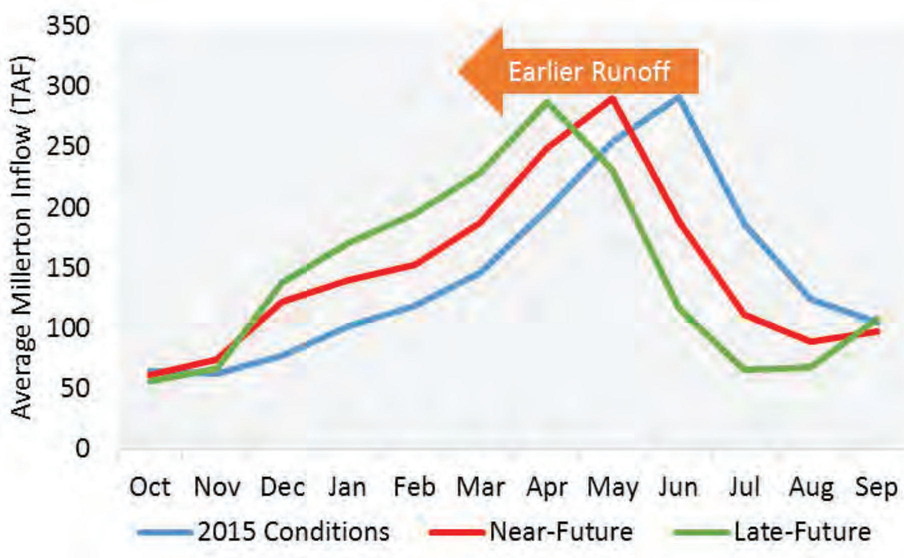



*Figure 3. Millerton Lake Inflow Change Due to Climate Change*

When analyzing CalSim-II outputs, the results are often summarized by water year type, which classifies groups of years with similar hydrologic characteristics. A water year starts October 1 of the preceding calendar year and ends September 30 of the current year. For example, water year 1922 starts October 1, 1921 and ends September 30, 1922. In this analysis the SJRRS water year type classification was used to summarize the estimated changes in Friant Division supplies. The SJRRS water year types are classified as follows: Wet, Normal-Wet, Normal-Dry, Dry, Critical High and Critical Low. For the CWC WSIP the SJRRP water year type classification remained unchanged between the five climate change conditions. In this TM, the SJRRS water year types were redefined based on Unimpaired Millerton Inflow (consistent with the SJRRS) from the CalSim II SV input files. This was done to update the SJRRS hydrographs to better reflect the anticipated climate change conditions. Table 3 summarizes the SJRRS water year types by climate condition. For reporting purposes, the designation of Critical water year type includes both Critical High and Critical Low SJRRS water year types.

**Table 3. SJRRS Water Year Types per Climate Condition by Number of Years and Percentage of Total Years**

| SJRRS WATER YEAR TYPE | 2015 CONDITIONS | NEAR-FUTURE, 2030 | LATE-FUTURE, 2070 | LATE-FUTURE, 2070 DEW | LATE-FUTURE, 2070 WMW |
|---|---|---|---|---|---|
| Wet | 16 (20%) | 18 (22%) | 19 (23%) | 21 (26%) | 35 (43%) |
| Normal-Wet | 25 (30%) | 21 (26%) | 20 (24%) | 12 (15%) | 21 (26%) |
| Normal-Dry | 24 (29%) | 25 (30%) | 20 (24%) | 11 (13%) | 15 (18%) |
| Dry | 12 (15%) | 11 (13%) | 16 (20%) | 20 (24%) | 9 (11%) |
| Critical[1] | 5 (6%) | 7 (9%) | 7 (9%) | 18 (22%) | 2 (2%) |
| **Long-Term[2]** | 82 | 82 | 82 | 82 | 82 |

Key:
DEW = Drier/Extreme Warming
DWR = California Department of Water Resources
SJRRS = San Joaquin River Restoration Settlement
WMW = Wetter/Moderate Warming
Note:
[1]For reporting purposes, the designation of Critical water year type includes both Critical High and Critical Low SJRRP water year types
[2]Long-Term average reflects the 82-year CalSim II simulation period (October 1921 thru September 2003)

# SJRRS IMPLEMENTATION

Implementation of the SJRRS includes actions to meet both the Restoration and Water Management Goals. Both goals have a direct effect on Friant Division water supplies, and both are expected to change in implementation over time.

Presently, both goals are implemented in a limited manner because of capacity restrictions in the San Joaquin River below Friant Dam (which constrict releases for the Restoration Goal) and the need for further buildout of groundwater infiltration facilities to take full advantage wet year supplies, when available (for the Water Management Goals). However, Reclamation has plans for implementation that will allow for virtually all SJRRS releases to be made by 2025 (SJRRP, 2018). Further, water users throughout the Friant Division are pursuing a broad array of facilities that will enhance the ability to implement Paragraph 16(b) water supplies, when available.

To represent the current and anticipated future implementation of the SJRRS, the following variations were constructed.

## Restoration Goal Implementation

Three levels of Restoration Goal implementation are considered, as follows:

1. **Pre-SJRRS:** This simulation sets the required minimum release from Millerton to the San Joaquin River to the values in the without project baseline conditions (SJRRP, 2009).
2. **Limited SJRRS:** This condition approximates current conditions, which are expected to remain limited until 2025. Simulations of this condition are based on the current channel capacity of 1,300 cubic feet per second (CFS) in Reach 2.
3. **Full SJRRS:** This condition represents the SJRRS hydrograph with capacities identified in the SJRRS Funding Constrained Framework. Under this plan, channel capacity will not exceed the identified 2025 channel capacity of 2,500 CFS in Reach 2. This hydrograph was used in the 2030, 2070, 2070 DEW, and 2070 WMW level of climate change simulations. Flow releases (Flow Schedules) for this condition were approximated with a spreadsheet developed by the SJRRP for the Framework Document (SJRRP, 2018). Table 3 shows the Full SJRRS Implementation hydrograph compared to the Funding Constrained Framework SJRRS hydrograph for the four climate change scenarios. The differences between the four climate change scenarios is due to the different number of years per SJRRS water year type, as shown in Table 3. Table 4 is not the impact of Friant Deliveries, but

represents the SJRRS releases under the Funding Constrained Framework under different climate change conditions.

**Table 4 Long-Term Average SJRRS Releases under Full SJRRS Implementation and the Funding Constrained Framework Four Climate Conditions**

| SJRRS WATER YEAR TYPE | FULL SJRRP IMPLEMENTATION (TAF/YEAR) | FUNDING CONSTRAINED FRAMEWORK | | | |
|---|---|---|---|---|---|
| | | NEAR-FUTURE, 2030 (TAF/YEAR) | LATE-FUTURE, 2070 (TAF/YEAR) | LATE-FUTURE, 2070 DEW (TAF/YEAR) | LATE-FUTURE, 2070 WMW (TAF/YEAR) |
| Wet | 674 | 633 | 633 | 628 | 633 |
| Normal-Wet | 474 | 434 | 433 | 428 | 432 |
| Normal-Dry | 365 | 365 | 364 | 363 | 357 |
| Dry | 302 | 297 | 296 | 296 | 300 |
| Critical High | 188 | 188 | 188 | 188 | 188 |
| Critical Low | 117 | 117 | 117 | 117 | 117 |
| **Long-Term**[1] | 438 | 417 | 414 | 376 | 483[2] |

Key:
DEW = Drier/Extreme Warming
DWR = California Department of Water Resources
SJRRS = San Joaquin River Restoration Settlement
TAF/year = thousand acre-feet per year
WMW = Wetter/Moderate Warming
Note:
[1]Long-Term average reflects the 82-year CalSim II simulation period (October 1921 thru September 2003)
[2] The Long-Term Average SJRRS release for 2070 WMW is higher than the Full SJRRP Implementation because, as Table 3 shows, the number of Wet water years increased from 16 years (20 percent) in the 2015 Condition to 35 years (43 percent) in the 2070 WMW Condition.

The quantification of SJRRS implementation impact is performed by comparing the with and without SJRRS water supplies diverted from Friant Dam.

In the course of compiling these model runs, it was discovered that previous studies had not correctly implemented SJRRS flows under climate change. SJRRS outflow requirements at Friant Dam are determined by the total annual hydrology, which can change enough under climate conditions to alter a given year's release requirements. All scenarios and results in this report have been adjusted to correctly set SJRRS flow requirements, including under climate change.

## Water Management Goal Implementation

Three levels of Water Management Goal implementation are considered, as follows:

1. **Pre-SJRRS**: This represents the without SJRRS condition.
2. **Limited Access:** This represents 16(a) supplies available to Friant Contractors as part of the SJRRS that provides for recapture and recirculation of flows released from Friant Dam for the purposes of meeting the Restoration Goal.
3. **Full Access:** This represents supplies anticipated with future ability to divert 16(a) and 16(b) supplies to Friant Contractors. 16(b) stipulates a Recovered Water Account (RWA) that represents water not required to meet SJRRS or other requirements be made available to Friant Contractors who experience a reduction in water deliveries from the implementation of the SJRRS. 16(b) water is made available to those Friant Contractors at $10 per acre-foot during wet condition.

The SJRRS and implementing documents identify several locations for recapture, however modeling conducted for the SJRRP PEIS/R only provided for estimated recapture as the incremental improvement in total Delta Exports that result from the SJRRS. The quantification of water supplies recaptured in the Delta in conformance with 16(a) is performed by comparing simulated Delta exports with and without the implementation of the SJRRS. The net improvement in export is identified as recapturable supply.

The CalSim-II model simulates 16(b) as an additional demand after Class 1 and Class 2 delivery allocations are met and before 215 ("Other") deliveries are made. The CalSim-II simulated 16(b) delivery via the Friant Kern and Madera canals is based on anticipated development of groundwater infiltration facilities throughout the Friant Division in response to SJRRS implementation. These facilities are not identified and are represented as surrogate water demands in the CalSim-II model. As a result, use of 16(b) water supply availability must be viewed as total opportunity that has not been attributed among individual water users at this time.

The quantification of water supplies diverted from Friant Dam for 16(b) is performed by comparing the with and without SJRRS simulations that allow for added diversions. This required the additional simulation for each scenario, to provide for comparison. The "#.b" scenarios are included in results for reference.

# GUIDANCE ON USE OF RESULTS

This TM provides descriptions of potential future water supplies for the Friant Division for five climate change conditions under different levels of SJRRS implementation.

The key outputs of this report are provided in tables by monthly and total volumes by contract year (which begins March 1 of the current calendar year and ends February 28 of the following year), except when noted, and summarized by SJRRS water year type classification and long-term average for each of the following:

- Millerton Lake Inflow
- Total Friant Division deliveries of:
  - Class 1
  - Class 2/Other
  - Paragraph 16(b) water (aka $10 water, or RWA water)
- Friant Dam Spill
- Potential Friant Division Delta Recapture (by year, only), for:
  - Class 1 Delta Recapture
  - Class 2 Delta Recapture
  - Total Delta Recapture

These data are provided in a spreadsheet, entitled: "Summary_FutureFriantSupplies_Final.xlsm"

Table 5 provides a portion of a tabulated output available in the spreadsheet. Tabulated information includes the average monthly and total volumes by SJRRS water year type classification and long-term average. For reporting purposes, the designation of Critical water year type includes both Critical-High and Critical-Low SJRRS water year types. Tabulated information also includes the monthly and total volumes per contract year (Mar-Feb). In the spreadsheet, the tables include the monthly and total volumes per contract year for the entire 82-year CalSim-II simulated period (October 1921 to September 2003).

**Table 5. Example Output Table for Class 1 Deliveries**

| 2015 SJRRP WY Type | Month Year | Mar TAF | Apr TAF | May TAF | Jun TAF | Jul TAF | Aug TAF | Sep TAF | Oct TAF | Nov TAF | Dec TAF | Jan TAF | Feb TAF | Total TAF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Class 1 Delivery** | | | | | | | | | | | | |
| | | Mar TAF | Apr TAF | May TAF | Jun TAF | Jul TAF | Aug TAF | Sep TAF | Oct TAF | Nov TAF | Dec TAF | Jan TAF | Feb TAF | Total TAF |
| | Wet | 16.1 | 28.1 | 51.6 | 123.4 | 189.9 | 181.5 | 106.3 | 48.5 | 12.2 | 6.4 | 6.3 | 29.8 | 800.0 |
| | Normal-Wet | 26.2 | 46.3 | 75.0 | 149.8 | 189.3 | 165.2 | 84.0 | 28.9 | 4.7 | 4.5 | 4.5 | 21.6 | 800.0 |
| | Normal-Dry | 32.9 | 56.7 | 92.1 | 158.6 | 184.4 | 152.5 | 67.9 | 20.9 | 3.6 | 3.6 | 3.4 | 19.7 | 796.3 |
| | Dry | 29.7 | 48.8 | 81.7 | 143.9 | 167.1 | 130.5 | 55.8 | 20.9 | 4.7 | 2.3 | 2.3 | 17.3 | 705.1 |
| | Critical | 16.7 | 19.9 | 36.4 | 86.6 | 111.5 | 65.2 | 31.0 | 19.9 | 6.6 | 0.0 | 0.0 | 9.9 | 403.8 |
| | Long Term | 26.1 | 44.6 | 74.1 | 142.4 | 179.9 | 153.4 | 76.2 | 28.7 | 6.0 | 4.0 | 3.9 | 21.3 | 760.4 |
| Normal-Wet | 1921 | | | | | | | | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Normal-Wet | 1922 | 22.3 | 37.4 | 59.8 | 138.2 | 189.1 | 174.0 | 97.8 | 36.4 | 5.5 | 5.3 | 5.3 | 28.9 | 800.0 |
| Normal-Wet | 1923 | 25.6 | 42.7 | 64.4 | 146.7 | 187.1 | 170.7 | 95.2 | 33.8 | 4.9 | 4.6 | 4.6 | 19.7 | 800.0 |
| Critical | 1924 | 17.9 | 21.4 | 39.2 | 93.2 | 120.0 | 72.2 | 31.6 | 21.4 | 7.1 | 0.0 | 0.0 | 10.7 | 434.7 |
| Normal-Dry | 1925 | 32.8 | 56.4 | 89.7 | 158.4 | 188.2 | 152.0 | 70.7 | 21.0 | 3.9 | 3.9 | 3.3 | 19.7 | 800.0 |
| Normal-Dry | 1926 | 33.2 | 57.1 | 98.8 | 160.4 | 183.9 | 151.2 | 65.6 | 19.9 | 3.3 | 3.3 | 3.3 | 19.9 | 800.0 |
| Normal-Wet | 1927 | 25.7 | 47.4 | 80.6 | 151.2 | 191.4 | 163.5 | 79.8 | 26.8 | 4.8 | 4.6 | 4.6 | 19.8 | 800.0 |
| Normal-Dry | 1928 | 31.6 | 57.8 | 92.0 | 162.4 | 186.2 | 153.1 | 66.4 | 20.2 | 3.4 | 3.4 | 3.4 | 20.2 | 800.0 |
| Dry | 1929 | 26.8 | 48.2 | 80.3 | 132.2 | 148.5 | 124.8 | 53.0 | 16.1 | 2.7 | 2.7 | 2.7 | 16.1 | 654.0 |
| Dry | 1930 | 27.1 | 48.8 | 81.1 | 133.6 | 150.1 | 126.2 | 53.6 | 16.3 | 2.7 | 2.7 | 2.7 | 16.3 | 661.1 |
| Critical | 1931 | 12.9 | 15.5 | 28.3 | 67.4 | 86.9 | 52.3 | 22.9 | 15.5 | 5.2 | 0.0 | 0.0 | 7.7 | 314.5 |
| Normal-Wet | 1932 | 25.6 | 42.7 | 64.4 | 146.7 | 187.1 | 170.7 | 95.2 | 33.8 | 4.9 | 4.6 | 4.6 | 19.7 | 800.0 |
| Normal-Dry | 1933 | 32.8 | 56.4 | 89.7 | 158.4 | 188.2 | 152.0 | 70.7 | 21.0 | 3.9 | 3.9 | 3.3 | 19.7 | 800.0 |
| Dry | 1934 | 24.0 | 28.7 | 52.2 | 124.2 | 159.9 | 96.2 | 42.2 | 28.5 | 9.5 | 0.0 | 0.0 | 14.2 | 579.6 |
| Normal-Wet | 1935 | 28.2 | 47.3 | 80.4 | 150.7 | 190.7 | 162.9 | 79.5 | 26.7 | 4.7 | 4.6 | 4.6 | 19.7 | 800.0 |
| Normal-Wet | 1936 | 28.2 | 47.2 | 80.3 | 150.7 | 190.7 | 162.9 | 79.5 | 26.7 | 5.0 | 4.6 | 4.6 | 19.7 | 800.0 |
| Normal-Wet | 1937 | 28.7 | 48.0 | 81.6 | 159.5 | 191.1 | 160.7 | 74.5 | 24.0 | 4.0 | 4.0 | 4.0 | 20.0 | 800.0 |
| Wet | 1938 | 17.2 | 28.4 | 52.1 | 115.8 | 193.9 | 182.0 | 104.2 | 49.9 | 13.0 | 6.6 | 6.6 | 30.4 | 800.0 |

# CLASS 1 AND CLASS 2 SUPPLY PROJECTIONS

While CalSim-II does produce estimated deliveries of Class 1 water supplies with some confidence, the simulated "Class 2" and "Other" model outputs have always been problematic. This is because CalSim-II approximations of wet year operations were calibrated to mimic total releases – not actual deliveries of Class 2 or (separately) Other supplies. As a result, the modeling outputs provided with this TM do not distinguish between Class 2 and Other modeling categories. These two data outputs have been grouped to describe Class 2 behavior in aggregate. Through previous modeling conducted for SJRRS implementation, Friant Division managers have found the aggregation of Class 2 and Other model outputs performs closer to actual experience with Class 2 deliveries.

CalSim-II does not determine delivery by Friant Contractor, it simulates the annual allocations and then distributes them over the year on a monthly pattern. CalSim- II does approximate the division of flows between the Madera and Friant-Kern canals, but the actual final deliveries simulated in CalSim-II are not to specific Friant contractors or physical locations. Standard practice in interpreting deliveries to Friant Contractors has been to split Class 1 and Class 2/Other deliveries among individual contractors by contract quantity. For example, a district with an 80 thousand acre-feet (TAF) Friant Division Class 1 contract (i.e., 10 percent of total Class 1) and 70 TAF of Class 2 (i.e., five percent of total Class 2), would have access to 10 percent of the Class 1 supplies and five percent of the Class 2/Other supplies in a given year. Table 6 lists the Friant Contractors corresponding Class 1 and Class 2 contract amounts by volume and percentage. These have been incorporated into the spreadsheet to facilitate use.

NOTE: The reader may note that Section 215 water supplies are not discussed. While the factors that produce "215 water" are presumed to exist in the future, the frequency and magnitude of their availability is expected to be greatly diminished by implementation of the SJRRS, which has made available water supplies to Friant Contractors through Paragraph 16(b) of the Settlement. The assumed low availability of 215 water comports with recent experience, even with partial SJRRS implementation. As a result, this analysis makes no attempt to quantify future 215 water supply availability, which may be presumed to be nearly zero for planning purposes. "16(b)" or "RWA" or "$10" water (all the same) is discussed in a later section.

**Table 6. Friant Contractor Summary**

| FRIANT CONTRACTOR | CLASS 1 ACRE-FEET | CLASS 2 ACRE-FEET | CLASS 1 PERCENTAGE | CLASS 2/OTHER PERCENTAGE |
|---|---|---|---|---|
| Arvin-Edison Water Storage District | 40,000 | 311,675 | 5.0% | 22.2% |
| Chowchilla Water District | 55,000 | 160,000 | 6.9% | 11.4% |
| City of Fresno | 60,000 | 0 | 7.5% | 0.0% |
| City of Lindsay | 2,500 | 0 | 0.3% | 0.0% |
| City of Orange Cove | 1,400 | 0 | 0.2% | 0.0% |
| Delano-Earlimart Irrigation District | 108,800 | 74,500 | 13.6% | 5.3% |
| Exeter Irrigation District | 11,100 | 19,000 | 1.4% | 1.4% |
| Fresno County Water Works District No. 18 | 150 | 0 | 0.0% | 0.0% |
| Fresno Irrigation District | 0 | 75,000 | 0.0% | 5.4% |
| Garfield Water District | 3,500 | 0 | 0.4% | 0.0% |
| Gravelly Ford Water District | 0 | 14,000 | 0.0% | 1.0% |
| Hills Valley Irrigation District | 1,250 | 0 | 0.2% | 0.0% |
| International Water District | 1,200 | 0 | 0.2% | 0.0% |
| Ivanhoe Irrigation District | 6,500 | 500 | 0.8% | 0.0% |
| Kaweah Delta Water Conservation District | 1,200 | 7,400 | 0.2% | 0.5% |
| Kern-Tulare Water District | 0 | 5,000 | 0.0% | 0.4% |
| Lewis Creek Water District | 1,200 | 0 | 0.2% | 0.0% |
| Lindmore Irrigation District | 33,000 | 22,000 | 4.1% | 1.6% |
| Lindsay-Strathmore Irrigation District | 27,500 | 0 | 3.4% | 0.0% |
| Lower Tule River Irrigation District | 61,200 | 238,000 | 7.7% | 17.0% |
| Madera County | 200 | 0 | 0.0% | 0.0% |
| Madera Irrigation District | 85,000 | 186,000 | 10.6% | 13.3% |
| Orange Cove Irrigation District | 39,200 | 0 | 4.9% | 0.0% |
| Porterville Irrigation District | 15,000 | 30,000 | 1.9% | 2.1% |
| Saucelito Irrigation District | 21,500 | 32,800 | 2.7% | 2.3% |
| Shafter-Wasco Irrigation District | 50,000 | 39,600 | 6.3% | 2.8% |
| Southern San Joaquin Municipal Utility District | 97,000 | 45,000 | 12.1% | 3.2% |
| Stone Corral Irrigation District | 10,000 | 0 | 1.3% | 0.0% |
| Tea Pot Dome Water District | 7,200 | 0 | 0.9% | 0.0% |
| Terra Bella Irrigation District | 29,000 | 0 | 3.6% | 0.0% |
| Tri-Valley Water District | 400 | 0 | 0.1% | 0.0% |
| Tulare Irrigation District | 30,000 | 141,000 | 3.8% | 10.1% |
| **Total** | 800,000 | 1,401,475 | 100% | 100% |

# SJRRS WATER SUPPLY PROJECTIONS

The SJRRS Water Management Goal creates two new categories of supplies for Friant Contractors that are described in paragraphs 16(a) and (b) of the Settlement.

Delta recapture (Paragraph 16(a) is quantified in this analysis by taking the difference in Delta Exports between the with and without SJRRS implementation and crediting the net volume of improvement to the SJRRS recapture program. This does not account for the ability to recapture water supplies on the lower San Joaquin River. Delta recapture is reported as an annual quantity to overcome limitations in the simulation of monthly operations, which are not appropriate for use as monthly recapture volumes at this time. This supply represents an upper bound for potential recapture in the Delta. Discussions between Reclamation, DWR, and

Friant are ongoing to establish the availability of this water supply through Delta pumping. At the time of this report, no processes are in place to recapture in the Delta.

In recent practice, recaptured supplies have been split between Class 1 and 2 contractors, using recapture to back-fill for water contract allocations. For this analysis, Delta recapture has been split between Class 1 and Class 2 contractors, based on recent practices by Reclamation. At the request of Friant Contractors, recapture is provided first to Class 1 water users up to the point that the combination of Friant Division deliveries and recapture equal a 100 percent Class 1 allocation. Any volumes in excess are allocated to Class 2 contractors, proportional to their Class 2 contract volumes. The spreadsheet includes summary tables of total Delta recapture, and a breakout of Class 1 and Class 2 recapture by Friant Contractor proportional to their contract amounts as shown in Table 5. Users of this data are encouraged to apply contract quantities (Table 6) to attribute allocations among Friant Contractors.

The second SJRRS water category, Paragraph 16(b) supplies, are quantified in the CalSim II model by assuming a demand for this potential supply and meeting this demand, limited by availability of flood water and channel capacity for delivery.  Any remaining flood water is then assumed available for 215/other delivery in the simulation.  Specific patterns for the use of this supply do not yet exist and, thus, CalSim-II makes no assertion about anything except for the expectation and potential for these supplies to be delivered.

For consistency with previous efforts to interpret the CalSim II model and its output, 16(b) supplies have been divided among Friant Contractors in proportion to their share of impact from the SJRRS that accumulates to their water supplies. The impact from the SJRRS is estimated by comparison of the total C1 and C2/Other delivery in the Pre-SJRRS and "limited" CalSim II simulations.  The allocation to the individual contractors was done based on percentage of impact from the Proposed Implementation Agreement of the Friant Settlement (SJRRP, 2009) and from the percentage impact computed from the new CalSim II simulation performed for this analysis.  For example, a Friant Contractor with five percent of reduction in total Class 1 and Class 2/Other is and would have access to five percent of the 16(b) supplies. Table 7 and 8 shows impact of SJRRS under the five climate change conditions and computed impacts from the Mediator's Report for the Friant Contractors.

**Table 7. Summary of Friant Contractor Impacts per Climate Change and Mediator's Report (Volume)**

| FRIANT CONTRACTOR | LONG-TERM AVERAGE CLASS 1 AND CLASS 2/OTHER IMPACTS | | | | | |
|---|---|---|---|---|---|---|
| | MEDIATOR'S REPORT | 2015 CONDITION | NEAR-FUTURE, 2030 | LATE-FUTURE, 2070 | LATE-FUTURE, 2070 DEW | LATE-FUTURE, 2070 WMW |
| | TAF | TAF | TAF | TAF | TAF | TAF |
| Arvin-Edison Water Storage District | 30.342 | 28.13 | 28.88 | 26.54 | 18.69 | 28.41 |
| Chowchilla Water District | 17.661 | 15.76 | 16.58 | 15.75 | 12.59 | 16.04 |
| City of Fresno | 3.629 | 2.30 | 3.06 | 3.71 | 5.22 | 2.52 |
| City of Lindsay | 0.151 | 0.10 | 0.13 | 0.15 | 0.22 | 0.11 |
| City of Orange Cove | 0.085 | 0.05 | 0.07 | 0.09 | 0.12 | 0.06 |
| Delano-Earlimart Irrigation District | 13.255 | 10.53 | 11.96 | 12.47 | 13.10 | 10.97 |
| Exeter Irrigation District | 2.398 | 2.05 | 2.20 | 2.15 | 1.89 | 2.10 |
| Fresno County Water Works District No. 18 | 0.009 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 |
| Fresno Irrigation District | 6.719 | 6.40 | 6.46 | 5.79 | 3.66 | 6.43 |
| Garfield Water District | 0.212 | 0.13 | 0.18 | 0.22 | 0.30 | 0.15 |
| Gravelly Ford Water District | 1.254 | 1.19 | 1.21 | 1.08 | 0.68 | 1.20 |
| Hills Valley Irrigation District[1] | 0.000 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| International Water District | 0.073 | 0.05 | 0.06 | 0.07 | 0.10 | 0.05 |
| Ivanhoe Irrigation District | 1.173 | 0.29 | 0.37 | 0.44 | 0.59 | 0.32 |
| Kaweah Delta Water Conservation District[1] | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Kern-Tulare Water District[1] | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Lewis Creek Water District | 0.088 | 0.05 | 0.06 | 0.07 | 0.10 | 0.05 |
| Lindmore Irrigation District | 3.967 | 3.14 | 3.58 | 3.74 | 3.94 | 3.28 |
| Lindsay-Strathmore Irrigation District | 1.663 | 1.06 | 1.40 | 1.70 | 2.39 | 1.16 |
| Lower Tule River Irrigation District | 25.024 | 22.66 | 23.62 | 22.16 | 16.94 | 22.99 |
| Madera County | 0.012 | 0.01 | 0.01 | 0.01 | 0.02 | 0.01 |
| Madera Irrigation District | 21.805 | 19.13 | 20.35 | 19.61 | 16.47 | 19.53 |
| Orange Cove Irrigation District | 2.371 | 1.50 | 2.00 | 2.42 | 3.41 | 1.65 |
| Porterville Irrigation District | 3.655 | 3.14 | 3.35 | 3.24 | 2.77 | 3.20 |
| Saucelito Irrigation District | 4.221 | 3.62 | 3.92 | 3.86 | 3.47 | 3.72 |
| Shafter-Wasco Irrigation District | 6.572 | 5.30 | 5.96 | 6.15 | 6.28 | 5.50 |
| Southern San Joaquin Municipal Utility District | 10.346 | 7.56 | 8.82 | 9.46 | 10.63 | 7.94 |
| Stone Corral Irrigation District | 0.605 | 0.38 | 0.51 | 0.62 | 0.87 | 0.42 |
| Tea Pot Dome Water District | 0.454 | 0.28 | 0.37 | 0.44 | 0.63 | 0.30 |
| Terra Bella Irrigation District | 1.754 | 1.11 | 1.48 | 1.79 | 2.52 | 1.22 |
| Tri-Valley Water District[1] | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| Tulare Irrigation District | 14.447 | 13.18 | 13.67 | 12.74 | 9.49 | 13.36 |
| **Total** | **173.945** | **149.13** | **160.26** | **156.49** | **137.14** | **152.67** |

Key:
DEW = Drier/Extreme Warming
TAF = thousand acre-feet
WMW = Wetter/Moderate Warming
Note:
[1] Friant Contractor calculated impact as zero because they do not receive a proportion of 16(b) supplies.

**Table 8. Summary of Friant Contractor Impacts per Climate Change and Mediator's Report (Percentage)**

| FRIANT CONTRACTOR | LONG-TERM AVERAGE CLASS 1 AND CLASS 2/OTHER IMPACTS | | | | | |
|---|---|---|---|---|---|---|
| | MEDIATOR'S REPORT | 2015 CONDITION | NEAR-FUTURE, 2030 | LATE-FUTURE, 2070 | LATE-FUTURE, 2070 DEW | LATE-FUTURE, 2070 WMW |
| | % | % | % | % | % | % |
| Arvin-Edison Water Storage District | 17.444% | 18.864% | 18.020% | 16.958% | 13.630% | 18.611% |
| Chowchilla Water District | 10.153% | 10.571% | 10.347% | 10.066% | 9.183% | 10.504% |
| City of Fresno | 2.086% | 1.544% | 1.909% | 2.368% | 3.806% | 1.653% |
| City of Lindsay | 0.087% | 0.064% | 0.080% | 0.099% | 0.159% | 0.069% |
| City of Orange Cove | 0.049% | 0.036% | 0.045% | 0.055% | 0.089% | 0.039% |
| Delano-Earlimart Irrigation District | 7.620% | 7.063% | 7.464% | 7.970% | 9.553% | 7.183% |
| Exeter Irrigation District | 1.378% | 1.373% | 1.374% | 1.376% | 1.380% | 1.373% |
| Fresno County Water Works District No. 18 | 0.005% | 0.004% | 0.005% | 0.006% | 0.010% | 0.004% |
| Fresno Irrigation District | 3.863% | 4.292% | 4.030% | 3.701% | 2.669% | 4.213% |
| Garfield Water District | 0.122% | 0.090% | 0.111% | 0.138% | 0.222% | 0.096% |
| Gravelly Ford Water District | 0.721% | 0.801% | 0.752% | 0.691% | 0.498% | 0.786% |
| Hills Valley Irrigation District[1] | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% |
| International Water District | 0.042% | 0.031% | 0.038% | 0.047% | 0.076% | 0.033% |
| Ivanhoe Irrigation District | 0.675% | 0.196% | 0.234% | 0.281% | 0.430% | 0.207% |
| Kaweah Delta Water Conservation District[1] | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% |
| Kern-Tulare Water District[1] | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% |
| Lewis Creek Water District | 0.050% | 0.031% | 0.038% | 0.047% | 0.076% | 0.033% |
| Lindmore Irrigation District | 2.281% | 2.108% | 2.232% | 2.388% | 2.876% | 2.145% |
| Lindsay-Strathmore Irrigation District | 0.956% | 0.708% | 0.875% | 1.085% | 1.744% | 0.758% |
| Lower Tule River Irrigation District | 14.386% | 15.194% | 14.736% | 14.159% | 12.352% | 15.057% |
| Madera County | 0.007% | 0.005% | 0.006% | 0.008% | 0.013% | 0.006% |
| Madera Irrigation District | 12.536% | 12.831% | 12.699% | 12.532% | 12.011% | 12.791% |
| Orange Cove Irrigation District | 1.363% | 1.009% | 1.247% | 1.547% | 2.486% | 1.080% |
| Porterville Irrigation District | 2.101% | 2.103% | 2.089% | 2.072% | 2.019% | 2.099% |
| Saucelito Irrigation District | 2.427% | 2.430% | 2.446% | 2.467% | 2.531% | 2.435% |
| Shafter-Wasco Irrigation District | 3.778% | 3.553% | 3.719% | 3.927% | 4.581% | 3.602% |
| Southern San Joaquin Municipal Utility District | 5.948% | 5.071% | 5.504% | 6.048% | 7.754% | 5.201% |
| Stone Corral Irrigation District | 0.348% | 0.257% | 0.318% | 0.395% | 0.634% | 0.276% |
| Tea Pot Dome Water District | 0.261% | 0.185% | 0.229% | 0.284% | 0.457% | 0.198% |
| Terra Bella Irrigation District | 1.008% | 0.746% | 0.923% | 1.144% | 1.839% | 0.799% |
| Tri-Valley Water District[1] | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% | 0.000% |
| Tulare Irrigation District | 8.305% | 8.840% | 8.531% | 8.141% | 6.921% | 8.748% |
| **Total** | **100.00%** | **100.00%** | **100.00%** | **100.00%** | **100.00%** | **100.000%** |

Key:
DEW = Drier/Extreme Warming
WMW = Wetter/Moderate Warming
Note:
[1] Friant Contractor does not receive a proportion of 16(b) supplies.

# REFERENCES


California Department of Water Resources. Land Use Viewer. September 2017 https://gis.water.ca.gov/app/CADWRLandUseViewer/

California Water Commission, Water Storage Investment Program, Technical Reference, November 2016 https://cwc.ca.gov/-/media/CWC-Website/Files/Documents/2017/WSIP/TechnicalReference.pdf

San Joaquin River Restoration Program, Funding Constrained Framework for Implementation, May 2018 http://www.restoresjr.net/program-releases-framework-to-guide-program-into-next-decade/

San Joaquin River Restoration Program, Programmatic Environmental Impact Statement, January 2009 https://www.usbr.gov/mp/nepa/nepa_project_details.php?Project_ID=2940

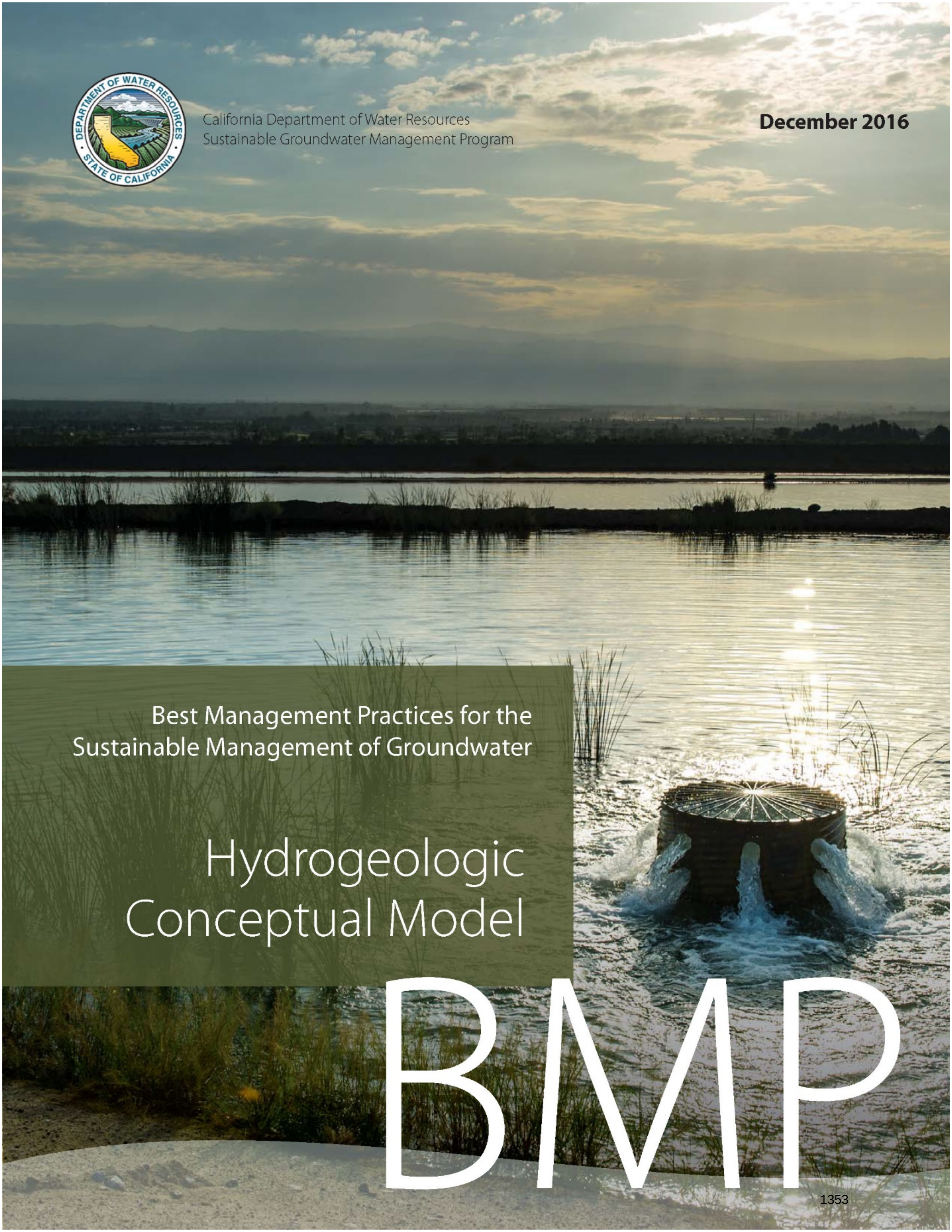
San Joaquin River Restoration Program, Proposed Implementation Agreement of the Friant Settlement, April 2009

San Joaquin River Restoration Program Settlement Agreement, October 2009 http://www.revivethesanjoaquin.org/content/san-joaquin-river-settlement-agreement

SJRRP, *see San Joaquin River Restoration Program*

# Appendix 2B

## DWR Hydrogeologic Conceptual Model BMP



California Department of Water Resources
Sustainable Groundwater Management Program

December 2016

Best Management Practices for the
Sustainable Management of Groundwater

# Hydrogeologic Conceptual Model

BMP

State of California
**Edmund G. Brown Jr., Governor**

California Natural Resources Agency
**John Laird, Secretary for Natural Resources**

Department of Water Resources
**Mark W. Cowin, Director**

**Carl A. Torgersen,** Chief Deputy Director

| | | |
|---|---|---|
| Office of the Chief Counsel<br>Spencer Kenner | Public Affairs Office<br>Ed Wilson | Government and Community Liaison<br>Anecita S. Agustinez |
| Office of Workforce Equality<br>Stephanie Varrelman | Policy Advisor<br>Waiman Yip | Legislative Affairs Office<br>Kasey Schimke, Ass't Dir. |

*Deputy Directors*

| | |
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| **William Croyle** | **Statewide Emergency Preparedness and Security** |
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| **John Pacheco** (Acting) | **California Energy Resources Scheduling** |
| **Kathie Kishaba** | **Business Operations** |
| **Taryn Ravazzini** | **Special Initiatives** |

*Division of Integrated Regional Water Management*

**Arthur Hinojosa Jr.**, Chief

*Prepared under the direction of:*

**David Gutierrez**, Sustainable Groundwater Management Program Manager
**Rich Juricich**, Sustainable Groundwater Management Branch

*Prepared by:*

**Trevor Joseph**, BMP Project Manager

Timothy Godwin
Dan McManus
Mark Nordberg
Heather Shannon
Steven Springhorn

*With assistance from:*

DWR Region Office Staff

# Hydrogeologic Conceptual Model
# Best Management Practice

## 1. OBJECTIVE

The objective of this Best Management Practice (BMP) is to assist in the use and development of *hydrogeologic conceptual models* (HCM). The California Department of Water Resources (the Department or DWR) has developed this document as part of the obligation in the Technical Assistance Chapter (Chapter 7) of the Sustainable Groundwater Management Act (SGMA) to support the long-term sustainability of California's groundwater *basins*. Information provided in this BMP is meant to provide support to Groundwater Sustainability Agencies (GSAs) when developing a HCM in accordance with the Groundwater Sustainability Plan (GSP) Emergency Regulations (GSP Regulations). This BMP identifies available resources to support development of HCMs.

This BMP includes the following sections:

1. Objective. The objective and brief description of the contents of this BMP.
2. Use and Limitations. A brief description of the use and limitations of this BMP.
3. HCM Fundamentals. A description of HCM fundamental concepts.
4. Relationship of HCM to other BMPs. A description of how the HCM relates to other BMPs and is the basis for development of other GSP requirements.
5. Technical Assistance. A description of technical assistance to support the development of a HCM and potential sources of information and relevant datasets that can be used to further define each component.
6. Key Definitions. Definitions relevant for this BMP as provided in the GSP and Basin Boundary Regulations and in SGMA.
7. Related Materials. References and other materials that provide supporting information related to the development of HCMs.

## 2. USE AND LIMITATIONS

BMPs developed by the Department are intended to provide technical guidance to GSAs and other stakeholders. Practices described in these BMPs do not replace or serve as a substitute for the GSP Regulations, nor do they create new requirements or obligations for GSAs or other stakeholders. While the use of BMPs is encouraged, use and/or adoption of BMPs does not equate to an approval determination by the Department. All references to GSP Regulations relate to Title 23 of the California Code of Regulations (CCR), Division 2, Chapter 1.5, and Subchapter 2. All references to SGMA relate to California Water Code sections in Division 6, Part 2.74.

## 3. HCM FUNDAMENTALS

A HCM:

1. Provides an understanding of the general physical characteristics related to regional hydrology, land use, geology and geologic structure, water quality, *principal aquifers*, and principal aquitards of the *basin setting*;
2. Provides the context to develop water budgets, mathematical (analytical or numerical) models, and monitoring networks; and
3. Provides a tool for stakeholder outreach and communication.

A HCM should be further developed and periodically updated as part of an iterative process as *data gaps* are addressed and new information becomes available. A HCM also serves as a foundation for understanding potential uncertainties of the physical characteristics of a basin which can be useful for identifying *data gaps* necessary to further refine the understanding of the hydrogeologic setting. An example of a HCM depicted as a three-dimensional block diagram is shown in **Figure 1**.

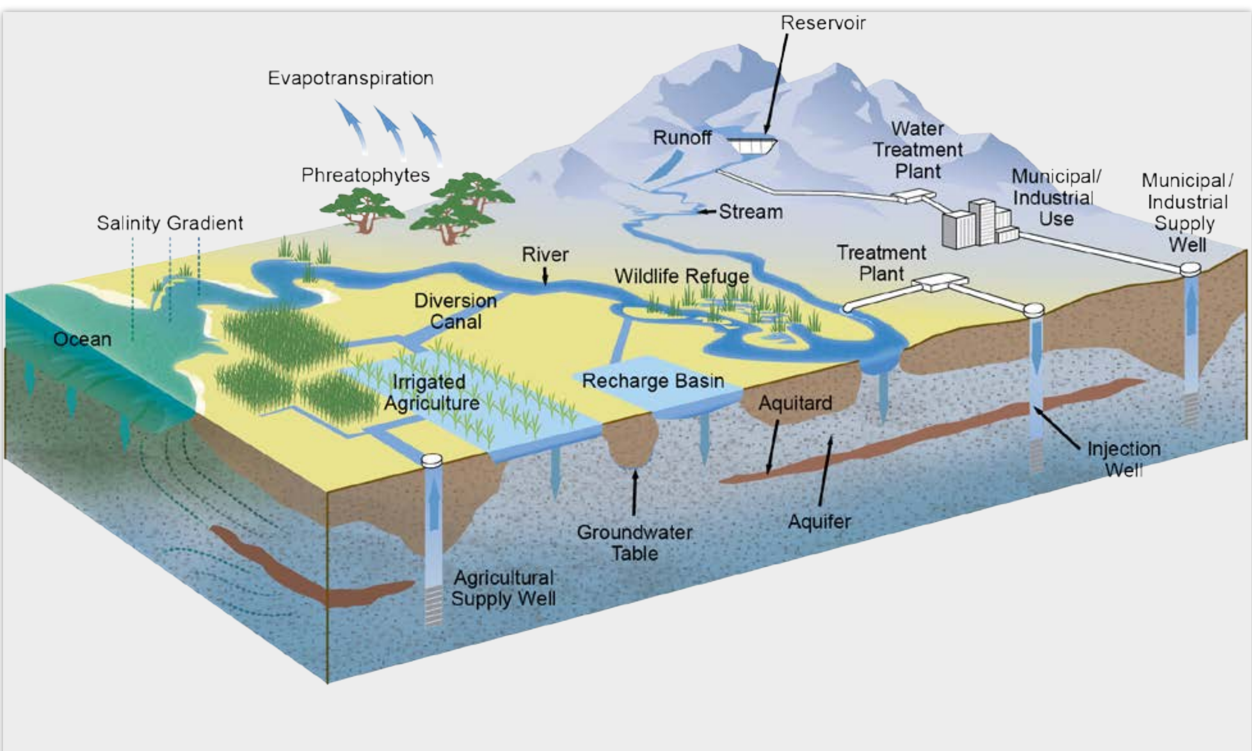



**Figure 1 – Example 3-D Graphic Representing a HCM**

## COMMON HCM USES

The following provides a limited list of common HCM uses:

- Develop an understanding and description of the basin to be managed, specifically the structural and physical characteristics that control the flow, storage, and quality of surface and groundwater
- Identify general water budget components
- Identify areas that are not well understood (*data gaps*)
- Inform monitoring requirements
- Facilitate or serve as the basis for the development, construction, and application of a mathematical (analytical or numerical) model
- Refine the understanding of basin characteristics over time, as new information is acquired from field investigation activities, monitoring networks, and modeling results
- Provide often highly-technical information in a format more easily understood to aid in stakeholder outreach and communication of the basin characteristics to local water users
- Help identify potential projects and management actions to achieve the sustainability goal within the basin

## HCM IN REFERENCE TO THE GSP REGULATIONS

> *23 CCR §354.14 (a): Each Plan shall include a descriptive hydrogeologic conceptual model of the basin based on technical studies and qualified maps that characterizes the physical components and interaction of the surface water and groundwater systems in the basin.*

GSP Regulations[1] require that each GSP include a HCM for the basin reported in a narrative and graphical form that provides an overview of the physical basin characteristics, uses of groundwater in the basin, and sets the stage for the *basin setting* (GSP §354.14(a)). The GSP Regulations identify the level of detail to be included for the HCM to aid in describing the *basin setting* for the GSP development and sustainability analysis.

[1] http://www.water.ca.gov/groundwater/sgm/pdfs/GSP_Emergency_Regulations.pdf

The HCM requirements outlined pertain to two main types of information:

1. The narrative description is accompanied by a graphical representation of the basin that clearly portrays the geographic setting, regional geology, basin geometry, general water quality, and consumptive water uses in the basin.
2. A series of geographic maps and scaled cross-sections to provide a vertical layering representation and a geographic view of individual datasets including the topography, geology, soils, *recharge* and discharge areas, source and point of delivery of imported water supplies, and surface water systems that are significant to management of the basin.

A HCM differs from a mathematical (analytical or numerical) model in that it does not compute specific quantities of water flowing through or moving into or out of a basin, but rather provides a general understanding of the physical setting, characteristics, and processes that govern groundwater occurrence within the basin. In that sense, the HCM forms the basis for mathematical (analytical or numerical) model development, and sets the stage for further quantification of the water budget components.

The intent of requiring HCMs in the GSP Regulations is not to provide a direct measure of sustainability, but rather to provide a useful tool for GSAs to develop their GSP and meet other requirements of SGMA.

## 4. RELATIONSHIP OF HCM TO OTHER BMPS

The purposes of the HCM in the broader context of SGMA implementation include:

- Supporting the evaluation of sustainability indicators, assessing the potential for undesirable results, and development of minimum thresholds;
- Supporting identification and development of potential projects and management actions to address undesirable results that exist or are likely to exist in the future; and
- Supporting the development of monitoring protocols, networks, and strategies to evaluate the sustainability of the basin over time.

The HCM is also linked to other related BMPs as illustrated in **Figure 2**. This figure provides the context of the BMPs as they relate to various steps to sustainability as outlined in the GSP Regulations. The HCM BMP is part of the *Basin Setting* development step in the GSP Regulations.

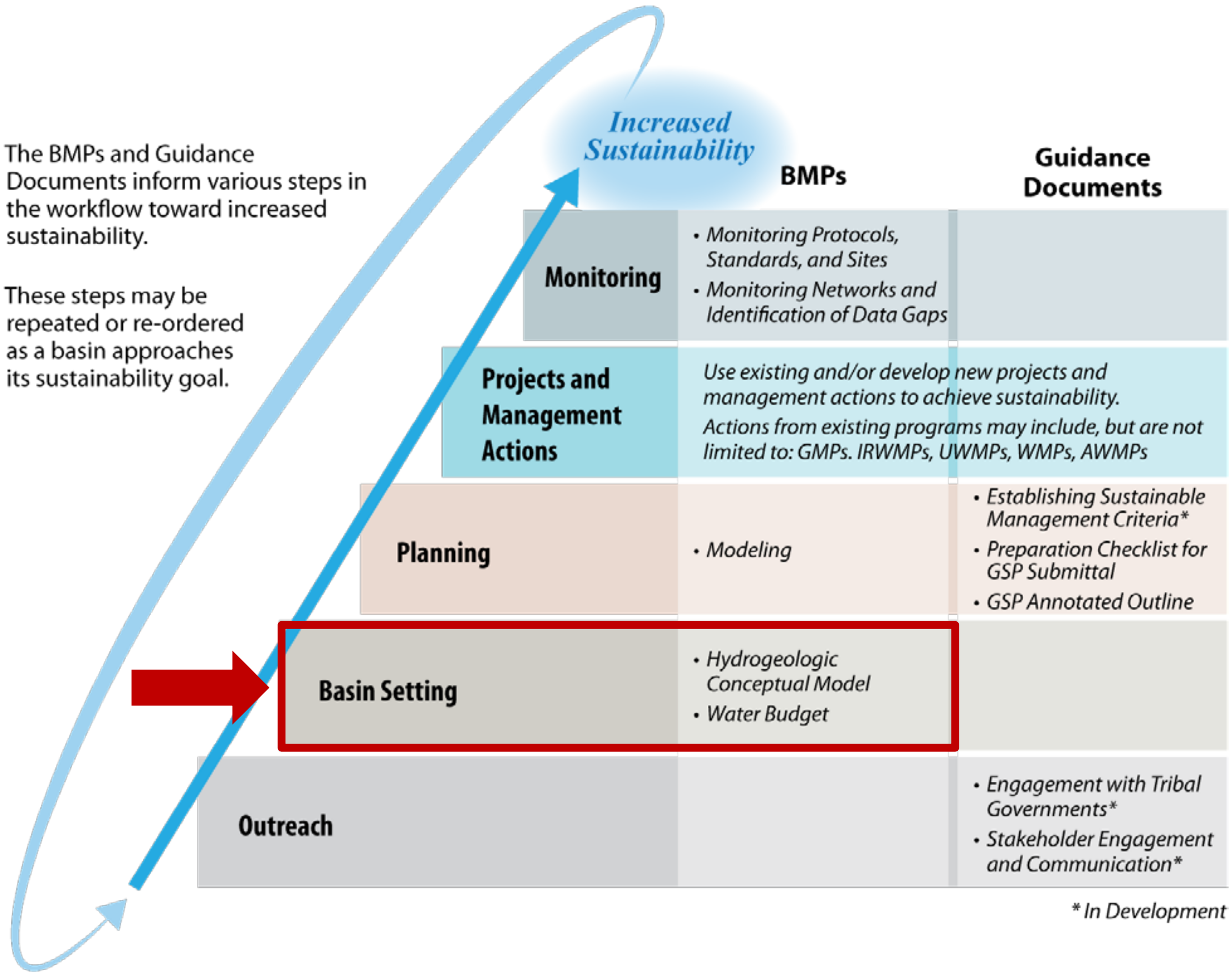



**Figure 2 – Logical Progression of Basin Activities Needed to Increase Basin Sustainability**

HCM development is the first step to understanding and conveying the GSP *basin setting*. The HCM is also linked to other GSP components (and applicable related BMPs) as illustrated **Figure 3**. For example, the HCM supports the development of the monitoring networks and activities needed to better understand the distribution and movement of water within a basin, which leads to the initial development and quantification of a water budget. Once the HCM and water budget have been developed, a mathematical (analytical or numerical) model may be built to further evaluate sustainability indicators, assess the probability of future undesirable results, and support basin management decisions as necessary to avoid the occurrence of undesirable results.

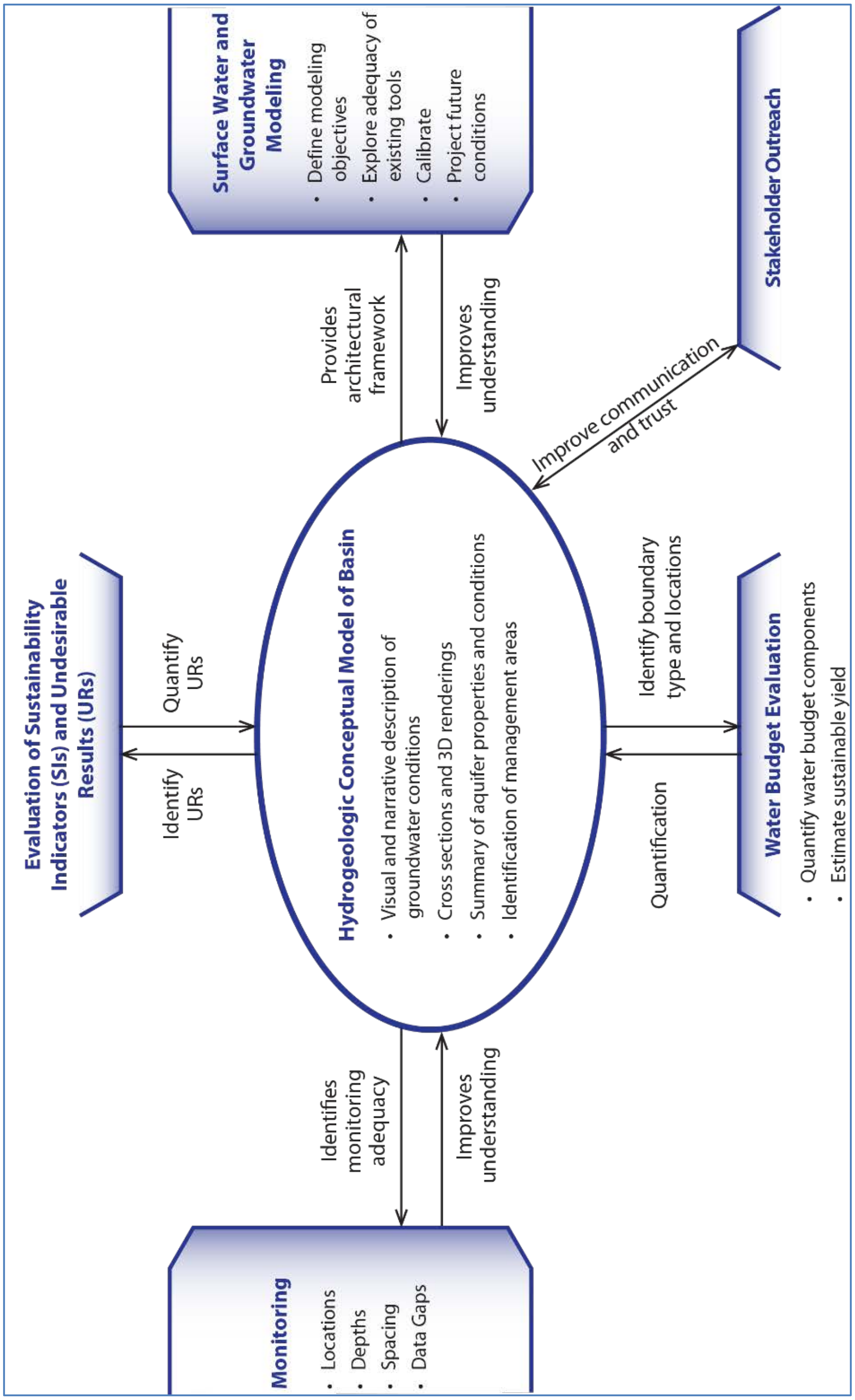



**Figure 3 – Interrelationship between HCM and Other BMPs and Guidance Documents**

# 5. TECHNICAL ASSISTANCE

This section provides technical assistance to support the development of a basin HCM including potential sources of information and relevant datasets that can be used to develop each HCM requirement. As described in the GSP Regulations Section 354.12, the Basin Setting shall be prepared by or under the direction of a professional geologist or professional engineer.

## CHARACTERIZING THE PHYSICAL COMPONENTS

Each section below is related to the specific GSP Regulation requirements and provides additional technical assistance for the GSA's consideration.

*23 CCR §354.14 (b)(1): The regional geologic and structural setting of the basin including the immediate surrounding area, as necessary for geologic consistency.*

The regional geologic and structural setting of a basin describes the distribution, extent, and characteristics of the geologic materials present in the basin along with the location and nature of significant structural features such as faults and bedrock outcrops that can influence groundwater behavior in the basin.

This type of information can often be found in existing geologic maps and documents published by the Department (specifically Bulletin 118 and 160), the United States Geological Survey (USGS), and other local government agencies (references are also provided in Section 7). Groundwater Management Plans and other technical reports prepared for the basin may also include information of this type.

*23 CCR §354.14 (b)(2): Lateral basin boundaries, including major geologic features that significantly affect groundwater flow.*

Basin boundaries are often geologically controlled and may include bedrock boundaries that define the margins of the alluvial groundwater *aquifer* system, and therefore represent barriers to groundwater flow. For a map of the Department's Bulletin 118 groundwater basins and subbasins refer to the Department's basin boundary website.

Other basin boundaries may include rivers and streams, or structural features such as faults. Additionally, basins on the coast can be subject to seawater intrusion, which creates another type of boundary to the freshwater basin. Information on these types of boundaries can also be found in reports prepared by State (California Geological Survey) or federal agencies (USGS) or by local agencies or districts. In addition, the presence of seawater along the coastal margin can also reflect the boundary of a coastal basin.

*23 CCR §354.14 (b)(3): Definable bottom of the basin.*

Several different techniques or types of existing information can be used in the evaluation of the definable bottom of the basin and extent of freshwater.

*Defining the Basin Bottom based on Physical Properties*

The bottom of the basin may be defined as the depth to bedrock also recognized as the top of bedrock below which no significant groundwater movement occurs. This type of information may be found from reviewing geologic logs from wells drilled for water extraction, as well as from oil and gas exploration wells which tend to be drilled deeper than usable aquifer systems.

*Defining the Basin Bottom based on Geochemical Properties*

In many basins of the Central Valley, freshwater is underlain by saltier or brackish water that is a remnant of the marine conditions that were present when the Valley was flooded in the geologic past. Several standards exist that can be used to define the base of freshwater and the bottom of the basin in the Central Valley:

- Base of freshwater maps in the Central Valley published by the Department and by USGS
- United States Environmental Protection Agency (US EPA) definition for Underground Source of Drinking Water (USDW)

The Department plans to release a freshwater map for the Central Valley that depicts the useable bottom of the alluvial aquifer. This map assumes that the base of freshwater is defined by the Title 22 State Water Resources Control Board (SWRCB) upper secondary maximum contaminant level recommendation of 1,000 milligrams per liter (mg/L) total dissolved solids (TDS).

The USGS has two base of fresh water maps available in the Central Valley based on 3,000 mg/L TDS.

An alternative threshold available to define the bottom of the groundwater basin is the US EPA USDW standard of less than 10,000 mg/L TDS. In some basins, oil and gas *aquifers* underlie the potable alluvial *aquifer* or USDW (defined as less than 10,000 mg/L TDS in Title 40, Section 144.3, of the Code of Federal Regulations). In basins where produced water from underlying oil and gas operations is beneficially used within the basin, or injected into the basin's USDW, the HCM can further characterize the geologic boundaries that separate the USDW from the oil and gas *aquifers*, and identify the "exempted *aquifer*" portion of the groundwater basin that has been permitted for underground injection control by the SWRCB Oil and Gas Monitoring Program or the Division of Oil, Gas and Geothermal Resources (DOGGR).

It should be noted that the definable bottom of the basin should be at least as deep as the deepest groundwater extractions; however, this may not be an appropriate method if it conflicts with other local, State, or Federal programs or ordinances. Finally, consideration should be given to how the bottom of the basin is defined in hydraulically-connected adjacent basins, as this could create additional complexity when developing and implementing GSPs.

*Defining the Basin Bottom based on Field Techniques*

Common field techniques used to define the bottom of alluvial basins can be subdivided into techniques utilizing direct measurements and those utilizing indirect measurements. The most common ones are listed below.

**Direct measurement** approaches typically involve drilling of multiple wells through the freshwater-bearing alluvial aquifer sediments and into the underlying lithologic units, whether it is bedrock or alluvium, containing groundwater that does not meet the criteria for potable water or an USDW. Once each borehole has been constructed, several different approaches can be taken to estimate the depth to the basin bottom at that location. Compilation of data from multiple wells can then be used to prepare a contour map of the depth to the basin bottom. Typical direct techniques include:

- Installation of multi-port well systems or installation of a nested well array
- Continuous profiling of lithology/groundwater quality using TDS, conductivity, or other downhole geophysical techniques
- Mapping depth to bedrock from borehole

**Indirect measurement** approaches are typically employed along the ground surface or from helicopters or fixed-wing aircraft. The most common methods used are geophysical techniques or surveys. Typical geophysical techniques that can be used to estimate bedrock depth or groundwater quality profiles include:

- Seismic refraction/reflection surveys
- Gravity surveys
- Magnetic surveys
- Resistivity surveys
- Radar, including ground penetrating radar
- Other Electromagnetic techniques

*23 CCR §354.14 (b)(4): Principal aquifers and aquitards, including the following information:*
*(A) Formation names, if defined.*
*(B) Physical properties of aquifers and aquitards, including the vertical and lateral extent, hydraulic conductivity, and storativity, which may be based on existing technical studies or other best available information.*
*(C) Structural properties of the basin that restrict groundwater flow within the principal aquifers, including information regarding stratigraphic changes, truncation of units, or other features.*
*(D) General water quality of the principal aquifers, which may be based on information derived from existing technical studies or regulatory programs.*
*(E) Identification of the primary use or uses of each aquifer, such as domestic, irrigation, or municipal water supply.*

*Aquifer* information is available in geologic reports from the Department and USGS, such as Bulletin 118, and local groundwater management plans and studies. Links to applicable reports are provided below. The USGS maintains very detailed reports and datasets for groundwater quality throughout the state that can be downloaded from their California Water Science Website (http://ca.water.usgs.gov/). The SWRCB also collects and maintains groundwater quality data, accessible through their GeoTracker GAMA website. (http://www.waterboards.ca.gov/gama/geotracker_gama.shtml)

In addition, the Regional Water Quality Control Boards, with coordination from the SWRCB, manage groundwater quality programs and data related to the Irrigated Lands Regulatory Program (http://www.swrcb.ca.gov/water_issues/programs/agriculture/). These programs are in the early phases of development, and data are being collected by local entities. As groundwater quality data become available through these programs, they may be a good source of information for HCM and GSP development. The Central Valley Regional Water Quality Control Board and SWRCB, in cooperation with stakeholders and the Central Valley Salinity Coalition, collaborate to review and update the basin plans for the Sacramento and San Joaquin river basins, the Tulare Lake Basin, and the Delta Plan for salinity management. As part of this program, technical reports are being developed and groundwater quality data are being collected in the Central Valley aquifer that provide other sources of information for those basins (http://www.cvsalinity.org/).

Uses of groundwater can be found within water quality control plans (known as basin plans), agricultural water management plans (AWMP) and urban water management plans (UWMP), which detail the use of water by agency and by types of beneficial uses. In addition, basin plans describe the water quality objectives and beneficial uses to be protected, with a program of implementation to achieve those objectives.

23 CCR *§354.14 (b)(5): Identification of data gaps and uncertainty within the hydrogeologic conceptual model.*

An assessment of the uncertainty in the HCM components, along with the identification of data gaps of the physical system and water use practices in the basin, are all necessary elements of the HCM. Typical data gaps and uncertainties related to the HCM include the hydraulic properties of the aquifer and aquitard materials, the depth and thickness of various geologic layers, and adequate geographic distribution of groundwater quality data, among others. It is important to adequately evaluate data gaps and uncertainties within a HCM as these data gaps often drive the types and locations of monitoring that should be conducted to reduce uncertainties in these conceptual model components.

For example, a portion of a groundwater basin may not be well characterized from previous studies and historic monitoring activities; therefore, there is less readily-available information to define the HCM in that portion of the basin. Specific data collection activities to address these *data gaps* could then be considered in the development of the GSP.

## GRAPHICAL AND MAPPING REQUIREMENTS

*23 CCR §354.14 (c): The hydrogeologic conceptual model shall be represented graphically by at least two scaled cross-sections that display the information required by this section and are sufficient to depict major stratigraphic and structural features in the basin.*

In addition to the narrative description of the HCM, another necessary element of a HCM is a graphical representation of the HCM components in the form of at least two geologic cross-sections. A cross-section depicts the vertical layering of the geology and major subsurface structural features in a basin, in addition, but not limited to, other HCM features such as the general location and depth of existing monitoring and production wells and the interaction of streams with the aquifer.

The locations selected for cross-section development in a basin are best informed by the sustainability indicators most critical to that basin, as well as the potential for undesirable results to occur. For example, if subsidence is a known issue in a basin, construction of cross-section(s) may be focused in areas where subsidence has occurred or is at risk of occurring. An example of a scaled cross-section is provided in **Figure 4**.

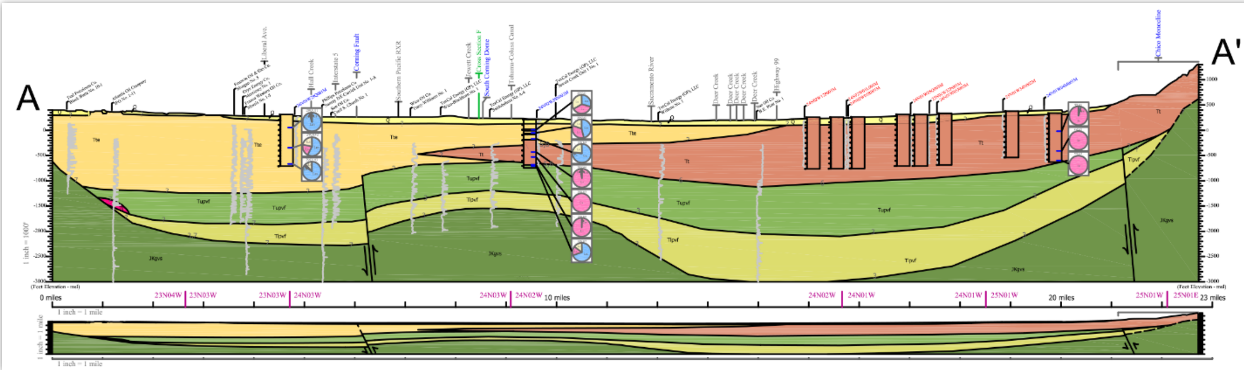



**Figure 4 – Example Scaled Cross-Section**

Geologic cross-sections should be constructed by a professional geologist, or a person knowledgeable of geologic principles such as the Laws of Superposition, Original Horizontality, cross-cutting relationships, and Walther's Law. The type of cross-section ranges from "conceptual to highly detailed", depending on the intended use. The type of cross-section also depends on the type of subsurface data that is available and the reliability of that data. A full understanding of, and appreciation for, the variety of depositional environments, like sequence stratigraphy, is needed to construct accurate geological cross sections. Cross-section construction considerations include, but are not limited to, the following:

- Geologic cross-sections are often oriented perpendicular to the strike of the regional bedding. If a line of section oblique to the strike of regional bedding is selected, apparent dip of bedding and structural features should be computed and included in the geologic cross-section. It is important to choose a geologically relevant orientation with respect to strike and dip (and to note whether any of the selected orientations depict an apparent dip much different than the true dip).

- The geologic cross-section should not change trend direction, or bend significantly as this can change the relationship of the deposition direction. North and east should be on the right side of the page. If wells logs are projected onto the section the distance they are projected from the section line should be noted.

- The location and orientation of the line of geologic cross-section should be presented in plan view on a geologic map. The horizontal distance between boreholes, geologic contacts, structural features, and surface features is interpreted from the scale of the geologic map. The horizontal scale can be enlarged or reduced, preserving the relative distances, based on cross-section size. The vertical scale of the cross-section can exceed the horizontal scale (vertical exaggeration) in order to more clearly present the subsurface data. However, the scale should be chosen without undue vertical exaggeration.

- Subsurface lithology and structural features should be projected from surface contacts at the dip angle (or apparent dip) reported on the geologic map. Subsurface contacts may be correlated/interpreted between boreholes based on available lithologic logs and professional judgement. The cross-sections should be tied where they cross and to the geologic map at formation contacts.

- Cross-sections should include major aquifer and aquitard units, but it may not be necessary to include all lithologic beds on the cross-section.

- The geologic cross-section should include information provided on lithologic logs for boreholes along the line of section. Information for wells off-set from the line of section can be projected onto the cross-section. The maximum distance for projection of data onto the cross-section will be dependent upon the scale; professional judgement should be used in the selection of the maximum projection distance. The distance for projection of data should be somewhat dependent on the reasonableness one can infer that the units or features continue with some level of certainty. Conversely, if there is uncertainty, dashed lines or question marks are often applied to denote uncertainty.

- The level of detail and quality of available subsurface lithologic logs will vary between boreholes. The quality of individual lithologic logs should be considered when correlating subsurface borehole information.

- Where two cross-section lines intersect, the subsurface interpretations presented on the geologic cross-sections should be consistent at the intersection.

- The data used for horizon boundaries should be shown and posted for reference; and any references used to depict the cross-sections should be cited.

If known, other details should also be included in hydrogeologic cross sections, such as: (1) static water level of each *aquifer*; (2) screened intervals; (3) total depth of the boring/well; (4) availability of geophysical logs; and (5) type of drilling method. Additional notation on the cross-section may also be helpful for illustration.

> *23 CCR §354.14 (d) Physical characteristics of the basin shall be represented on one or more maps that depict the following:*
> *(1) Topographic information derived from the U.S. Geological Survey or another reliable source.*
> *(2) Surficial geology derived from a qualified map including the locations of cross sections required by this Section.*
> *(3) Soil characteristics as described by the appropriate Natural Resources Conservation Service soil survey or other applicable studies.*
> *(4) Delineation of existing recharge areas that substantially contribute to the replenishment of the basin, potential recharge areas, and discharge areas, including significant active springs, seeps, and wetlands within or adjacent to the basin.*
> *(5) Surface water bodies that are significant to the management of the basin.*
> *(6) The source and point of delivery for imported water supplies.*

Geographical representations of the distribution of major data elements in a groundwater basin in map form help illustrate the layout of data and information presented in the HCM. The data for these maps are generally available from various sources such as GIS Shapefiles that can be overlain on a basin-wide base map.

As stated in the GSP Regulations, physical characteristics of the basin need to be displayed on maps. Information is provided on the types of datasets readily available for mapping.

- Topographic information can be found from online USGS topographic maps or more detailed high resolution Digital Elevation Model (DEM) mapping GIS datasets. There are several sources of topographic and DEMs available online, such as the ones provided in Section 7.

- In addition, the ESRI ArcGIS platform also includes DEM data available for use in conjunction with the ESRI GIS software.

- Surficial Geologic information can be downloaded from the California Geological Survey (CGS) and USGS from their interactive mapping tool.
    - CGS - http://maps.conservation.ca.gov/cgs/gmc/
    - USGS - http://ngmdb.usgs.gov/ngmdb/ngmdb_home.html

  The map that is produced to illustrate the surficial geology of the basin should also include the location of the cross-sections.

- The National Resource Conservation Service (NRCS) maintains soil data and Shapefiles nationwide on a county basis available at their website: http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx.
  For additional related soil characteristics in California, see the UC Davis soil interactive maps (http://casoilresource.lawr.ucdavis.edu/).

- *Recharge* and discharge areas of groundwater are generally not well mapped. This type of information may be available from local and regional groundwater management planning documents, or larger reports form the Department and USGS. Additional *recharge* maps in California have been developed by the California Soil Resource Lab at UC Davis – The following link is to their Soil Agricultural Groundwater Banking Index (SAGBI): http://casoilresource.lawr.ucdavis.edu/sagbi/

- Surface water mapping data can be downloaded from ESRI base maps within ArcGIS, or downloaded from the National Hydrography Datasets (NHD) datasets: http://viewer.nationalmap.gov/viewer/nhd.html?p=nhd

- Water supplies imported into a basin from state, federal, or local projects need to be mapped for the HCM. This information is generally available from the major suppliers of surface water such as the Department, United States Bureau of Reclamation (USBR), and local water and irrigation districts.

Additional useful information to be mapped may include:

- Groundwater elevation contour maps show the spatial distribution of groundwater elevations and help identify areas of low and high groundwater level areas within a basin. Elevation contour maps can be created from water level data collected from wells that are screened within the same principal aquifers. Information on water level data interpolation to create contour maps can be found in Tonkin et. al (2002).

- Land use maps detail the agricultural and urban land uses, and the distribution of natural vegetation, including potentially groundwater-dependent ecosystems. Land use maps shall use the Department land use classification scheme and maps provided by the Department.

An example of a geologic map is provided in **Figure 5**.

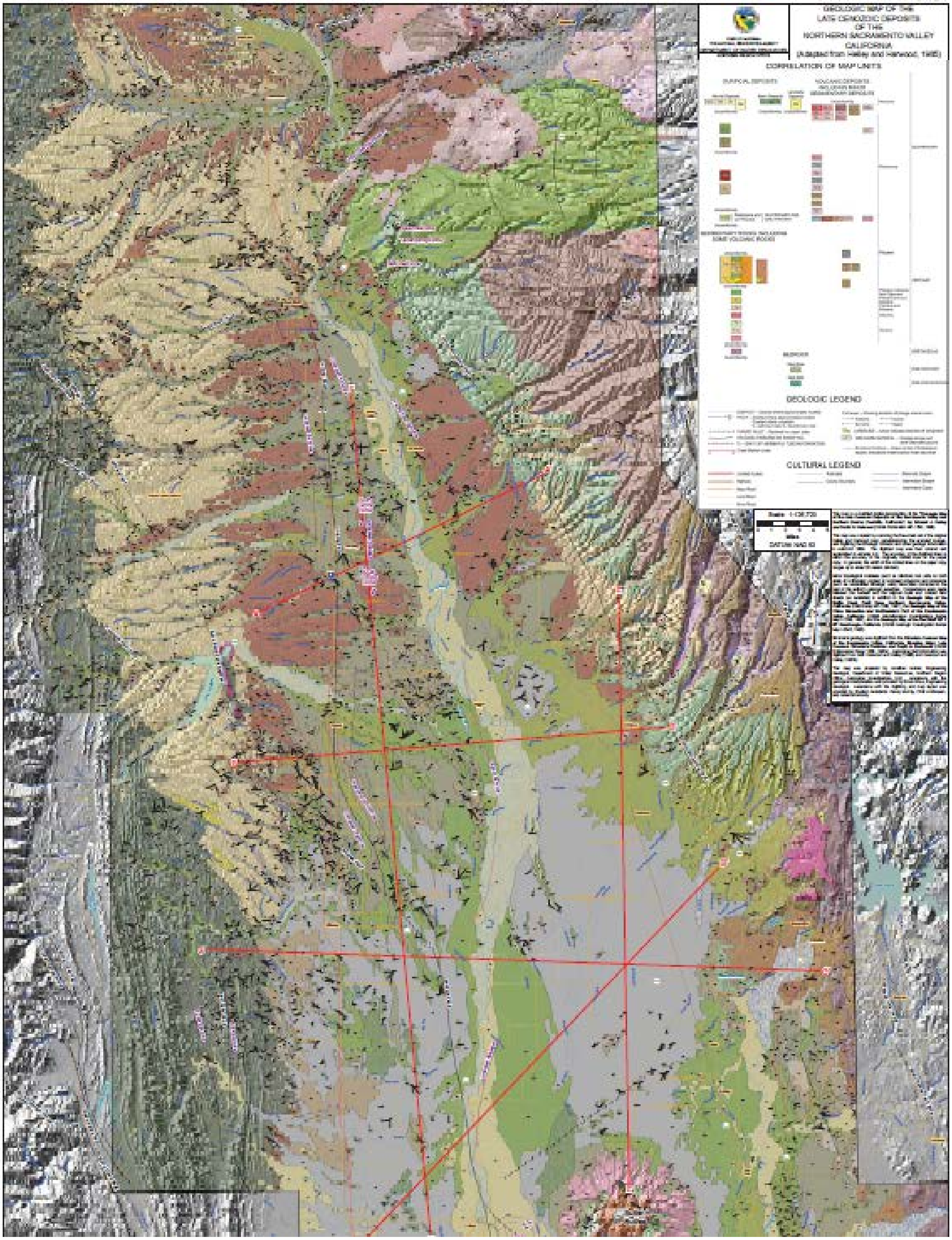



**Figure 5 – Example Geologic Map**

## TYPICAL FLOW OF GRAPHICAL HCM DEVELOPMENT

The HCM requirements outlined in the GSP Regulations pertain to two main types of information:

1. Narrative description of the basin, which can be accompanied by a three-dimensional graphic illustration of the HCM to complement the narrative; and
2. At least two scaled cross-sections and geographic maps to provide vertical layering representation and a geographic view of individual datasets, respectively.

The typical flow of graphical HCM development is presented in **Figure 6**. This figure shows the level of technical representation and detail, from basic cartoon-type representation, to a geographic representation map, to a scaled vertical cross-section that provides more subsurface detail for the HCM.

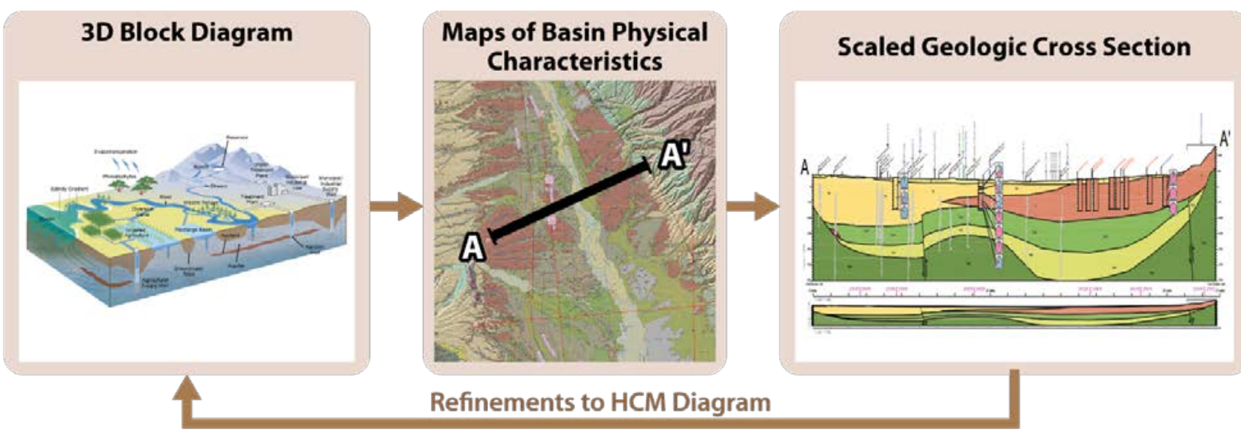



Figure 6 – Steps to Developing Graphic Representations of the HCM

## 6. Key Definitions

The key definitions related to HCM development outlined in applicable SGMA code and regulations are provided below for reference.

**SGMA Definitions (California Water Code §10721)**

- "Groundwater recharge" or "recharge" means the augmentation of groundwater by natural or artificial means.

- "Recharge area" means the area that supplies water to an aquifer in a groundwater basin.

**Groundwater Basin Boundaries Regulations (California Code of Regulations §341)**

- "Aquifer" refers to a three-dimensional body of porous and permeable sediment or sedimentary rock that contains sufficient saturated material to yield significant quantities of groundwater to wells and springs, as further defined or characterized in Bulletin 118.

- "Hydrogeologic conceptual model" means a description of the geologic and hydrologic framework governing the occurrence of groundwater and its flow through and across the boundaries of a basin and the general groundwater conditions in a basin or subbasin.

- "Qualified map" means a geologic map of a scale no smaller than 1:250,000 that is published by the U. S. Geological Survey or the California Geological Survey, or is a map published as part of a geologic investigation conducted by a state or federal agency, or is a geologic map prepared and signed by a Professional Geologist that is acceptable to the Department.

- "Technical study" means a geologic or hydrologic report prepared and published by a state or federal agency, or a study published in a peer-reviewed scientific journal, or a report prepared and signed by a Professional Geologist or by a Professional Engineer.

**Groundwater Sustainability Plan Regulations (California Code of Regulations §351)**

- "Basin setting" refers to the information about the physical setting, characteristics, and current conditions of the basin as described by the Agency in the hydrogeologic conceptual model, the groundwater conditions, and the water budget, pursuant to Subarticle 2 of Article 5.

- "Best available science" refers to the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision, that is consistent with scientific and engineering professional standards of practice.

- "Data gap" refers to a lack of information that significantly affects the understanding of the basin setting or evaluation of the efficacy of Plan implementation, and could limit the ability to assess whether a basin is being sustainably managed.

- "Principal aquifers" refer to aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems.

- "Uncertainty" refers to a lack of understanding of the basin setting that significantly affects an Agency's ability to develop sustainable management criteria and appropriate projects and management actions in a Plan, or to evaluate the efficacy of Plan implementation, and therefore may limit the ability to assess whether a basin is being sustainably managed.

- "Water source type" represents the source from which water is derived to meet the applied beneficial uses, including groundwater, recycled water, reused water, and surface water sources identified as Central Valley Project, the State Water Project, the Colorado River Project, local supplies, and local imported supplies.

- "Water use sector" refers to categories of water demand based on the general land uses to which the water is applied, including urban, industrial, agricultural, managed wetlands, managed *recharge*, and native vegetation.

## 7. Related Materials

This section provides a list of related materials including general references, standards, guidance documents, and selected case studies and examples pertinent to the development of HCMs. For the items identified, available links to access the materials are also provided. In addition, common data sources and links to web-materials are also provided. By providing these links, DWR neither implies approval, nor expressly approves of these documents.

It should also be noted that existing Groundwater Management Plans (GMP), Salt & Nutrient Management Plans (SNMP), Urban Water Management Plans (UWMP), Drinking Water Source Assessment Plans (DWSAP), Agricultural Water Management Plans (AWMP), and Integrated Regional Water Management Plans (IRWMP) may be useful references in the development of HCMs. To the extent practicable, GSAs should utilize and build on available information.

### STANDARDS

- ASTM D5979 – 96 (2014) Standard Guide for Conceptualization and Characterization of Groundwater Systems

### REFERENCES FOR FURTHER GUIDANCE

Basin Boundary Modifications web page. California Department of Water Resources. http://www.water.ca.gov/groundwater/sgm/basin_boundaries.cfm *Accessed December 2016.*

California Geological Survey web page. California Department of Conservation. http://www.quake.ca.gov/ *Accessed December 2016.*

California Soil Resource Lab web page. University of California, Davis. https://casoilresource.lawr.ucdavis.edu/ *Accessed December 2016.*

California Water Plan (Bulletin 160). California Department of Water Resources. http://www.water.ca.gov/waterplan/cwpu2013/final/index.cfm *Accessed December 2016.*

California Water Science Center. U.S. Geological Survey. http://ca.water.usgs.gov/ *Accessed December 2016.*

California's Groundwater, Bulletin 118. California Department of Water Resources. http://water.ca.gov/groundwater/bulletin118.cfm *Accessed December 2016.*

Central Valley Salinity Alternatives for Long-term Sustainability web page. Central Valley Salinity Coalition. http://www.cvsalinity.org/ *Accessed December 2016.*

European Commission. 2010. *Common Implementation Strategy for the Water Framework Directive (2000/60/EC). Guidance Document No. 26. Guidance on Risk Assessment and the Use of Conceptual Models for Groundwater.* Technical Report – 2010-042.

Fulton, J.W., et. al. 2005. *Hydrogeologic Setting and Conceptual Hydrologic Model of the Spring Creek Basin, Centre County, Pennsylvania, June 2005.* USGS Scientific Investigation Report 2005-5091.
http://pubs.usgs.gov/sir/2005/5091/sir2005-5091.pdf

Geologic Map of California (GMC). California Department of Conservation.
http://maps.conservation.ca.gov/cgs/gmc/ *Accessed December 2016.*

Groundwater Ambient Monitoring and Assessment Program (GAMA) web page. State Water Resources Control Board.
http://www.waterboards.ca.gov/gama/geotracker_gama.shtml *Accessed December 2016.*

Interactive Fault Map. U.S. Geological Survey.
http://earthquake.usgs.gov/hazards/qfaults/map/#qfaults *Accessed December 2016.*

Irrigated Lands Regulatory Program web page. State Water Resources Control Board.
http://www.swrcb.ca.gov/water_issues/programs/agriculture/ *Accessed December 2016.*

National Geologic Map Database. U.S. Geological Survey.
https://ngmdb.usgs.gov/ngmdb/ngmdb_home.html *Accessed December 2016.*

National Map Hydrography. U.S. Geological Survey.
https://viewer.nationalmap.gov/viewer/nhd.html?p=nhd *Accessed December 2016.*

Oil and Gas Monitoring Program web page. State Water Resources Control Board.
http://www.waterboards.ca.gov/water_issues/programs/groundwater/sb4/index.shtml
*Accessed December 2016.*

Teresita Betancur V., Carlos Alberto Palacio T. and John Fernando Escobar M. 2012. *Conceptual Models in Hydrogeology, Methodology and Results - A Global Perspective,* Dr. Gholam A. Kazemi (Ed.), ISBN: 978-953-51-0048-5, InTech, Available from: http://www.intechopen.com/books/hydrogeology-a-globalperspective/conceptual-models-in-hydrogeology-methodologies-and-results

Tonkin, M. and Larson, S. 2002. *Kriging Water Levels with a Regional-Linear and Point-Logarithmic Drift*, Ground Water, March-April 2002.

Toth, J. 1970. *A conceptual model of the groundwater regime and the hydrogeologic environment.* Journal Of Hydrology, Volume 10, Issue 1. February. doi:10.1016/0022-1694(70)90186-1

Web Soil Survey. U.S. Department of Agriculture Natural Resources Conservation Service. http://websoilsurvey.sc.egov.usda.gov/App/WebSoilSurvey.aspx *Accessed December 2016.*

## REFERENCES FOR CROSS SECTIONS

Suggestions to Authors of the Reports of the United States Geological Survey, Seventh Edition, 1991. See Section named Cross Sections and Stratigraphic Sections and Preparing Maps and Other Illustrations, with a subsection titled Cross Sections.

Manual of Field Geology, Robert Compton, 1962. Chapter 11, Preparing Geologic Reports, Section 11-10 Detailed Geologic Maps and Cross Sections.

Walker, Roger G. (editor), 1981, Facies Models, Geological Association of Canada Publications, Toronto, Canada, 211 pages.

Reading, H.G. (editor), 1978, Sedimentary Environments and Facies, Elsevier Press New York, 569 pages.

Krumbein, K.C. and L.L. Sloss. 1963, Stratigraphy and Sedimentation, W.H. Freeman and Company, San Francisco, 660 pages.

## DATA SOURCES

**Geology reports**:

**Geology of the Northern Sacramento Valley, CA:**
http://www.water.ca.gov/pubs/geology/geology_of_the_northern_sacramento_valley__california__june_2014-web/geology_of_the_northern_sacramento_valley__california__june_2014__updated_09_22_2014__website_copy_.pdf

**Digital Elevation Models (DEMs)**:

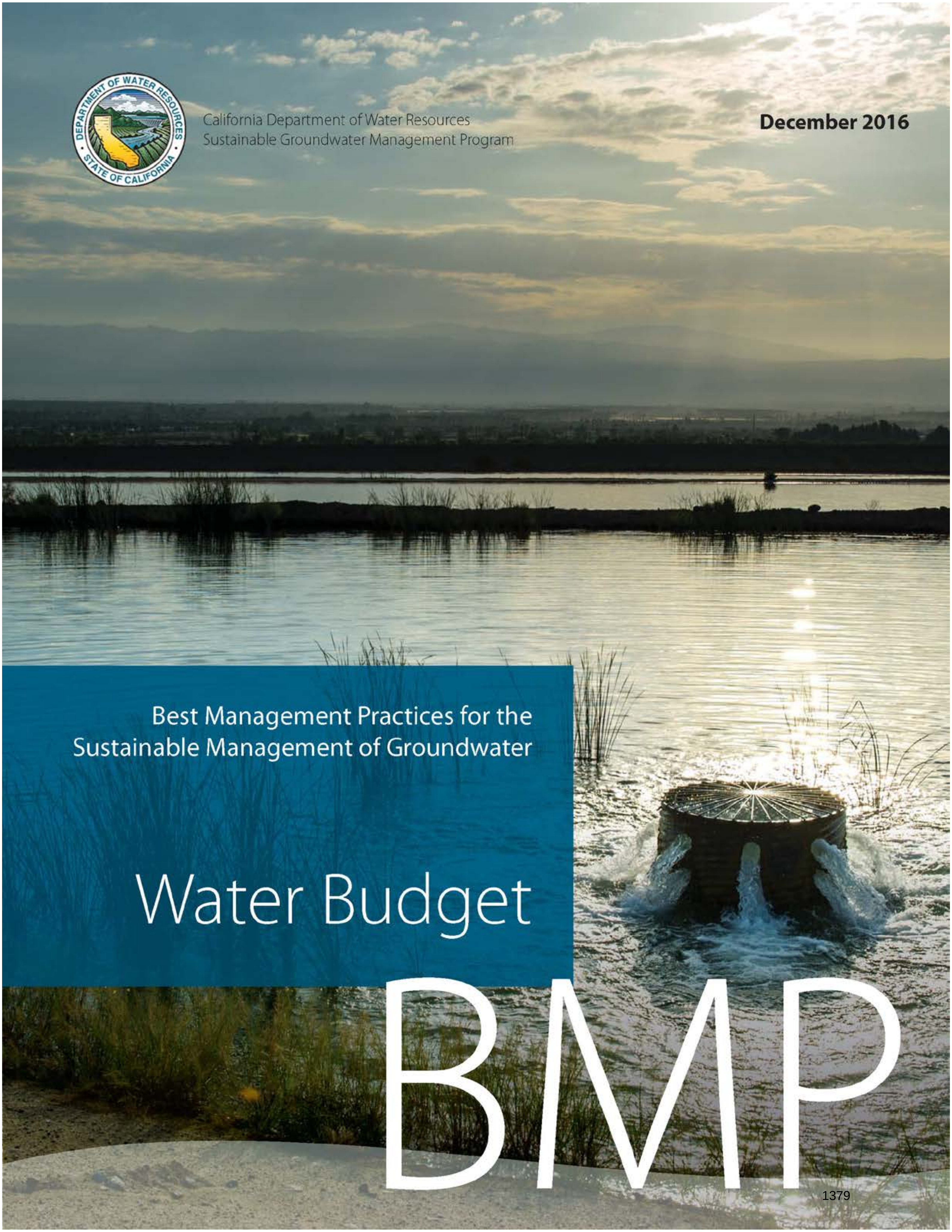
- http://www.opendem.info/opendem_client.html

- http://viewer.nationalmap.gov/basic/?basemap=b1&category=ned,nedsrc&title=3DEP%20View

- http://www.brenorbrophy.com/California-DEM.htm.

# Appendix 2C

# DWR Water Budget BMP



California Department of Water Resources
Sustainable Groundwater Management Program

December 2016

Best Management Practices for the Sustainable Management of Groundwater

# Water Budget

# BMP

State of California
**Edmund G. Brown Jr., Governor**

California Natural Resources Agency
**John Laird, Secretary for Natural Resources**

Department of Water Resources
**Mark W. Cowin, Director**

**Carl A. Torgersen,** Chief Deputy Director

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| **John Pacheco** (Acting) | **California Energy Resources Scheduling** |
| **Kathie Kishaba** | **Business Operations** |
| **Taryn Ravazzini** | **Special Initiatives** |

*Division of Integrated Regional Water Management*

**Arthur Hinojosa Jr.**, Chief

*Prepared under the direction of:*

**David Gutierrez**, Sustainable Groundwater Management Program Manager
**Rich Juricich**, Sustainable Groundwater Management Branch

*Prepared by:*

**Trevor Joseph**, BMP Project Manager

Timothy Godwin
Dan McManus
Mark Nordberg
Heather Shannon
Steven Springhorn

*With assistance from:*

DWR Region Office Staff

# Water Budget
# Best Management Practice

## 1. OBJECTIVE

The objective of this Best Management Practice (BMP) is to assist the use and development of *water budgets*. The Department of Water Resources (the Department or DWR) has developed this document as part of the obligation in the Technical Assistance Chapter (Chapter 7) of the Sustainable Groundwater Management Act (SGMA) to support the long-term sustainability of California's groundwater *basins*. Information provided in this BMP provides technical assistance to Groundwater Sustainability Agencies (GSAs) and other stakeholders on how to address water budget requirements outlined in the Groundwater Sustainability Plan (GSP) Emergency Regulations (GSP Regulations). This BMP identifies available resources to support development, implementation, and reporting of water budget information.

This BMP includes the following sections:

1. Objective. The objective and brief description of the contents of this BMP.
2. Use and Limitations. A brief description of the use and limitations of this BMP.
3. Water Budget Fundamentals. A description of fundamental water budget concepts.
4. Relationship of Water Budgets to other BMPs. A description of how the water budget BMP relates to other BMPs and how water budget information may be used to support development of other GSP requirements.
5. Technical Assistance. A description of technical assistance to support the development of a water budget, potential sources of information, and relevant datasets that can be used to further define each component.
6. Key Definitions. Definitions relevant for this BMP as provided in the GSP Regulations, Basin Boundary Regulations, SGMA, and DWR *Bulletin 118*.
7. Related Materials. References and other materials that provide supporting information related to the development of water budget estimates.

## 2. USE AND LIMITATIONS

This BMP is intended only to provide technical assistance to GSAs and other stakeholders. GSAs and other stakeholders may use this BMP. The BMP does not create any new requirements or obligations for the GSA or other stakeholders. This BMP is not a substitute for the GSP Regulations and SGMA. Those submitting a GSP are strongly encouraged to read the GSP Regulations and SGMA. In addition, using this BMP to develop a GSP does not equate to an approval by the Department. All references to GSP Regulations relate to Title 23 of the California Code of Regulations (CCR), Division 2, Chapter 1.5, and Subchapter 2. All references to SGMA relate to California Water Code sections in Division 6, Part 2.74.

## 3. WATER BUDGET FUNDAMENTALS

Earth's water is moved, stored, and exchanged between the atmosphere, land surface, and the subsurface according to the hydrologic cycle (**Figure 1**). The hydrologic cycle begins with evaporation from the ocean. As the evaporated water rises, the water vapor cools, condenses, and ultimately returns to the Earth's surface as precipitation (rain or snow). As the precipitation falls on the land surface, some water may infiltrate into the ground to become groundwater, some water may run off and contribute to streamflow, some may evaporate, and some may be used by plants and transpired back into the atmosphere to continue the hydrologic cycle (Healy, R.W. et al., 2007).

A water budget takes into account the storage and movement of water between the four physical systems of the hydrologic cycle, the atmospheric system, the land surface system, the river and stream system, and the groundwater system. A water budget is a foundational tool used to compile water inflows (supplies) and outflows (demands). It is an accounting of the total groundwater and surface water entering and leaving a basin or user-defined area. The difference between inflows and outflows is a change in the amount of water stored.

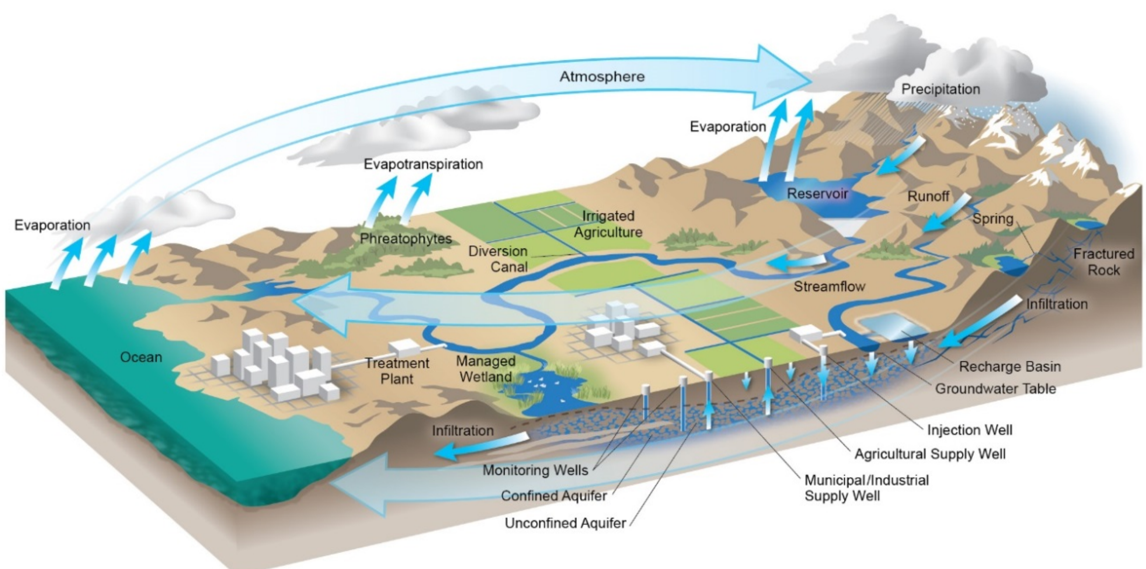


**Figure 1 – The Hydrologic Cycle**

In resource management it's said, "You can't manage what you don't measure." Similar to a checking account, water budget deposits (inflows) and withdrawals (outflows) are tracked and compared over a given time period to identify if the change in account balance is positive (increase in amount of water stored) or negative (decrease in the amount of water stored). During periods when inflows exceed outflows, the change in volume stored is positive. Conversely, during periods when inflows are less than outflows, the change in storage is negative. Surpluses from previous budget periods can act as a buffer towards isolated annual water budget deficits, but a series of ongoing negative balances can result in long-term conditions of overdraft.

Water budgets can be highly variable between groundwater basins. In some basins, precipitation may be the largest contributor to groundwater recharge. In other basins, leading sources of recharge may stem from infiltration and seepage of irrigation water, conveyance systems, septic systems, and various surface water systems (streams, lakes, reservoirs, etc.). In some areas, high groundwater levels result in seasonal or continuous outflow from the groundwater system to overlying surface water systems. In other basins, lower groundwater levels result in the continuous movement of water from the surface water system to the groundwater system. Assessment and comparison of annual water budget data requires using a consistent, user-defined area and period of evaluation. Under the GSP Regulations, the water budget is developed for the groundwater basin according to the annual *water year* period (October 1 to September 30).

In principle, a water budget is a simple concept that provides the accounting framework to measure and evaluate all inflows and outflows from all parts of the hydrologic cycle – atmospheric, land surface, surface water, and groundwater systems. In reality, it can be difficult to accurately measure and account for all components of the water budget for a given area. Some water budget components may be estimated independent of the water budget, while others may be calculated based on the fundamental principle that the difference between basin inflows and outflows is balanced by a change in the volume of water in storage. This principle is quantified according to the following water budget equation.

$$\text{Inflow}(a, b, c) - \text{Outflow}(a, b, c) = \text{Change in Storage}$$

**Equation 1 – Water Budget Equation**

Because groundwater basin inflows and outflows are balanced by a change in the amount of water in storage, the above equation may be rearranged to calculate, or "back into", an unknown component of the water budget equation. For example, if one wishes to determine unknown Outflow component "a", and all other components of the water budget for the groundwater system have been determined, Outflow "a" can be calculated by rearranging the above water balance equation as follows:

Outflow (a) = Inflow (a, b, c) – Outflow (b, c) – Change in Storage

To illustrate this example, consider a water budget scenario where total inflow from components "a", "b", and "c" equals 100 units of water; total outflow from all components other than "a" equals 40 units of water; and the annual change in storage identified through groundwater level measurements is approximately equal to +10 units of water. An estimate of outflow "a" during this period may be calculated from the above water budget equation as shown below. Note that "change in storage" is represented as a positive number to denote an increase in storage and a negative number to denote a decrease in storage.

Outflow (a) = Inflow (a, b, c) – Outflow (b, c) – Change in Storage
50 units = 100 units – 40 units – 10 units

Identifying which water budget components are most appropriate to estimate through balancing of the water budget equation will depend on the local ability to independently measure or estimate the remaining water budget components. It also depends on the relative importance, versus *uncertainty*, associated with each component in the overall water budget. A higher level of water budget uncertainty often translates to a higher risk that the projects and management actions being evaluated to achieve sustainability, based on future water budget projections, may not achieve the intended outcome within the intended timeframe.

An important consideration when implementing water resource management is the interaction between groundwater and surface water systems. *Groundwater flow* naturally moves down-gradient, from areas of high groundwater elevation to areas of lower groundwater elevation. In areas where groundwater levels are below the surface water system, the direction of groundwater flow will be from the surface water system to the groundwater system. Streams that receive water from the groundwater system are called "gaining" streams and those that lose water to the groundwater system are called "losing" streams (see **Figure 2**). The gaining or losing character of streamflow may be consistent throughout a stream system or it may be highly variable based on stream reach location and based on seasonal versus annual changes in local climatic conditions and the water inflow (recharge) or outflow (groundwater extraction) for the basin. It is therefore important to clearly identify and characterize stream segments included in the water budget calculation.

Unless additional inflows or supplies are developed, increases in groundwater extraction may eventually result in a hydraulic disconnection between the surface water and groundwater systems in basins where these systems are currently interconnected. Groundwater systems that are disconnected from the surface water system will still receive recharge from the surface water system. However, all further extraction from the groundwater system may be largely balanced through a decline of *groundwater in storage* and/or a reduction of subsurface outflow from the basin over time.

Another important water budget consideration is stream depletion due to groundwater pumping. In basins with *interconnected surface water* systems, if inflows (recharge) to the basin remain fixed while the amount of groundwater extraction increases, the increased volume of groundwater extraction, while initially resulting in a decline in the volume of *aquifer* storage, will eventually be balanced by decreases in the groundwater flow to springs, gaining streams, groundwater-dependent ecosystems or an increase in discharge from losing streams. Shallow production wells in close proximity to surface water systems commonly capture flow directly from the surface water system through induced recharge. Stream depletion associated with pumping wells further removed from surface water systems is more commonly the result of the indirect capture of groundwater flow that would otherwise have discharged to the surface water system sometime in the future. In both situations, streamflow depletion will continue until a new equilibrium between the outflow associated with groundwater extraction and the inflow from surface water depletion is established.

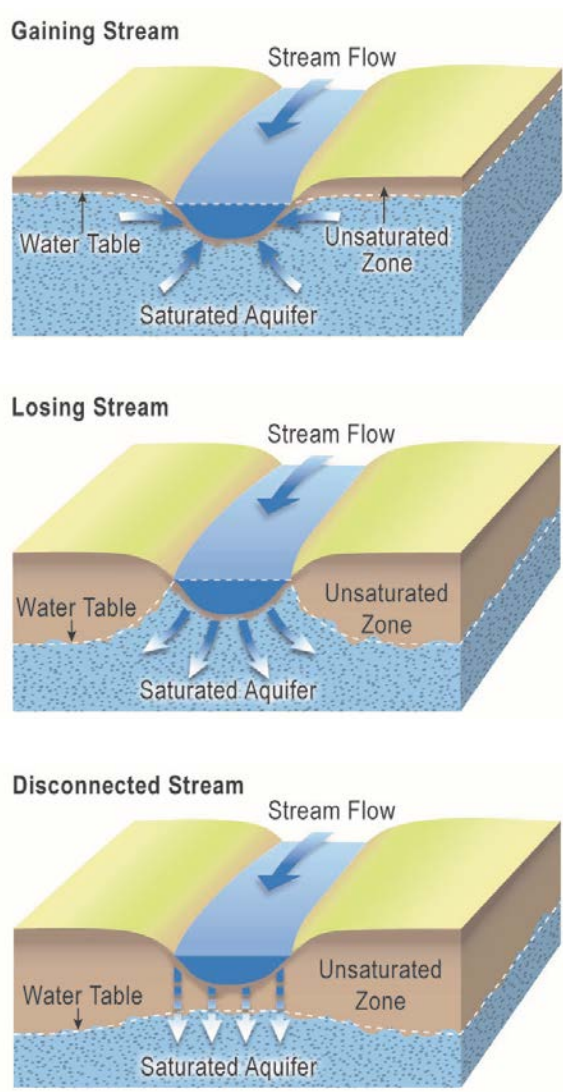


**Figure 2 – Gaining, Losing, and Disconnected Streams**

The transition from storage depletion to stream depletion will affect water budget accounting over time. The time lag to reach this new equilibrium is directly related to the location and construction of production wells, the thickness and hydrologic conductivity of the aquifer system, and the capacity and timing of the groundwater extraction. In many basins, stream depletion due to groundwater extraction will continue for decades prior to reaching a new equilibrium (Barlow, P.M. and Leake, S.A., 2012). Because of this transitional process, a water budget based on "average conditions" will not reflect this slow and progressive change. It's also important to recognize that water budget accounting during early stages of groundwater basin development will have different storage and basin outflow values than water budget accounting for a later time period, when the basin is approaching equilibrium.

To accurately identify and evaluate the various inflow and outflow components of the water budget, it is important to adequately characterize the interaction between surface water and groundwater systems through sufficient monitoring of groundwater levels and streamflow conditions. The *Monitoring Networks and Identification of Data Gaps* and *Monitoring Protocol, Standards, and Sites* BMPs have additional information regarding GSP monitoring requirements.

Due to the complexities of characterizing stream depletion due to groundwater extraction, integrated groundwater-surface water models are often used to assist with water budget accounting and forecasting. In addition, where *interconnected surface water* systems exist, the quantification and forecasting of streamflow depletion may be extremely difficult without the use of a numerical groundwater and surface water model. Additional information regarding consideration of models under the GSP Regulations is provided in the Modeling BMP and in Section 5 of this BMP.

## Water Budget Uses

Water budget accounting may be very general or very detailed, depending on the hydrologic complexities of the basin, the scale and intent of water budget accounting, and the importance of understanding the individual water budget components necessary to support water resource decision making. Some of the general and GSP Regulation-specific water budget uses and applications are provided below.

### *General Water Budget Uses*

- Develop an accounting and characterize spatial and temporal distribution of inflows and outflows to a watershed, groundwater basin, or *management area*.

- Identify the primary *beneficial uses* and users of water and determine which water budget components are most critical to the area.
- Improve communication between the local land use planners and water resource managers.
- Estimate water budget components that are not easily measured or well understood.
- Evaluate how the surface and groundwater systems respond to the seasonal and long-term changes to supplies, demands, and climatic conditions.
- Identify the timing and volume of inflows and outflows that will result in a balanced water budget condition for a management area.
- Develop a water supply assessment of future conditions to better understand the effects of proposed land and water use changes, climate change, and other factors to the local and regional water budget.
- Inform additional monitoring needs.
- Identify the interaction between surface water and groundwater systems, including changes over time.

### *GSP-Related Water Budget Uses*

SGMA requires local agencies to develop and implement GSPs that achieve *sustainable groundwater management* by implementing projects and management actions intended to ensure that the basin is operated within its *sustainable yield* by avoiding *undesirable results*. A key component in support of this effort is an accounting and assessment of the current, historical, and projected water budgets for the basin. The following provides a partial list of GSP-related water budget applications and uses:

- Develop an accounting and characterize spatial and temporal distribution of inflows and outflows to the basin by *water source type* and *water use sector*, to identify the main beneficial uses and users, and determine which water budget components are most critical to achieving sustainable groundwater management (§354.18(b)).
- Assess how annual changes in historical inflows, outflows, and change in basin storage vary by *water year type* (hydrology) and water supply reliability (§354.18(c)(2)).
- Develop an understanding of how historical conditions concerning hydrology, water demand, and surface water supply availability or reliability have impacted the ability to operate the basin within the sustainable yield (§10733.6(b)(3)).

- Improve coordination and communication between the GSA and water supply or management agencies, local land use approval agencies, and interested parties who may be subject to sustainable groundwater management fees (§355.4(b)(4)).
- Facilitate coordination of water budget data and methodologies between agencies preparing a GSP within the basin (§357.4) or between basins (§357.2).
- Identify *data gaps* and *uncertainty* associated with key water budget components and develop an understanding of how these gaps and uncertainty may affect implementation of proposed projects and water management actions.
- Evaluate how the surface and groundwater systems have responded to the annual historical changes in the water budget inflows and outflows (§354.18(c)(2)).
- Determine the rate and volume of surface water depletion caused by groundwater use that has adverse impacts on the beneficial uses of the surface water and may lead to undesirable results (§354.16(f) and 354.28(c)(1)).
- Identify which water budget conditions commonly result in *overdraft conditions* (354.18(b)(5).
- Estimate the sustainable yield for the basin (§354.18 and 10727.6(g)).
- Forecast projected inflows and outflows to the basin over the *planning and implementation horizon* (§354.18(c)(3)).
- Evaluate the effect of proposed projects and management actions on future water budget projections (§354.44(b)).
- Evaluate future scenarios of water demand uncertainty associated with projected changes in local land use planning, population growth, and climate (§65362.5(a)).
- Inform monitoring requirements (§354.34(b)(4)).
- Inform development and quantification of sustainable management criteria, such as the *sustainability goal*, undesirable results, *minimum thresholds*, and *measureable objectives* (§354.22).
- Help identify potential projects and management actions to achieve the sustainability goal for the basin within 20 years of GSP implementation (§354.44).

**Water Budgets in Reference to the GSP Regulations**

With respect to the GSP Regulations, developing a water budget that accurately identifies and tracks changing inflows and outflows to a basin will be a critically important tool to support decision making.

Complexity of water budgets will vary by groundwater basin according to the local complexities of the basin hydrology, physical setting, spatial and temporal distribution of supplies and demands, historical water management practices and the presence or absence of undesirable results. Ongoing parallel efforts to monitor and verify water budget components will help improve accuracy; however, some level of uncertainty is inherent in each water budget. An important objective of water budget accounting under the GSP Regulations is to develop an understanding of what level of water budget certainty and detail is sufficient for making effective basin management decisions.

The GSP water budget requirements are not intended to be a direct measure of groundwater basin sustainability; rather, the intent is to quantify the water budget in sufficient detail so as to build local understanding of how historical changes to supply, demand, hydrology, population, land use, and climatic conditions have affected the six *sustainability indicators* in the basin, and ultimately use this information to predict how these same variables may affect or guide future management actions. Building a coordinated understanding of the interrelationship between changing water budget components and aquifer response will allow local water resource managers to effectively identify future management actions and projects most likely to achieve and maintain the sustainability goal for the basin.

Another important aspect of documenting water budget information in the GSP is to ensure the Department is provided with sufficient information to demonstrate that the GSP conforms to all SGMA and GSP Regulation requirements, and, when implemented, is likely to achieve the sustainability goal within 20 years and maintain sustainability over the 50 year planning and implementation horizon.

## 4. RELATIONSHIP OF THE WATER BUDGET TO OTHER BMPS

Quantifying the current, historical, and projected water budget for the basin is just one of several interrelated GSP elements the GSAs will use to help understand the basin setting, evaluate groundwater conditions, determine undesirable results, develop sustainability criteria, establish appropriate monitoring networks, and ultimately identify future projects and management actions that are likely to achieve and maintain the sustainability goal for the basin. **Figure 3** illustrates the relationship of the water budget BMP to the other BMPs, and to the overall steps towards achieving sustainability under SGMA and the GSP Regulations.

**Figure 3** identifies the water budget BMP as part of the Basin Setting portion of the GSP Regulations (§354.12). However, the water budget BMP also directly supports, or is supported by, several other BMPs and Guidance Documents such as stakeholder outreach, development of the *Hydrogeologic Conceptual Model* (HCM), modeling, monitoring networks, monitoring protocols, and establishing sustainable management criteria. Basin monitoring feeds into the understanding of the HCM and groundwater conditions, which then supports the understanding and quantification of the water budget and model development. It ultimately supports evaluation of sustainability indicators, undesirable results, and basin management decisions to achieve the sustainability goal for the basin.

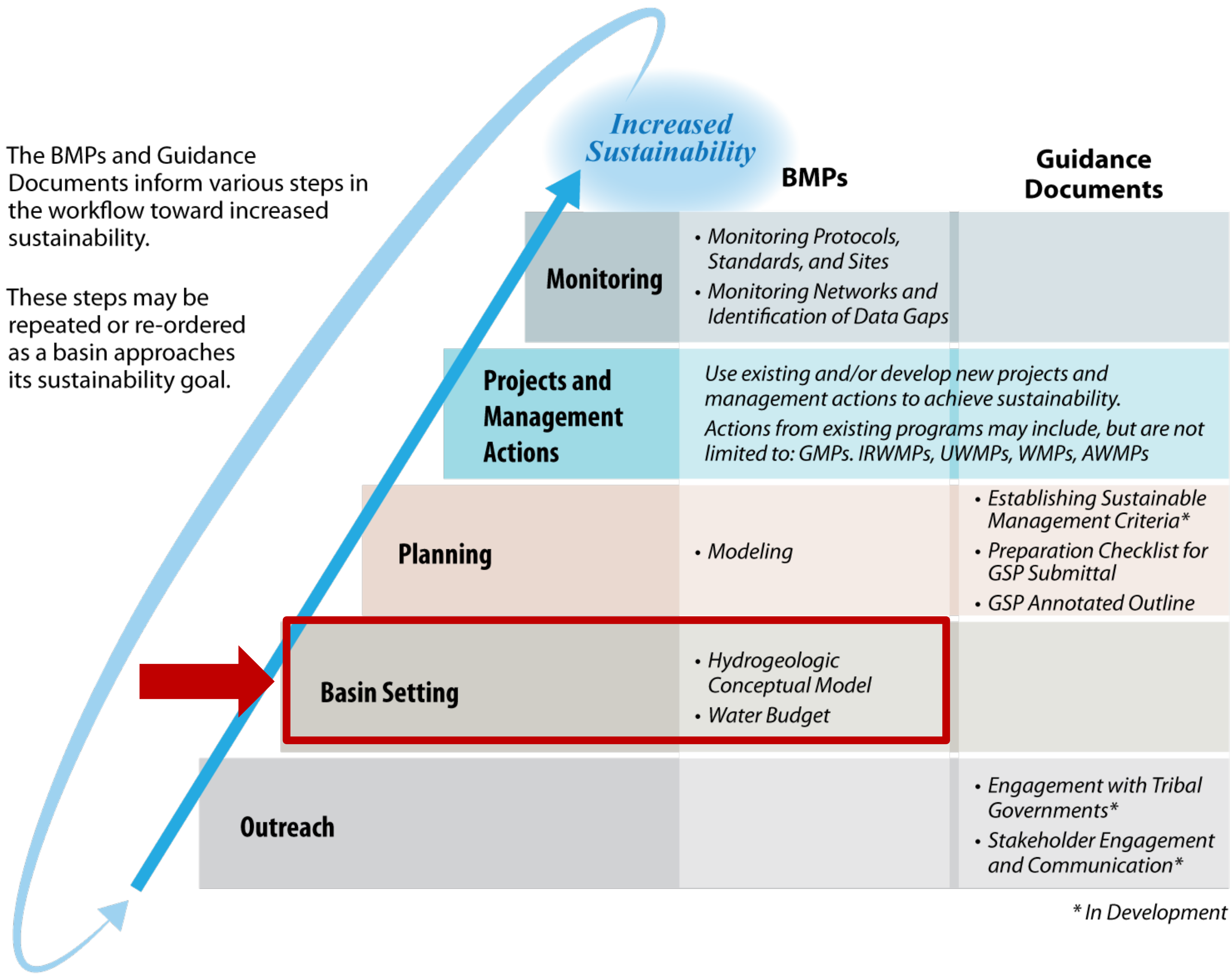


**Figure 3 – Logical Progression of Basin Activities Needed to Increase Basin Sustainability**

## 5. Technical Assistance

Implementing sustainable groundwater management under SGMA and the GSP Regulations requires development of a water budget. It should identify and account for basin inflows, outflows, and change in storage over changing temporal and spatial conditions of supply, demand, and climate with sufficient accuracy. This section provides guidance for the development of a water budget, including potential sources of information, reporting formats, and relevant datasets that can be used to further quantify and estimate the various water budget components.

### GENERAL WATER BUDGET REQUIREMENTS

The following section highlights and provides guidance and technical assistance on the general requirements for all GSP-developed water budgets.

***Subarticle 2. Basin Setting***
***23 CCR §354.12: Introduction to Basin Setting***
*Information provided pursuant to this Subarticle shall be prepared by or under the direction of a professional geologist or professional engineer.*

#### Professional Certification

Water budget requirements are provided in Subarticle 2, under the Basin Setting portion of the GSP Regulations. Introduction to the basin setting stipulates that GSP water budget information, and all information provided under Subarticle 2 of the GSP Regulations, is to be prepared by or under the direction of a professional geologist or professional engineer. The qualifications and requirements for professional engineers and geologists are governed by the Professional Engineers Act (Business and Professions Code §6700) and the Geologist and Geophysicist Act (Business and Professions Code §8700). Information regarding the professional codes and licensing lookup are provided below.

- **Professional Engineers Act:** http://www.bpelsg.ca.gov/laws/pe_act.pdf
- **Professional Geologist and Geophysicist Act:** http://www.bpelsg.ca.gov/laws/gg_act.pdf
- **Professional License Lookup:** http://www.bpelsg.ca.gov/consumers/lic_lookup.shtml

## Water Budget Data, Information, and Modeling Requirements

> **23 CCR §354.18(e):** *Each Plan shall rely on the best available information and best available science to quantify the water budget for the basin in order to provide an understanding of historical and projected hydrology, water demand, water supply, land use, population, climate change, sea level rise, groundwater and surface water interaction, and subsurface groundwater flow. If a numerical groundwater and surface water model is not used to quantify and evaluate the projected water budget conditions and the potential impacts to beneficial uses and users of groundwater, the Plan shall identify and describe an equally effective method, tool, or analytical model to evaluate projected water budget conditions.*

***Water Budget Data Requirements:*** GSP Regulations stipulate the need to use the best available information and the *best available science* to quantify the water budget for the basin. Best available information is common terminology that is not defined under SGMA or the GSP Regulations. Best available science, as defined in the GSP Regulations, refers to the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision, which is consistent with scientific and engineering professional standards of practice.

It is understood that initial steps to compile and quantify water budget components may be constrained by GSP timelines and limited funding, and may consequently need to rely on the best available information that is obtainable at the time the GSP is developed. Information describing potential sources of data to support the quantification of water budget components is provided later in this BMP under *Water Budget Data Resources*. This section also includes a listing of data to be provided by the Department as part of the Department's technical assistance.

As GSAs compile and assess the various water budget components for the basin, each GSA will work to identify, prioritize, and fill data gaps as an ongoing effort to further refine water budget data and information based on the best available science.

Sustainability will ultimately depend on the GSA's ability to manage the basin within the identified uncertainty of water budget information to meet the locally defined objectives and thresholds of the outcome-based sustainable management criteria identified in §354.22. However, the initial approval of the GSP by the Department requires GSAs to gather and present a level and quality of water budget information that will demonstrate the GSP will likely achieve the sustainability goal for the basin under the substantial compliance requirements in §355.2 of the GSP Regulations.

***Use of Models to Determine Water Budgets***: GSP Regulations do not require the use of a model to quantify and evaluate the projected water budget conditions and the potential impacts to beneficial uses and users of groundwater. However, if a model is not used, the GSA is required to describe in the GSP an equally effective method, tool, or analytical model to evaluate projected water budget conditions.

Groundwater basins with acceptable water budget conditions, minimal undesirable results, and limited proposed changes to future groundwater demands may be able to identify and describe equally effective methods or tools to quantify and forecast future water budget conditions in sufficient detail.

In basins with *interconnected surface water* systems or complex spatial and temporal variations in water budget components, quantifying and forecasting streamflow depletion and other water budget components may be extremely difficult without the use of a numerical groundwater and surface water model. Modeling results may also be an effective tool for outreach and communication, and can prove useful in analyzing and quantifying some of the more difficult-to-measure water budget components.

Additional information regarding the requirements, application, and availability of models and modeling data is provided in the Modeling BMP.

**Defining Basin Area and Water Budget Systems**

***23 CCR §354.18(a):*** *Each Plan shall include a water budget for the basin that provides an accounting and assessment of the total annual volume of groundwater and surface water entering and leaving the basin, including historical, current and projected water budget conditions, and the change in the volume of water stored. Water budget information shall be reported in tabular and graphical form.*

***Three-Dimensional Basin Area:*** Prior to developing a water budget for the basin, GSAs must first identify the vertical and lateral extent of the basin as described under the HCM (§354.14) portion of the GSP Regulations. The HCM is based on technical studies and qualified maps that characterize the physical basin area and the interaction of surface water and groundwater systems in the basin. It requires evaluation of the physical systems related to regional hydrology, land use, geology and geologic structure, water quality, *principal aquifers*, and principal aquitards in the basin. Additional information regarding development of the HCM may be found in the HCM BMP.

The lateral boundaries of the basin are determined by the Department and conform to those boundaries provided in Bulletin 118. The vertical basin boundary, or definable bottom of the basin, is determined by the GSA and may be delineated by either, 1) a structural barrier to groundwater flow as determined by local geology, or 2) the base of fresh water as determined by groundwater quality information. In general, deep portions of the basin not part of the groundwater flow path can be excluded from analysis; conversely, if the those portions of the basin are part of the flow path or are being managed, they should be included in the analysis. Basin boundaries may be periodically modified through SGMA under §10722.

In addition to the lateral and vertical basin boundaries, the water budget accounting takes into consideration the exchange of water between subsystems within the hydrologic cycle. **Figure 4** is a generalized schematic illustrating the potential interaction between water budget components and the surface water system and groundwater system for a groundwater basin or management area.

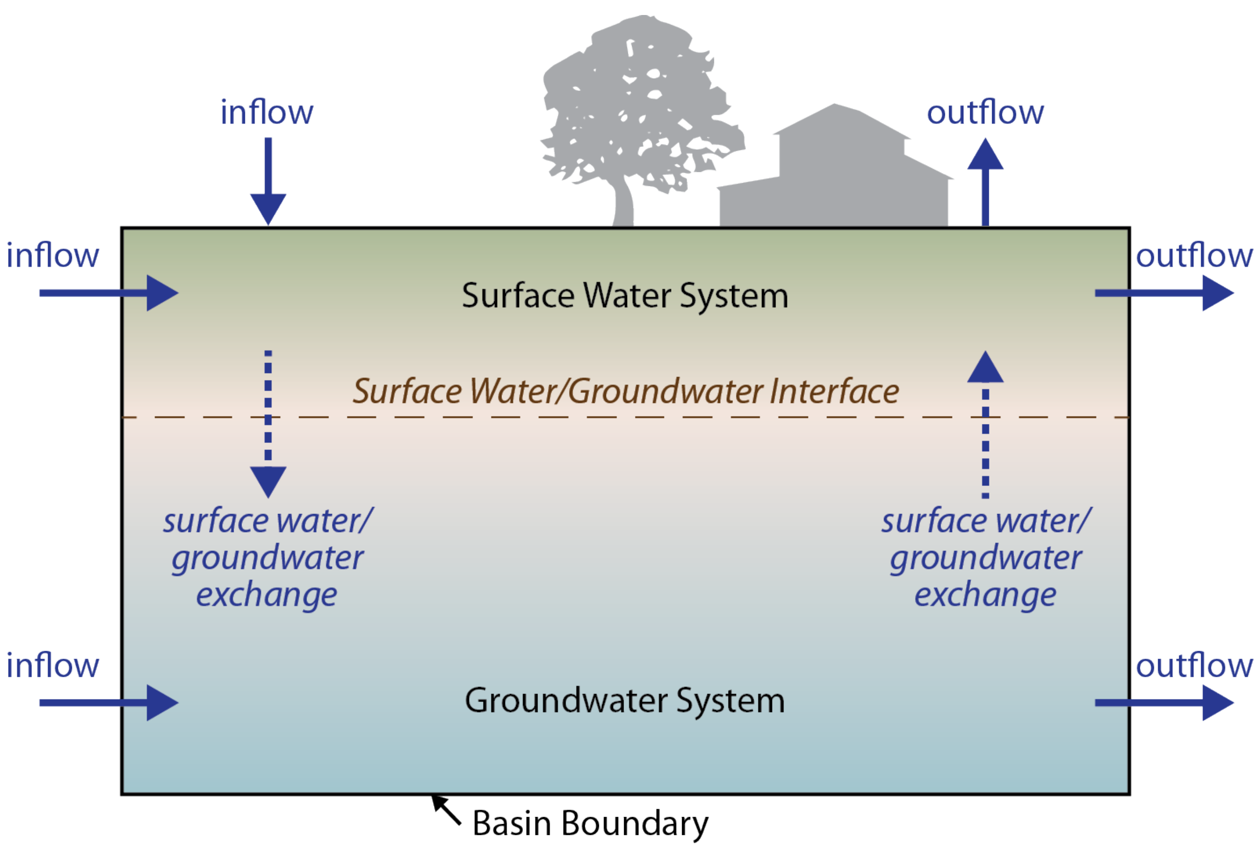


**Figure 4 – Conceptual Basin Boundary, Surface Water and Groundwater Systems, and Inflows and Outflows**

The surface water system is represented by water at the land surface within the lateral boundaries of the basin. Surface water systems include lakes, streams, springs, and man-made conveyance systems (including canals, drains, and pipelines). Near-surface processes such as stream underflow, infiltration from surface water systems or outflow due to evapotranspiration from the root zone are often included for convenience as part of the surface water accounting. Root zone processes may also be accounted for explicitly by defining a separate land surface system and quantifying exchanges with the surface water system and groundwater system, as well as exchanges with the atmosphere. An example of explicit accounting for the land surface system is provided later in this document based on water budgets prepared as part of the California Water Plan (DWR Bulletin 160).

The groundwater system is represented by that portion of the basin from the ground surface to the definable bottom of the basin, extending to the lateral boundary of the basin. The groundwater system will be characterized by one or more *principal aquifers* and represents the physical basin area used to quantify the annual change in volume of groundwater stored, as required in the water budget. The same three-dimensional basin area should also be used for GSAs to optionally identify the volume of groundwater in storage or the *groundwater storage capacity*, as necessary, to assist in the determination of sustainable yield.

> ***23 CCR §354.20(a). Management Areas:*** *Each Agency may define one or more management areas within a basin if the Agency has determined that creation of management areas will facilitate implementation of the Plan. Management areas may define different minimum thresholds and be operated to different measurable objectives than the basin at large, provided that undesirable results are defined consistently throughout the basin.*

***Management Areas:*** Although the GSP Regulations only require quantification of water budget components for the basin, each GSA may choose to further subdivide and report the water budget by one or more management areas to help facilitate GSP implementation, and to help demonstrate GSP substantial compliance to the Department under §355.2 of the GSP Regulations (*Department Review of Adopted Plan*). If management areas are developed, additional information and graphics will be needed to define the names, locations, and distribution of management areas within the basin. Graphical representations of the physical setting and characteristics of the basin will be largely provided under HCM requirements in §354.14 of the GSP Regulations.

> ***23 CCR §357.4(a). Coordination Agreements:*** *Agencies intending to develop and implement multiple Plans pursuant to Water Code Section 10727(b)(3) shall enter into a coordination agreement to ensure that the Plans are developed and implemented utilizing the same data and methodologies, and that elements of the Plans necessary to achieve the sustainability goal for the basin are based upon consistent interpretations of the basin setting.*

***Coordination of Water Budget Data:*** When one or more GSPs are being developed by one or more GSAs for the same basin, §10727(b)(3) of SGMA and §357.4 of the GSP Regulations require a coordination agreement between all GSAs developing a GSP within the basin. As stated in the GSP Regulations citation above, the coordination agreement is to ensure that GSPs are developed and implemented using the same data and methodologies. Specifically, the coordination agreements need to describe how the Agencies utilize the same data and methodologies for the following water budget related components:

- Surface water supply
- Total water use
- Change in groundwater storage
- Water budget
- Sustainable yield

Thus, when presenting water budget information for basins with one or more GSPs, all GSPs for the basin need to identify and describe the existing coordination agreements for the basin, the point of contact of each agreement, how the individual coordinating agencies have taken steps to ensure that each GSP for the basin is utilizing the same data and methodologies for the above water budget components, and how the GSP is fulfilling the coordination requirements identified under §357.4 of the GSP Regulations.

For many basins within the Central Valley, Salinas Valley and elsewhere, not all lateral boundaries for contiguous basins serve as a barrier to groundwater or surface water flow. In situations where a basin is adjacent or contiguous to one or more additional basins, or when a stream or river serves as the lateral boundary between two basins, it is necessary to coordinate and share water budget data and assumptions. This is to ensure compatible sustainability goals and accounting of groundwater flows across basins, as described in §357.2 (Interbasin Agreements) of the GSP Regulations.

As described in SGMA, the Department shall evaluate whether a GSP adversely affects the ability of an adjacent basin to implement its GSP or impedes the ability to achieve its sustainability goal. In order to adequately evaluate this condition, in many cases this will necessitate GSA coordination and sharing of water budget data, methodologies, and assumptions between contiguous basins including:

- Accurate accounting and forecasting of surface water and groundwater flows across the basin boundaries
- Application of best available data and the best available science

In these interbasin situations, it is highly recommended that water budget accounting describe how individual agencies took steps to ensure that each GSP for the basin is utilizing compatible data and methodologies for the water budget components identified under interbasin coordination in §357.4 of the GSP Regulations.

**Accounting and Quantification of Water Budget Components**

*23 CCR §354.18(b): The water budget shall quantify the following, either through direct measurements or estimates based on data:*

*(1) Total surface water entering and leaving a basin by water source type.*

*(2) Inflow to the groundwater system by water source type, including subsurface groundwater inflow and infiltration of precipitation, applied water, and surface water systems, such as lakes, streams, rivers, canals, springs and conveyance systems.*

*(3) Outflows from the groundwater system by water use sector, including evapotranspiration, groundwater extraction, groundwater discharge to surface water sources, and subsurface groundwater outflow.*

*(4) The change in the annual volume of groundwater in storage between seasonal high conditions.*

*(5) If overdraft conditions occur, as defined in Bulletin 118, the water budget shall include a quantification of overdraft over a period of years during which water year and water supply conditions approximate average conditions.*

*(6) The water year type associated with the annual supply, demand, and change in groundwater stored.*

*(7) An estimate of sustainable yield for the basin.*

Accounting of the water budget components includes: 1) an annual quantification of inflows and outflows across the basin boundaries, 2) the exchange of water between the surface water system and groundwater system, and 3) the change in volume of groundwater in storage. Surface water entering and leaving the basin and inflow to the groundwater system must be accounted for by water source type. Outflows from the groundwater system must be accounted for by *water use sector*. The annual accounting of surface water entering and leaving the basin should also include the annual change in surface water storage within lakes and reservoirs that contribute significant water supplies to the basin.

The GSP water budget components are conceptually illustrated in the water budget schematic shown previously in **Figure 4**. **Figure 5** expands upon **Figure 4** by depicting the individual water budget components identified by the GSP Regulations.

Quantification of the annual water budget inflows, outflows, and change in storage for the basin is to be generated by water year through direct measurements or estimates based on data. As previously discussed, the water budget must also be based on best available information and science. Methods to quantify water budget components may vary depending on basin-specific conditions, best available information, and the consideration of uncertainties associated with each method. Methods may change over time as monitoring networks are improved and data gaps are filled.

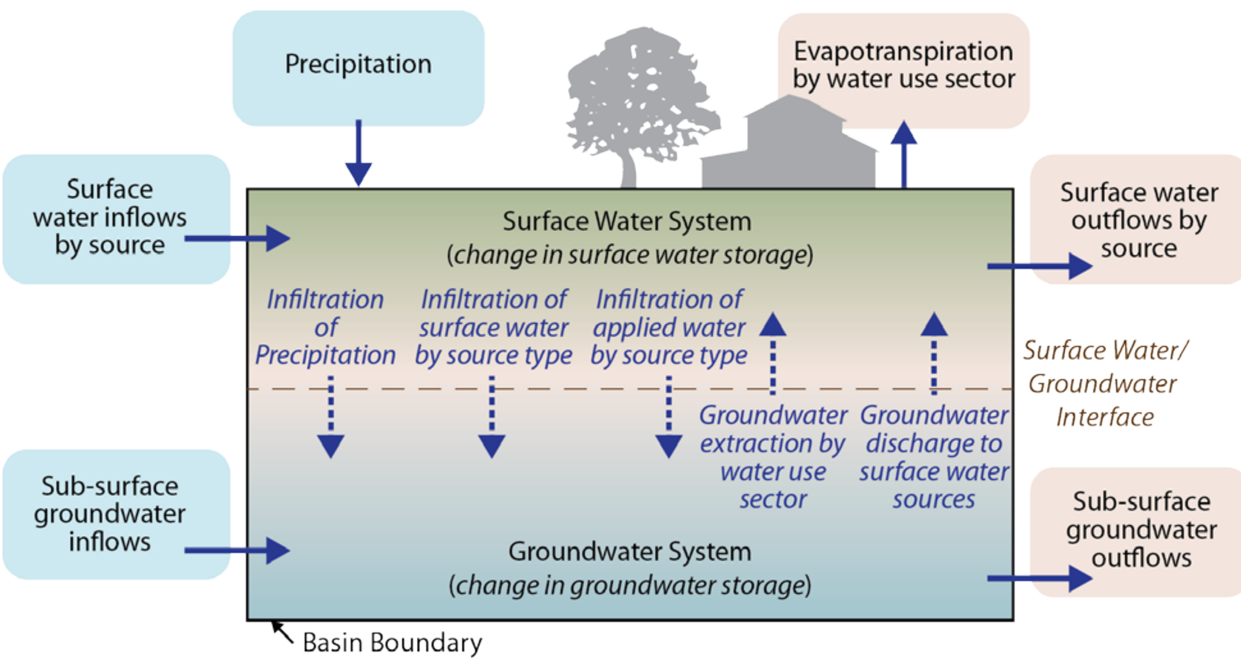


**Figure 5 – Required Water Budget Components**

Additional discussion regarding consideration of direct and indirect approaches to quantify water budget components is provided under *Identifying and Selecting Methodologies to Estimate Water Budget Components*. Information describing potential data sources to support quantification of change in storage is provided later in this section under *Water Budget Data Resources*, including data to be provided by the Department specifically for the purpose of supporting GSP water budget development.

The following information provides a breakdown of the seven overarching water budget component requirements listed above and included in §354.18(b) of the GSP Regulations.

***(1) Total surface water entering and leaving the basin by water source type.***

Water budget components associated with the river and stream system include the surface water entering (inflow) and leaving the basin (outflow). The inflow and outflow of surface water to the basin is required to be annually quantified as a total annual volume in acre-feet per year (af/yr) according to the surface water body (name) and the water sources type. Water source type represents the source from which water is derived to meet the applied beneficial uses. Surface water sources should be identified as one of the following:

- Central Valley Project
- State Water Project
- Colorado River Project
- Local supplies
- Local imported supplies

Much of the surface water flowing into the basin is diverted and applied to meet the beneficial uses within the basin. It is recommended that total annual volume of applied surface water (af/yr) also be quantified according to the appropriate water use sector and the total applied water area (acres). For urban water suppliers, the diverted and applied surface water use should include the total annual volume of use for all urban areas within the basin and the average daily gallons of per capita use (gpcd) for the basin. A breakdown of the applied surface water accounting by basin and by water use sector is provided as follows:

- Urban: total annual volume (af/yr) and the average daily per capita use (gpcd)
- Industrial: total annual volume (af/yr) and total applied water area (acres)
- Agricultural: total annual volume (af/yr) and applied water area (acres)
- Managed Wetlands: total annual volume (af/yr) and applied water area (acres)
- Managed Recharge: total annual volume (af/yr) and applied water area (acres)
- Native Vegetation: total annual volume (af/yr) and applied water area (acres)
- Other (as needed): total annual volume (af/yr) and applied water area (acres)

Applied surface water supply may be further subdivided by *management area* as needed to facilitate water budget accounting and to help demonstrate GSP substantial compliance under §355.2 of the GSP Regulations.

***Surface Water Available for Groundwater Recharge or In-Lieu Use*:** In addition to the above GSP Regulation requirement to include an accounting of the total surface water entering and leaving the basin, §10727.2(d)(5) of SGMA requires the GSP include a description of the surface water supply used, or available for use, for groundwater recharge or in-lieu use.

The Department currently estimates the volume of water available for replenishment of the groundwater in the State. The statewide water available for replenishment is being estimated on a regional basis. This regional estimate will not fulfill the SGMA requirement to identify the surface water supply used, or available for use, for groundwater recharge or in-lieu use at the basin level. However, the Department's process, methods, and sources of data for surface water supply availability should provide valuable assistance to GSAs. The Department's report on Water Available for Replenishment is currently under development.

***(2) Inflow to the groundwater system by water source type, including subsurface groundwater inflow and infiltration of precipitation, applied water, and surface water systems, such as lakes, streams, rivers, canals, springs and conveyance systems.***

### Oil & Gas Field-Produced Water

Significant quantities of water are produced as a by-product of oil and gas extraction in some basins. Where applicable, it is important to characterize this water in terms of aquifer depletion, beneficial use, quality, and reliability.

- <u>Aquifer Depletion</u>. Oil and gas-bearing formations are often at a depth below the groundwater flow system. Is the quantity of produced water accounted for in the hydrogeologic conceptual model? Will depletion of this water cause Undesirable Results such as subsidence?
- <u>Beneficial Use.</u> Describe the uses for the produced water. Is the produced water being supplied as a beneficial use such as irrigation or recharge, or is it being evaporated? If so, it should be included as a water supply type in the water budget accounting.
- <u>Quality.</u> Describe the quality of the produced water, existing use permits, and any treatment processes employed. Describe the use or discharge relative to RWQCB Basin Plan Objectives.
- <u>Reliability</u>. Availability of produced water will fluctuate with oil and gas production. Oil fields have limited production durations that may be incompatible with long-term groundwater sustainability. Oil field-produced water will generally not be an acceptable supply for establishing sustainability, but may be a component of an initial basin recovery effort. The reliability of produced water should be characterized in the GSP if it is being use as a source of supply.

Inflows to the groundwater system are to be annually quantified by water year type for the basin as the total annual volume (af/yr) according to the water source type and water use sector.

An accounting of inflows to the groundwater systems should include, but may not be limited to, the following:

- Subsurface groundwater inflow (af/yr)
- Infiltration of precipitation (af/yr)
- Infiltration of applied water (af/yr)
- Infiltration from surface water systems (af/yr)
- Infiltration or injection from managed recharge projects (af/yr)

It is also important to identify and account for inflows or outflows to the groundwater system that may originate from outside the identified basin area. For example, application and infiltration of oil field-produced water should be identified as a separate source of imported water, while the injection of water beneath the definable bottom of the basin should be identified as an outflow from the basin when applicable (see text box discussion of oil field-produced water considerations). In addition, depending on the definable bottom of the basin, groundwater being injected to maintain a *seawater intrusion* barrier may need to be recognized as an outflow from the groundwater basin. Subsurface outflow needed to prevent seawater intrusion should be quantified.

For areas having *Urban Water Management Plans* (UWMP) or *Agricultural Water Management Plans* (AWMP), the GSP water budget assessment of urban and agricultural areas should be consistent with the water budget reporting in the most recent UWMPs and AWMPs, unless more recent information is available.

*(3)* ***Outflows from the groundwater system by water use sector, including evapotranspiration, groundwater extraction, groundwater discharge to surface water sources, and subsurface groundwater outflow.***

An annual accounting of groundwater outflow from the basin should be total volume (ac-ft) by water source type and water use sector. Sources of groundwater outflow should include, but not be limited to, the following:

- Evapotranspiration: (af/yr)
- Groundwater discharge to surface water sources (af/yr)
- Subsurface groundwater outflow (af/yr)

- Groundwater extraction by water use sector:
    - Urban (af/yr) and (gpcd)
    - Industrial (af/yr)
    - Agricultural (af/yr)
- Managed Wetlands (af/yr)
- Managed Recharge (af/yr)
- Infiltration from the following: (af/yr)
    - Native vegetation (af/yr)
    - Other (as needed)

  Note: if oil and gas production wells are producing or applying water within the basin, as defined in the HCM, an accounting of the produced water is to be included as a source of applied water.

Outflows from the groundwater system may be further subdivided by management area as needed to facilitate water budget accounting and to help demonstrate GSP substantial compliance under §355.2 of the GSP Regulations.

***(4) The change in the annual volume of groundwater in storage between seasonal high conditions.***

In addition to the inflow and outflow components of the water budget, the annual change in the volume of groundwater in storage (af/yr) is required to be provided in tabular and graphical form according to water year type and the associated total annual volume of groundwater extraction for the basin. In addition, the GSP should provide some level of discussion regarding the variation between annual change of groundwater in storage versus annual changes in surface water supply, water year type, water use sector, sustainable yield and overdraft conditions (if present or potentially present).

The change in groundwater in storage is the total change in storage between *seasonal high* conditions, which typically occurs in the spring. It is recommended that the change in storage estimates be based on observed changes in groundwater levels within the basin. However, change in groundwater storage may also be calculated as the difference between annual inflows and outflows according to the water budget equation in Section 3, where all inflows and outflows can be reliably measured or estimated.

Similar to other water budget components, the method to quantify change in storage will likely vary depending on basin-specific conditions and available information, and include consideration of uncertainties associated with each method.

Assessment of change in storage under future water budget projections may require the use and application of a groundwater flow model. If a model is used to estimate future changes in groundwater storage, the Modeling BMP should be followed.

Changes in surface water storage (reservoirs, lakes, and ponds) will also be an important water budget component in some basins. For these basins, change in storage should be identified as change in groundwater storage and surface water storage.

The annual change in groundwater storage may also be further subdivided according to *management areas,* as needed, to help facilitate water budget accounting and to help demonstrate GSP substantial compliance under §355.2 of the GSP Regulations.

*(5)* ***If overdraft conditions occur, as defined in Bulletin 118, the water budget shall include a quantification of overdraft over a period of years during which water year and water supply conditions approximate average conditions****.*

The GSP water budget must include an assessment of *groundwater overdraft* conditions. Determination of overdraft conditions requires the evaluation of current and historical water budget conditions. As described in DWR Bulletin 118, overdraft occurs when groundwater extraction exceeds groundwater recharge over a period of years, resulting in a decrease in groundwater storage.

Overdraft conditions should be assessed by calculating change in groundwater storage over a period of years during which water year and water supply conditions approximate average conditions. Overdraft conditions should be evaluated as changes in groundwater storage by water year type. For basins without an existing water year index, water year types will be developed, classified, and provided by the Department based on annual precipitation as a percentage of the previous 30-year average precipitation for the basin. Water year classifications will be divided into five categories ranging from wet, above normal, below normal, dry, to critically dry conditions.

Single-year reduction in groundwater storage during critical, dry or below normal water years may not represent overdraft conditions. Reductions in groundwater storage in above normal or wet years or over a period of average water year conditions may indicate overdraft conditions. All annual change in groundwater storage estimates from water budget accounting should be included and discussed in the GSP.

If overdraft conditions are identified, the GSP shall describe projects or management actions, including a quantification of demand reduction or other methods, for the mitigation of overdraft, as required under §354.44(b)(2) of the GSP Regulations.

When evaluating if the GSP is likely to achieve the sustainability goal for the basin, the Department will consider whether the GSP includes a reasonable assessment of overdraft conditions and a reasonable means to mitigate overdraft as required under §354.4(b)(6) of the GSP Regulations.

***(6) The water year type associated with the annual supply, demand, and change in groundwater stored.***

In order for local resource managers to develop an understanding of the relationship between changing hydrologic conditions and the associated aquifer response to changing water supply, demand, and storage, the GSP water budget accounting must be reported according to water year type. Even though the GSP Regulations only require annual water budget accounting and reporting, in order for local water resource managers to adequately understand the timing and distribution of water supply and demand and to implement effective water management actions, local water budget accounting may need to be conducted on a monthly or more frequent basis. As mentioned previously in the overdraft discussion, water year types will be developed, classified, and provided by the Department for those basins not having an existing water year index. GSP water budgets detailing supply, demand, and change in groundwater stored according to water year type will help facilitate assessment of overdraft conditions and estimates of sustainable yield for the basin.

***(7) An estimate of sustainable yield for the basin***

Estimating sustainable yield includes evaluating current, historical, and projected water budget conditions. Sustainable yield is defined in SGMA legislation and refers to the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin, and including any temporary surplus that can be withdrawn annually from a groundwater supply without causing an undesirable result. Water budget accounting information should directly support the estimate of sustainable yield for the basin and include an explanation of how the estimate of sustainable yield will allow the basin to be operated to avoid locally defined undesirable results. The explanation should include a discussion of the relationship or linkage between the estimated sustainable yield for the basin and local determination of the sustainable management criteria (sustainability goal, undesirable results, minimum thresholds, and measureable objectives).

## TABULAR AND GRAPHICAL REPRESENTATION OF THE WATER BUDGET COMPONENTS

The water budget information is to be in tabular and graphical form. This presentation of the data may take many forms depending on the sources of water inflow and outflow to the basin and the water use sectors within the basin.

A sample water budget tabulation is illustrated in **Table 1**. **Table 1** includes a listing of required water budget components to support a complete accounting of groundwater basin inflows and outflows. Additional water budget components not explicitly listed in the Regulations may be necessary for some basins in order to adequately evaluate sustainability and to identify and evaluate projects and management actions to address undesirable results. For example, in basins where treated produced water generated from oil and gas operations is used as a source of supply, the annual volume of the produced water being applied for beneficial use should be quantified and described according to water supply type and water use sector.

Additional tables depicting a breakdown of water budget accounting by water use sector and water source type may be needed to better understand the individual supplies and demands for some basins, and the percent of total supply that is met by each water source type.

Multiple graphical depictions of the various water budget components will likely be needed to fully illustrate the water budget accounting in many basins. The graphics should include charts and maps to show the trends and spatial distribution of the various water budget components. A general graphic summarizing the inflows, outflows and change in storage by water year type will be needed to provide an understanding of the overall water balance for the basin by water year type. Graphics and tables should depict complete and separate water budgets for the basin as a whole, the surface water system, and the groundwater system by basin or management area and by water year type. In addition, more detailed maps and figures that separately depict basin inflows and outflows by water source type, water use sector, and water year will likely be needed to better understand the relationship and overall importance of the various water sources and water use sectors.

Water Year:
Water Year Type:

| INFLOWS | | OUTFLOWS | |
|---|---|---|---|
| Inflow Source | Volume (af/yr) | Outflow Sink | Volume (af/yr) |
| Surface Water Inflow\1 | | Surface Water Outflow\1 | |
| Precipitation | | Evapotranspiration\4 | |
| Subsurface Groundwater Inflow | | Subsurface Groundwater Outflow | |
| Total Basin Inflow | | Total Basin Outflow | |
| Subsurface Groundwater Inflow | | Subsurface Groundwater Outflow | |
| Infiltration of Precipitation | | Groundwater Extraction\1 | |
| Infiltration from Surface Water Systems\2 | | Discharge to surface water systems\2 | |
| Infiltration of Applied Water\3 | | | |
| Total Groundwater Inflow | | Total Groundwater Outflow | |

| | |
|---|---|
| Change in Surface Storage Volume | |
| Change in Groundwater Volume | |

\1 by water source type
\2 lakes, streams, canals, springs, conveyance systems
\3 includes applied surface water, groundwater, recycled water, and reused water
\4 by water use sector

## Table 1 – Simple Water Budget Tabulation Example

A sample paired bar graphic illustrating balanced water budgets for both the basin and the groundwater system including the required water budget components is presented as **Figure 6**. Each pair of bars shows inflows on the left and outflows on the right. In this illustration, more water flows out of the basin than flows in during the water year, resulting in an annual reduction in groundwater storage.

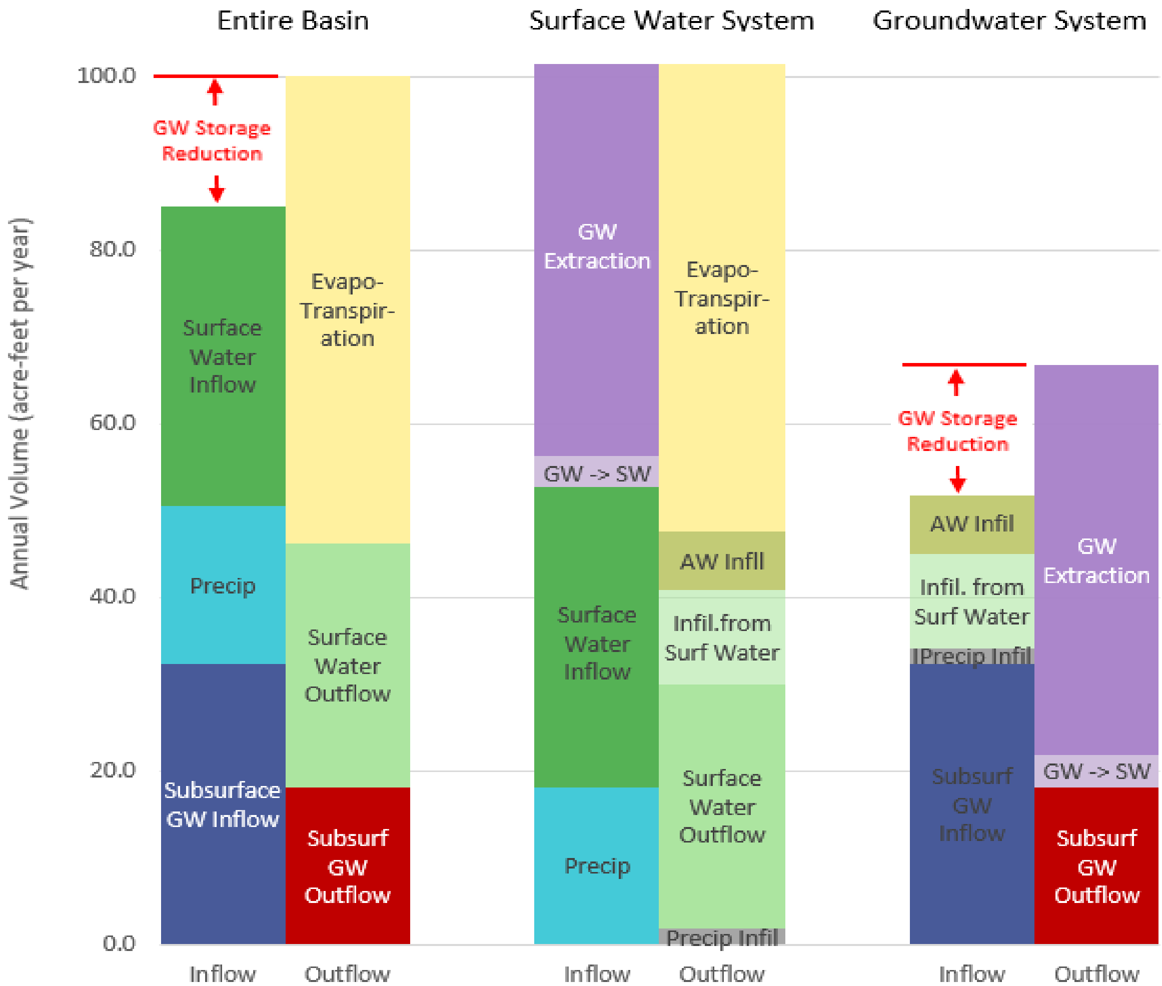


**Figure 6 – Paired Bar Water Budgets**

Additional graphical examples depicting water supplies and water use by water year type are provided in the Department's *California Water Plan Update 2013* (*Volume 1, Chapter 3, pages 3-33 - 3-40)*, and the *California Groundwater Update 2013 (Chapter 2, pages 17-22)*. Online links to these reports are provided in Section 7, under *Guidance and General References*. Supplementary example graphics are being developed and will be provided as part of the Department's technical assistance.

An example of a detailed water budget developed by the Department as part of a pilot project to develop water budgets for future California Water Plan updates is provided in the text boxes on the following pages. The example includes hydrologic systems (e.g., the atmospheric system and land surface system) and other water budget components not explicitly required by the GSP Regulations. Conversely, the example does not explicitly include all of the water budget components required by the GSP Regulations. For example, deep percolation from the land surface to the groundwater system is included in the example, as compared to infiltration of precipitation and infiltration of applied water as required by the GSP Regulations. As discussed previously, more detailed accounting than required by the GSP Regulations, including additional components included in the example, may be necessary in some basins to adequately evaluate sustainability, and to identify and evaluate projects and management actions to address undesirable results.

## Example of a Detailed Water Budget Including Additional Components Not Identified in the GSP Regulations

It may be useful in some basins to develop water budgets with additional detail not explicitly identified in the GSP Regulations. The following example, based on water budgets being developed as part of future updates of the California Water Plan, illustrates additional water budget components that may be included. **Figure 6** depicts the water budget as a combination of four hydrologic systems, including the atmospheric system, the land surface system, the river and stream system (also including conveyances and lakes and reservoirs), and the groundwater system. In contrast to the GSP Regulations, wherein the land surface system and river and stream system are, in essence, combined to form the surface water system, these systems are broken out explicitly.

Inflows and outflows to and from the user-defined area are illustrated in **Figure 7** as blue and orange arrows, while the flow of water within the user-defined area is shown as a series of purple arrows. Although not specifically depicted in **Figure 7**, the exchange of water in the root zone is included within the lower portion of the land surface system. The unsaturated zone in **Figure 7** is the portion of the subsurface that lies between the land surface system and the groundwater table, which defines the upper portion of the groundwater system. In reality, the thickness and distribution of the unsaturated zone may vary significantly according to the historical groundwater demand and water management practices in the basin. In areas with shallow groundwater conditions, the groundwater system may connect directly to the land surface system, eliminating the unsaturated zone and causing groundwater to discharge directly to the land surface through seeps, wetlands, or springs.

Short descriptions of the various water budget components within the user-defined area for the example are provided below.

**River and Stream System:** The river and stream system includes an accounting of water budget components for rivers and streams, lakes and reservoirs, and conveyance systems. Water budget components for the river and stream system include surface water entering and leaving the basin or user-defined area (includes imported or exported surface water), as well as the interaction of surface water with the atmospheric, land surface, and groundwater systems within the basin. **Figure 7** shows that inflows to the river and stream system may include stream flows entering into the basin, inflow from rainfall-runoff and agricultural and urban return flow contributions from the land surface system, inflow from the groundwater system, and direct precipitation to the surface water body. Outflows from the river and stream system primarily include diversions, conveyance seepage, streamflow losses to the groundwater, evaporation to the atmospheric system, and stream flows leaving the user-defined area.

**Land Surface System:** The land surface system includes an accounting of inflows and outflows associated with the various native and managed land use activities. It includes the exchange of water over the land surface, including the root zone, and the exchange of water with the other hydrologic systems within the user-defined area. The root zone occupies the upper portion the land surface where plants extract moisture to meet their water needs. The unsaturated zone is below the land surface system and represents the portion of the basin that receives percolated water from the root zone and either transmits it as deep percolation to the groundwater system or to reuse within the land surface system, or both. Subsurface soil and geologic conditions will help inform estimates of reuse and deep percolation.

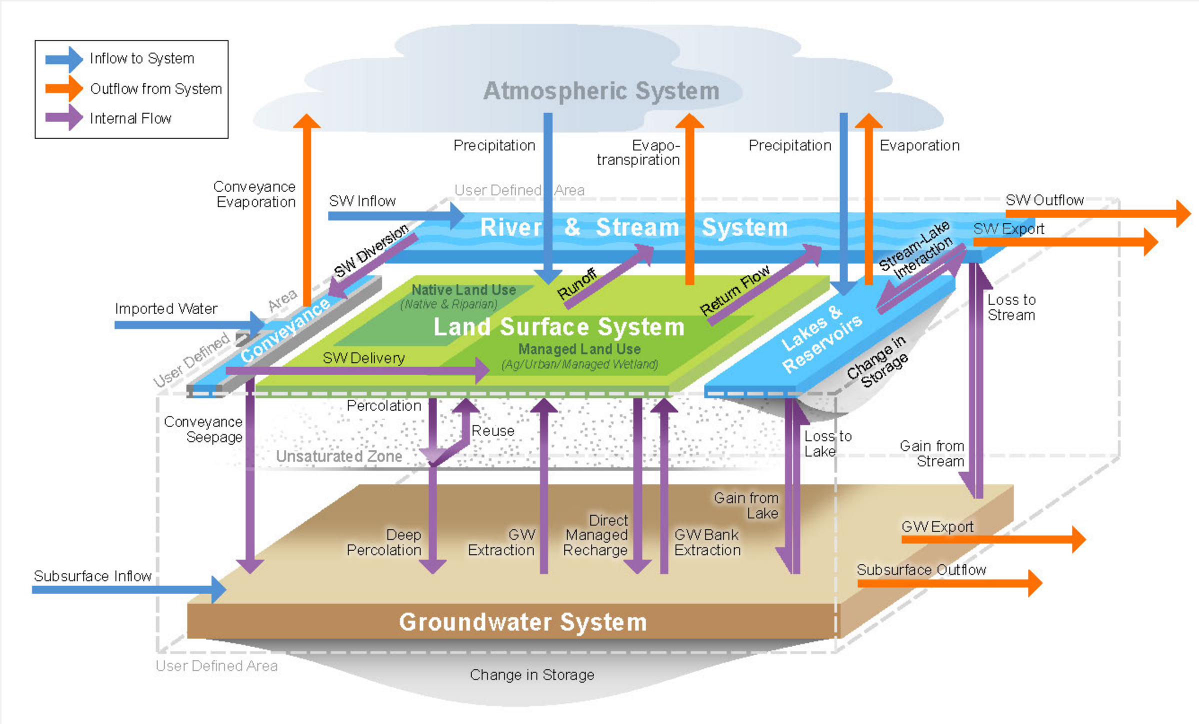


**Figure 7 – Water Budget Schematic Showing the Interrelationships among Potential Water Budget Components and the Water Systems that Comprise the Hydrologic Cycle**

Inflows to the land surface system may include the inflow of water from diversions from the river and stream system, groundwater extraction, direct precipitation to the land surface, and reuse of percolated water from the unsaturated zone. In areas having a high groundwater table or in locations where the subsurface geology causes outflow from the groundwater system to the land surface, inflows to the land surface system may also come from the capillary movement or direct outflow of groundwater into the land surface system through seeps, wetlands, or springs. Outflows from the land surface system include rainfall-runoff, agricultural and urban return flows to the river and stream system, percolation of precipitation of applied water and direct managed recharge to the groundwater system, and evapotranspiration to the atmospheric system.

Groundwater System: The groundwater system is represented by that portion of the user-defined area extending vertically from the base of the unsaturated zone to the definable bottom of the basin and laterally to the DWR Bulletin 118 basin boundary. In the GSP, the groundwater system will also be characterized by one or more principal aquifers and represent the physical extent of the basin that is used to quantify the annual change in volume of groundwater stored. The same three-dimensional basin should also be used for GSAs to optionally identify the volume of groundwater in storage or the groundwater storage capacity, as necessary, to assist in the determination of sustainable yield.

Inflows to the groundwater system include subsurface groundwater flow entering the user-defined area, deep percolation generated by precipitation and irrigation water infiltrating downward through the root and unsaturated zones, seepage into the aquifer from the river and stream system, and managed recharge through spreading basins or aquifer injection wells. Outflows from the groundwater system primarily include subsurface groundwater outflow leaving user-defined area, groundwater extraction from wells, and discharge to the river and stream system. Additional outflows from the groundwater system may also occur due to shallow groundwater discharge from seeps, wetlands, and springs. In situations where groundwater rises within the root zone of the land surface system, outflows due to evapotranspiration are typically attributed to the groundwater system.

Based on the detailed water budget example, graphics and tables can be developed to depict complete and separate water budgets for the land surface system, the groundwater system, the river and stream system, and a combination of these systems. These graphics and tables can be developed by water year type for the basin as a whole, by management area, or for other user-defined areas of interest. Examples of graphics depicting water budgets over time for the basin as a whole and for the groundwater system are provided in **Figure 8**. In this figure, the outflows are shown to the left, and the inflows are shown on the right. Annual change in storage may be represented as an inflow or an outflow depending on whether the amount of water in storage increases or decreases during a given time period of interest. An increase in storage is represented as an outflow, while a decrease in storage is represented as an inflow.

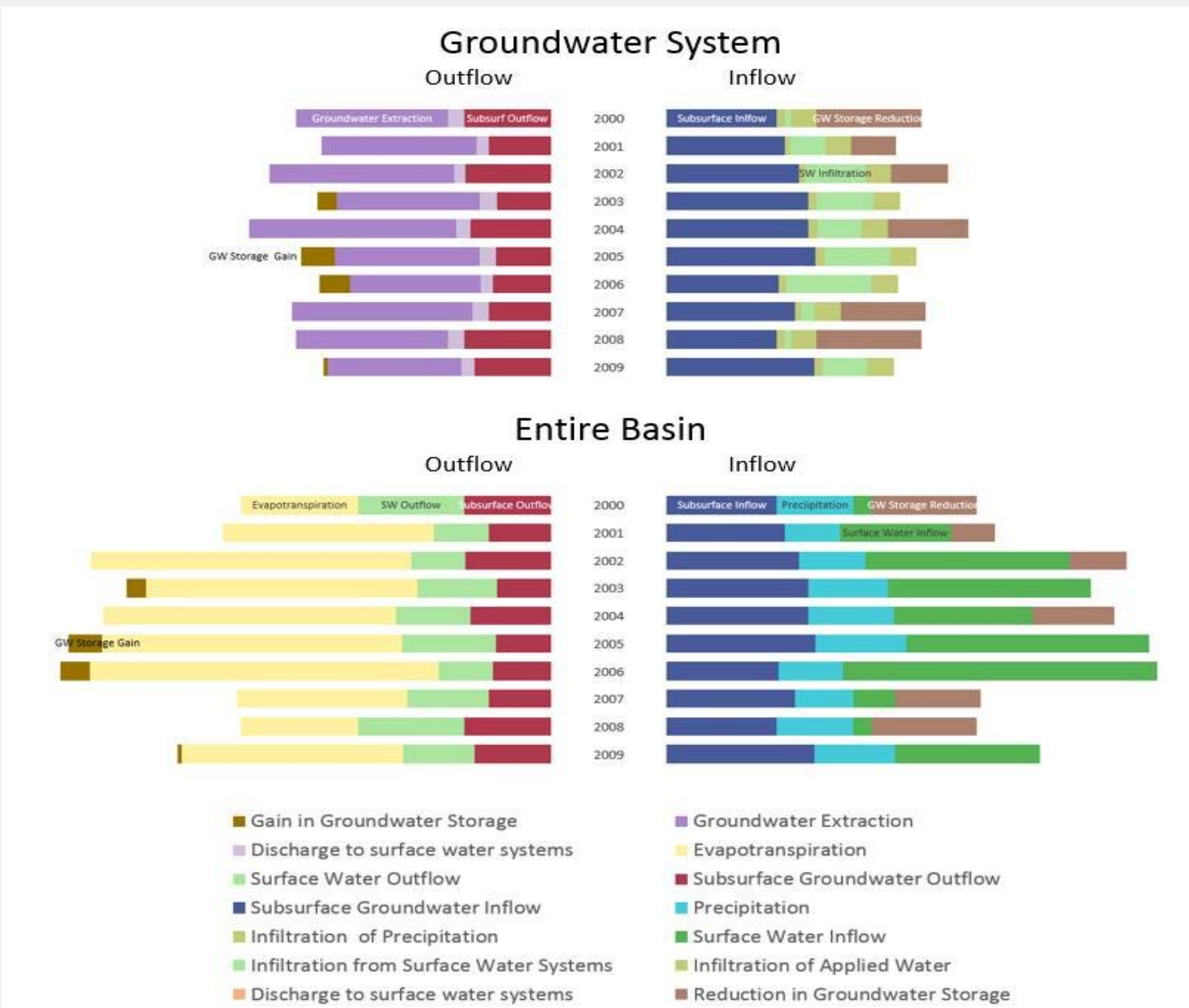


**Figure 8 – Water Budget Inflows, Outflows, and Change in Storage by Water Year for Groundwater System and Entire Basin**

## DEFINING WATER BUDGET TIME FRAMES

*23 CCR §354.18(c): Each Plan shall quantify the current, historical, and projected water budget for the basin.*

The GSP Regulations require a water budget for current, historical, and projected basin conditions. Descriptions of the water budget requirements are provided below.

### Current Water Budget Assessment §354.18(c)(1)

The GSP is required to provide an accounting of current water budget conditions to inform local resource managers and help the Department understand the existing supply, demand and change in storage under the most recent population, land use, and hydrologic conditions. The current water budget is required to quantify all seven of the general water budget requirements listed in §354.18(b).

### Historical Water Budget Assessment §354.18(c)(2)

The historical water budget accounting is required to evaluate how past water supply availability or reliability has previously affected aquifer conditions and the ability of the local resource managers to operate the basin within sustainable yield. The historical assessment is specifically required to include the following:

- Use at least the most recent ten years of surface water supply information to quantify the availability of historical surface water supply deliveries. The reliability of historical surface water deliveries is to be calculated based on the planned versus actual annual surface water deliveries, by surface water source, and water year type.
- Quantify and assess at least the most recent ten years of historical water budget information by water year type. The ten years of historical water budget information is to be used to help estimate the projected future water budgets and future aquifer response to the sustainable groundwater management projects and actions being proposed over the GSP planning and implementation horizon. The intent of the historical water budget evaluation is also to provide the necessary data and information to calibrate the tools or methods used to project future water budget conditions. Depending on the historical variability of supplies, demands, and land use; the level of historical groundwater monitoring in the basin; and the type of tool being used to estimate future projects and associated aquifer response; additional historical water budget information may be needed for adequate calibration.

- Use at least the most recent ten years of water supply reliability and water budget information to describe how the historical conditions concerning hydrology, water demand, and surface water supply availability or reliability have impacted the ability of the local agency to operate the basin within sustainable yield. To assist in the evaluation, sustainable yield should be evaluated by water year type, as previously described in (7) *An estimate of sustainable yield for the basin.*

**Projected Water Budget Assessment §354.18(c)(3)**

The projected water budget accounting is used to quantify the estimated future *baseline conditions* of supply, demand, and aquifer response to GSP implementation. It is also required to evaluate and identify the level of uncertainty in the estimate, and to include historical water budget information to estimate future baseline conditions concerning hydrology, water demand and surface water supply reliability over the 50-year planning and implementation horizon. Methods used to estimate the projected water budget include the following three requirements:

- Use 50 years of historical precipitation, evapotranspiration, and stream flow information as the future baseline hydrology conditions, while taking into consideration uncertainties associated with the estimated climate change and sea level rise projections.
- Use the most recent land use, evapotranspiration, and crop coefficient information as the baseline condition for estimating future water demands, while taking into account future water demand uncertainty associated with projected changes in local land use planning, population growth, and climate.
- Use the most recent water supply information as the baseline condition for estimating future surface water supply, while applying the historical surface water supply reliability identified in §354.18(c)(2) and taking into consideration the projected changes in local land use planning, population growth, and climate.

Time frames required for the evaluation of current, historical, and projected water budget conditions are illustrated graphically in **Figure 9**. The illustration also includes a description of data to be supplied by the Department. Additional discussion of data and data sources is provided in greater detail in subsequent sections of this BMP (*Water Budget Data Resources)*.

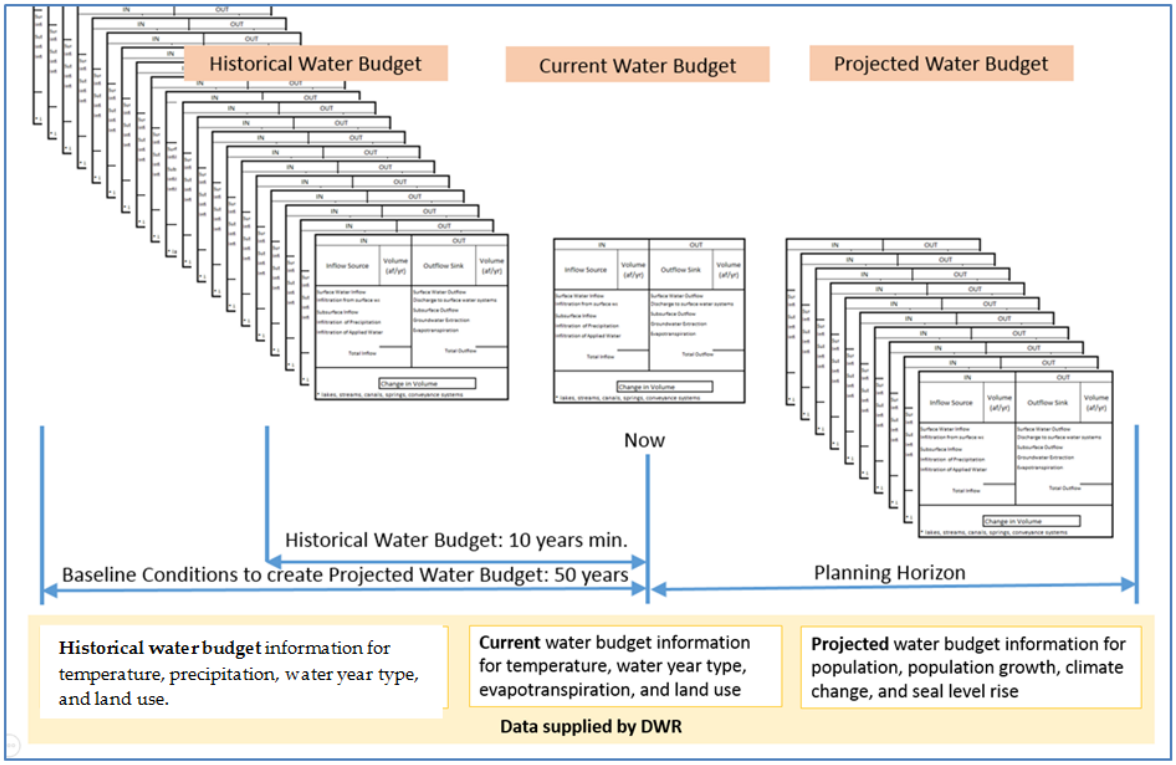


**Figure 9 – GSP Water Budget Time Frames**

Although the GSP Regulations only require annual quantification of the current, historical, and projected water budget information, in order to adequately assess projected water budget scenarios, GSAs may want to perform water budget accounting on a monthly or even a daily basis, especially if a groundwater model is used to compile and assess future water budget and aquifer conditions. In these situations, model results can be aggregated to annual values to support the GSP and subsequent *annual reporting*. Water budget accounting for shorter than annual time periods provides information necessary to support sustainable management of the basin through more timely evaluation of the water supply and demands by water use sector, of the potential undesirable results, and of the associated need for potential projects and management actions.

## IDENTIFYING AND SELECTING METHODOLOGIES TO ESTIMATE WATER BUDGET COMPONENTS

As discussed above, individual components of the water budget may be estimated independently or based on estimates of other water budget components using the water budget equation. A comprehensive review of methodologies for each water budget component is beyond the scope of this BMP; however, the reader is encouraged to review water budget data resources described under *Water Budget Data Resources* and related materials referenced in Section 7. Selection of a methodology for a particular water budget component should consider the following:

- Whether the basin includes multiple GSAs intending to implement multiple GSPs (requires coordination agreement and description of how the same data and methodology are being used).
- How historical conditions concerning hydrology, water demand, and surface water supply availability or reliability have impacted the ability to operate the basin within sustainable yield.
- Past and current approaches to quantifying water budget components in the basin.
- Alternative approaches representing the best available information and the best available science.
- Data available to support application of the methodology.
- The methods being used for GSP development in adjacent basins.
- The magnitude of the water budget component relative to other components in the basin.
- Accuracy and uncertainty associated with the methodology and supporting data.

Some water budget components lend themselves to direct monitoring and measurement more than others. For example, physical processes at the ground surface, such as surface water diversion, groundwater extraction, and precipitation can be directly measured with a high degree of accuracy, certainty, and reliability using various meters, data loggers, and other readily available monitoring devices. These approaches to monitoring support utilization of the best available science, reflect industry standards, and result in defensible data that meets the uncodified finding of SGMA to collect data necessary to resolve disputes regarding sustainable yield, beneficial uses, and water rights (SGMA Uncodified Findings (b)(3)).

In contrast, other water budget components such as infiltration from surface water systems, subsurface *groundwater flows* across basin boundaries, and seawater intrusion into the basin cannot be measured directly and must be estimated using other approaches.

The methodologies, assumptions, and data sources used to quantify water budget components are to be documented in the GSP. Much of the information needed to quantify a component of the water budget may be available in existing planning documents and on-line data sources (see *Water Budget Data Resources* below).

As described in the *Coordination of Water Budget Data* section in this BMP, for situations where basin boundaries are adjacent or contiguous to one or more additional basins, or when a stream or river serve as the lateral boundary between two basins, it is recommended that water budget accounting in adjacent basins develop "interbasin" agreements to facilitate exchange of water budget information, as described in §357.2 of the GSP Regulations.

## EVALUATING ACCURACY AND UNCERTAINTY OF WATER BUDGET COMPONENTS

Careful consideration should be given to documenting the accuracy and uncertainty of the data being used and in selecting which components are estimated independently versus estimated based on the principle of mass balance, as described above. In all cases, any components estimated based on the water budget equation (Equation 1) should be examined closely for reasonableness. For example, if past experience suggests that a typical value for infiltration of precipitation is around 5 to 10 percent of the total inflow for a given basin, but solution of the water budget equation for infiltration of precipitation results in an estimate of 50 percent of total inflow from infiltration of precipitation, additional examination of the other water budget components is warranted.

Evaluation of accuracy and uncertainty associated with individual water budget components is important because it improves understanding of the sensitivity and range of uncertainty of the various water budget components, which subsequently supports and informs development of GSP sustainable management criteria (§354.22) and projects and management actions (§354.44) that are being implemented and proposed to achieve sustainability.

## WATER BUDGET DATA RESOURCES

Data resources to assist in development of a water budget will vary according to past water management studies and water resource investigations conducted in the region. However, several sources of potentially useful information were identified and are described below. These sources include data to be provided by the Department as part of technical assistance to support GSP development and sustainable water management, as well as other available sources of information.

**Data Provided by the Department (§354.18(d) and (f))**

Data from the Department, as available, to develop the water budget identified in the Regulations includes the following (§354.18(d) and (f)):

- **Historical Information:** Monthly minimum, maximum, and mean temperature and precipitation; water year type for areas outside the Central Valley; and Central Valley land use information.
- **Current Information:** Monthly minimum, maximum, and mean temperature; water year type; evapotranspiration, and statewide land use information.
- **Projected Information:** Population, population growth, climate change, and sea level rise.
- **Modeling Support**: The California Central Valley Groundwater-Surface Water Simulation Model (C2VSIM) and Integrated Water Flow Model (IWFM).

Agencies developing a water budget may choose to use other data of comparable quality, as allowed by GSP Regulation §354.18(d). As mentioned previously, if a numerical groundwater and surface water model is not used to quantify and evaluate the projected water budget conditions, an equally effective method, tool, or analytical model must be identified and described in the plan (§354.18(e)). A water budget completed outside of a model may be useful as part of model calibration to confirm the reasonableness of water budget produced by the model.

***Climate Change and Sea Level Rise***. GSP Regulations require future water budget estimates to take into consideration changing climate and sea level rise when evaluating water supply, demand, and reliability for the basin over the planning and implementation horizon. Due to the spatial and temporal complexities associated with evaluating the basin response to changing climate, land use, and proposed projects, it is anticipated that most GSAs will utilize a hydrologic model to evaluate the various potential future basin conditions. In an effort to support consistent GSP analysis of future sustainability conditions, the Department will provide GSAs with a climate change guidance document to qualify data sources and identify acceptable methods for analyzing future climate change conditions for GSP development. These datasets will be publically posted and include future condition estimates of temperature, precipitation, runoff, sea level, and projected SWP and CVP deliveries. The data will not assume implementation of the California WaterFix Program.

### Additional Data and Resources

Several other data sources exist in addition to those data specifically identified in the GSP Regulations to be provided by the Department. Some of these include data available from the Department not specifically listed in the GSP Regulations. A summary of data available to support water budget development is provided in **Table 2**. The table is not intended to provide an exhaustive list of data and sources to support water budget development, but rather to provide a reference to data that may be helpful. Specific data selected to support water budget development will depend on methodologies selected to estimate water budget components.

**Table 2 – Potential Data Sources to Support Water Budget Development**

| Data Type | Data Sources | Notes |
|---|---|---|
| Air Temperature | DWR, PRISM, CIMIS, NOAA, USBR | Historical and current conditions available from DWR, PRISM, CIMIS, and NOAA. Projected future conditions available from DWR and USBR. |
| Precipitation | DWR, PRISM, CIMIS, NOAA, NASA, USBR | Historical and current conditions available from DWR, PRISM, CIMIS, NOAA, and NASA. Projected future conditions available from DWR and USBR. |
| Water Year Type | DWR | |
| Land Use | DWR, USDA, City, County General Plans, Local Agencies | Historical and current conditions available from DWR, USDA CDL, city & county general plans, and local agencies (including county agricultural commissioners). |
| Evapotranspiration | DWR, CIMIS, CalSIMETAW, UCCE | Historical and current conditions include reference evapotranspiration, total evapotranspiration, and amount of evapotranspiration derived from applied irrigation water. Could include traditional approaches and/or satellite remote sensing approaches. |
| Population | DWR, State Dept. of Finance, U.S. Census Bureau, UWMPs | Historical and current conditions from Dept. of Finance, U.S. Census, and UWMPs. Projected future conditions from DWR and UWMPs. |
| Climate Change | DWR, USBR | May include projected temperature, precipitation, evapotranspiration, streamflows, projected project supplies, etc. |
| Sea Level Rise | DWR | |
| Applied Water | AWMPs, UWMPs, UCCE, DWR | Historical and current applied irrigation water demands reported in AWMPs, UCCE publications, and DWR reports. Historical, current, and projected urban demands described in UWMPs. |
| Groundwater Level | DWR, USGS, Local Agencies | DWR sources include GIC and WDL. |
| Aquifer Thickness and Layering | DWR, USGS, Local/Regional Studies | DWR and USGS sources include C2VSIM and CVHM models and other studies. Local and regional studies and models may also be available. |

| Data Type | Data Sources | Notes |
|---|---|---|
| Aquifer Hydraulic Conductivity | DWR, USGS, Local/Regional Studies | DWR and USGS sources include C2VSIM and CVHM models and other studies. Local and regional studies and models may also be available. |
| Digital Elevation Model | USGS | Utilized to estimate surface water runoff from precipitation. |
| Streamflow | DWR, USGS, Local Agencies | DWR sources include CDEC and WDL. |
| Surface Water Diversions | Local Agencies, SWRCB eWRIMS, DWR, USBR | |
| Municipal/Industrial Groundwater Pumping | UWMPs | |
| Agricultural Groundwater Pumping | AWMPs, DWR, USGS | |
| Specific Yield | DWR, USGS, Local/Regional Studies | DWR and USGS sources include C2VSIM and CVHM models and other studies. Local and regional studies and models may also be available. |
| Surface Soil Properties | NRCS | |
| Per-Capita Water Use | UWMPs, DWR, USGS | |

**Tabled Acronyms:**

AWMP – Agricultural Water Management Plan
C2VSIM – California Central Valley Groundwater-Surface Water Simulation Model
CalSIMETAW – California Simulation of Evapotranspiration of Applied Water Model
CDEC – California Data Exchange Center
CIMIS – California Irrigation Management Information System
CVHM – Central Valley Hydrologic Model
DWR – Department of Water Resources
eWRIMS – Electronic Water Rights Information Management System
GIC – Groundwater Information Center
NASA – National Aeronautics and Space Administration
NOAA – National Oceanic and Atmospheric Administration
NRCS – Natural Resources Conservation Service
PRISM –Parameter-elevation Relationships on Independent Slopes Model
SWRCB – State Water Resources Control Board
UCCE – University of California Cooperative Extension
USBR – United States Bureau of Reclamation
USDA – United States Department of Agriculture
USGS – United States Geological Survey
UWMP – Urban Water Management Plan
WDL – Water Data Library

**Additional Data Sources**

Additional sources of available information include data from State and federal agencies, research institutions, local water resource management entities, and other local data collection and sharing activities. A partial list of data sources associated with existing water resource management programs are provided below:

- Urban Water Management Plans (UWMPs) http://www.water.ca.gov/urbanwatermanagement/
- Agricultural Water Management Plans (AWMPs), http://www.water.ca.gov/wateruseefficiency/agricultural/agmgmt.cfm
- Groundwater Management Plans (GWMPs), http://water.ca.gov/groundwater/groundwater_management/GWM_Plans_inCA.cfm
- Integrated Regional Water Management Plans (IRWMPs), http://water.ca.gov/irwm/stratplan/
- Groundwater Ambient Monitoring and Assessment Program (GAMA), http://www.swrcb.ca.gov/gama/
- Irrigated Lands Regulatory Program (ILRP) http://www.waterboards.ca.gov/centralvalley/water_issues/irrigated_lands/

A comprehensive list of all available sources of water budget data from state and federal agencies, research institutions, and local water management entities is beyond the scope of this BMP. Some additional sources of water budget-related information from select State and federal agencies are provided below.

***Department of Water Resources***

- Groundwater Information Center (GIC) http://water.ca.gov/groundwater/gwinfo/index.cfm
- California Statewide Groundwater Elevation Monitoring Program (CASGEM) http://water.ca.gov/groundwater/casgem/
- Water Data Library (WDL) http://www.water.ca.gov/waterdatalibrary/
- California Data Exchange Center (CDEC) http://cdec.water.ca.gov/
- California Irrigation Management Information System (CIMIS) http://wwwcimis.water.ca.gov/cimis/welcome.jsp
- Land Use Surveys: http://www.water.ca.gov/landwateruse/lusrvymain.cfm

- Groundwater –Surface Water Simulation Model: The following the Department Bay-Delta site list information for the C2VSim Central Valley Groundwater-Surface water simulation model. This same website contains additional links to the Department water budget tools such as:
  - California Central Valley Groundwater-Surface Water Simulation Model
  - http://baydeltaoffice.water.ca.gov/modeling/hydrology/C2VSim/index_C2VSIM.cfm
  - Integrated Water Flow Model (IWFM) http://baydeltaoffice.water.ca.gov/modeling/hydrology/IWFM/index.cfm
  - Irrigation Demand Calculator (IDC) http://baydeltaoffice.water.ca.gov/modeling/hydrology/IDC/index_IDC.cfm
  - CalLite: Central Valley Water Management Screening Model http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalLite/index.cfm
  - Water Resource Intergraded Modeling System (WRIMS) model engine (formally named CALSIM) http://baydeltaoffice.water.ca.gov/modeling/hydrology/CalSim/index.cfm
  - Delta Simulation Model II (DSM2) http://baydeltaoffice.water.ca.gov/modeling/deltamodeling/models/dsm2/dsm2.cfm
- Bulletin 118 http://water.ca.gov/groundwater/bulletin118/index.cfm
- California Groundwater Update 2013 http://www.water.ca.gov/waterplan/topics/groundwater/index.cfm
- Bulletin 160: California Water Plan Update 2013 http://www.water.ca.gov/waterplan/cwpu2013/final/index.cfm
- Bulletin 230-81: Index to Sources of Hydrologic Data http://www.water.ca.gov/waterdatalibrary/docs/historic/Bulletins/Bulletin_230/Bulletin_230__1981.pdf
- Additional DWR Data Topics http://water.ca.gov/nav/index.cfm?id=106
- Additional DWR Bulletin and Reports http://water.ca.gov/waterdatalibrary/docs/historic/bulletins.cfm

### *State Water Resources Control Board*

- Electronic Water Rights Information Management System (eWRIMS) http://www.swrcb.ca.gov/waterrights/water_issues/programs/ewrims/
- GeoTracker https://geotracker.waterboards.ca.gov/

#### *United States Geological Survey:*

- Central Valley Hydrologic Model (CVHM) http://ca.water.usgs.gov/projects/central-valley/central-valley-hydrologic-model.html
- Water Data Discovery: http://water.usgs.gov/data/
- Surface Water Information: http://water.usgs.gov/osw/
- Groundwater Information Pages: http://water.usgs.gov/ogw/

### Additional USGS Water Budget Related Materials by Topic

#### *Developing a Water Budget*

This USGS Circular is a general reference for developing a water budget; it includes the key components of the water budget, exchanges of water between these components, and case studies of water-budget development and the use of water budgets in managing hydrologic systems. http://pubs.usgs.gov/circ/2007/1308/

#### *Recharge Estimation*

Modeling, field-based, and other methods have been used to estimate recharge. Those included here are examples of methods potentially applicable to relatively large areas. A comprehensive overview of recharge estimation methods is available in this book: https://pubs.er.usgs.gov/publication/70156906.

This USGS report is a compilation of methods and case studies for recharge estimation in the arid and semiarid southwestern U.S., including eastern and southeastern California: http://pubs.usgs.gov/pp/pp1703/index.html

#### *Modeling of Recharge*

**Basin Characterization Model (BCM)**: developed by USGS for use in estimating natural recharge, and has been applied to all of California and other regions in the western US and internationally. This regional water-balance model differs from rainfall-runoff models because it incorporates estimates of shallow bedrock permeability to spatially distribute in-place natural recharge across the landscape. Content on the website below describes the model and associated methods, and provides links to output datasets available for historical and future projections of climate, and to associated publications of applications. The BCM is currently undergoing revisions to further improve the accuracy of recharge estimates for California; these revisions will be completed in mid-2017.
http://ca.water.usgs.gov/projects/reg_hydro/projects/dataset.html

**The Farm Process:** a tool developed by the USGS to improve the estimation of recharge (and pumping) associated with irrigated agriculture. It is available in various versions of MODFLOW; the most recent version is in MODFLOW-OWHM.

- Primary documentation, Version 1: http://pubs.usgs.gov/tm/2006/tm6A17/
- Documentation of Version 2: http://pubs.usgs.gov/tm/tm6a32/
- Version 3 is in MODFLOW-OWHM: http://water.usgs.gov/ogw/modflow-owhm/

**GSFLOW**: a coupled ground-water and surface-water flow model developed by the USGS and based on the integration of the Precipitation-Runoff Modeling System (PRMS) and the Modular Ground-Water Flow Model (MODFLOW-2005). Features of both PRMS and MODFLOW aid in recharge estimation. http://pubs.usgs.gov/tm/tm6d1/

**SWB**: a modified Thornthwaite-Mather soil-water-balance code developed by the USGS for estimating groundwater recharge. http://pubs.usgs.gov/tm/tm6-a31/

**INFIL**: a grid-based, distributed-parameter watershed model developed by the USGS, for estimating net infiltration below the root zone. The link below provides documentation of the model, the associated software, and examples of applications.
http://water.usgs.gov/nrp/gwsoftware/Infil/Infil.html

### *Case Studies for Recharge Estimation using Modeling*

**MODFLOW:** Natural recharge estimates, and uncertainty analysis of recharge estimates, using a regional-scale model of groundwater flow and land subsidence, Antelope Valley, California. https://pubs.er.usgs.gov/publication/70155814

**INFIL**: Estimating spatially and temporally varying recharge and runoff from precipitation and urban irrigation in the Los Angeles Basin, California.
http://dx.doi.org/10.3133/sir20165068

### *Geophysical Methods for Estimating Recharge*

This USGS report describes many geophysical methods for investigating groundwater recharge; it includes case studies and a list of references for further information.
http://pubs.usgs.gov/pp/pp1703/app2/pp1703_appendix2.pdf

### *Surface-Water/Groundwater Interactions*

- This USGS Circular is a general reference for groundwater and surface water, and their interdependence: http://pubs.usgs.gov/circ/circ1139/

- This USGS Circular describes the process of streamflow depletion by wells, and ways of understanding and managing the effects of groundwater pumping on streamflow: http://pubs.usgs.gov/circ/1376/
- This USGS document outlines *Field Techniques for Estimating Water Fluxes Between Surface Water and Ground Water*: http://pubs.usgs.gov/tm/04d02/
- This USGS document identifies methodologies for *Using Diurnal Temperature Signals to Infer Vertical Groundwater-Surface Water Exchange*: http://onlinelibrary.wiley.com/doi/10.1111/gwat.12459/abstract

### *Baseflow Analysis*

- General link to USGS software associated with baseflow analysis http://water.usgs.gov/software/lists/groundwater#flow-based
- U.S. Geological Survey Groundwater Toolbox, A Graphical and Mapping Interface for Analysis of Hydrologic Data (Version 1.0)—User Guide for Estimation of Base Flow, Runoff, and Groundwater Recharge From Streamflow Data: http://pubs.usgs.gov/tm/03/b10/ and http://water.usgs.gov/ogw/gwtoolbox/

### *Streamflow Trend Evaluation*

User Guide to Exploration and Graphics for RivEr Trends (EGRET) and dataRetrieval: R Packages for Hydrologic Data: http://pubs.usgs.gov/tm/04/a10/

### *Water Use*

Guidelines for preparation of State water-use estimates for 2005: http://pubs.usgs.gov/tm/2007/tm4e1/

### *Climate-Related Analysis*

*HydroClimATe:* Hydrologic and Climatic Analysis Toolkit: http://pubs.usgs.gov/tm/tm4a9/

*BCM Time Series Graph Tool:* Enabling analyses of climate and hydrology variables, including recharge and runoff, for all HUC-8 watersheds in California for historical and future climates:http://climate.calcommons.org/article/about-bcm-time-series-graph-tool

**Climate Smart Watershed Analyst:** Enabling analyses of climate and hydrology variables, for time series and seasonality for planning watersheds in the San Francisco Bay Area for historical and future climates: http://geo.pointblue.org/watershed-analyst/

## 6. KEY DEFINITIONS

The key definitions related to Water Budget development outlined in applicable SGMA code and regulations are provided below for reference.

**SGMA Definitions (California Water Code §10721)**

(b) "Basin" means a groundwater basin or subbasin identified and defined in Bulletin 118 or as modified pursuant to Water Code § 10722.

(c) "Bulletin 118" means the department's report entitled "California's Groundwater: Bulletin 118" updated in 2003, as it may be subsequently updated or revised in accordance with § 12924.

(r) "Planning and implementation horizon" means a 50-year time period over which a groundwater sustainability agency determines that plans and measures will be implemented in a basin to ensure that the basin is operated within its sustainable yield.

(t) "Recharge area" means the area that supplies water to an aquifer in a groundwater basin.

(v) "Sustainable groundwater management" means the management and use of groundwater in a manner that can be maintained during the planning and implementation horizon without causing undesirable results.

(w) "Sustainable yield" means the maximum quantity of water, calculated over a base period representative of long-term conditions in the basin and including any temporary surplus, that can be withdrawn annually from a groundwater supply without causing an undesirable result.

(x) "Undesirable result" means one or more of the following effects caused by groundwater conditions occurring throughout the basin:

(1) Chronic lowering of groundwater levels indicating a significant and unreasonable depletion of supply if continued over the planning and implementation horizon. Overdraft during a period of drought is not sufficient to establish a chronic lowering of groundwater levels if extractions and groundwater recharge are managed as necessary to ensure that reductions in groundwater levels or storage during a period of drought are offset by increases in groundwater levels or storage during other periods.

(2) Significant and unreasonable reduction of groundwater storage.

(3) Significant and unreasonable seawater intrusion.

(4) Significant and unreasonable degraded water quality, including the migration of contaminant plumes that impair water supplies.

(5) Significant and unreasonable land subsidence that substantially interferes with surface land uses.

(6) Depletions of interconnected surface water that have significant and unreasonable adverse impacts on beneficial uses of the surface water.

(y) "Water budget" means an accounting of the total groundwater and surface water entering and leaving a basin including the changes in the amount of water stored.

(aa) "Water year" means the period from October 1 through the following September 30, inclusive

**Groundwater Basin Boundaries Regulations (California Code of Regulations §341)**

(f) "Aquifer" refers to a three-dimensional body of porous and permeable sediment or sedimentary rock that contains sufficient saturated material to yield significant quantities of groundwater to wells and springs, as further defined or characterized in Bulletin 118.

(q) "Hydrogeologic conceptual model" means a description of the geologic and hydrologic framework governing the occurrence of groundwater and its flow through and across the boundaries of a basin and the general groundwater conditions in a basin or subbasin.

**Groundwater Sustainability Plan Regulations (California Code of Regulations §351)**

(b) "Agricultural water management plan" refers to a plan adopted pursuant to the Agricultural Water Management Planning Act as described in Part 2.8 of Division 6 of the Water Code, commencing with Section 10800 et seq.

(d) "Annual report" refers to the report required by Water Code §10728.

(e) "Baseline" or "baseline conditions" refer to historic information used to project future conditions for hydrology, water demand, and availability of surface water and to evaluate potential sustainable management practices of a basin.

(g) "Basin setting" refers to the information about the physical setting, characteristics, and current conditions of the basin as described by the Agency in the hydrogeologic conceptual model, the groundwater conditions, and the water budget, pursuant to Subarticle 2 of Article 5.

(h) "Best available science" refers to the use of sufficient and credible information and data, specific to the decision being made and the time frame available for making that decision, that is consistent with scientific and engineering professional standards of practice.

(l) "Data gap" refers to a lack of information that significantly affects the understanding of the basin setting or evaluation of the efficacy of Plan implementation, and could limit the ability to assess whether a basin is being sustainably managed.

(n) "Groundwater flow" refers to the volume and direction of groundwater movement into, out of, or throughout a basin.

(o) "Interconnected surface water" refers to surface water that is hydraulically connected at any point by a continuous saturated zone to the underlying aquifer and the overlying surface water is not completely depleted.

(q) "Interim milestone" refers to a target value representing measurable groundwater conditions, in increments of five years, set by an Agency as part of a Plan.

(r) "Management area" refers to an area within a basin for which the Plan may identify different minimum thresholds, measurable objectives, monitoring, or projects and management actions based on differences in water use sector, water source type, geology, aquifer characteristics, or other factors.

(s) "Measurable objectives" refer to specific, quantifiable goals for the maintenance or improvement of specified groundwater conditions that have been included in an adopted Plan to achieve the sustainability goal for the basin.

(t) "Minimum threshold" refers to a numeric value for each sustainability indicator used to define undesirable results.

(aa) "Principal aquifers" refer to aquifers or aquifer systems that store, transmit, and yield significant or economic quantities of groundwater to wells, springs, or surface water systems.

(ad) "Seasonal high" refers to the highest annual static groundwater elevation that is typically measured in the Spring and associated with stable aquifer conditions following a period of lowest annual groundwater demand.

(ae) "Seasonal low" refers to the lowest annual static groundwater elevation that is typically measured in the Summer or Fall, and associated with a period of stable aquifer conditions following a period of highest annual groundwater demand.

(af) "Seawater intrusion" refers to the advancement of seawater into a groundwater supply that results in degradation of water quality in the basin, and includes seawater from any source.

(ah) "Sustainability indicator" refers to any of the effects caused by groundwater conditions occurring throughout the basin that, when significant and unreasonable, cause undesirable results, as described in Water Code §10721(x).

(ai) "Uncertainty" refers to a lack of understanding of the basin setting that significantly affects an Agency's ability to develop sustainable management criteria and appropriate projects and management actions in a Plan, or to evaluate the efficacy of Plan implementation, and therefore may limit the ability to assess whether a basin is being sustainably managed.

(aj) "Urban water management plan" refers to a plan adopted pursuant to the Urban Water Management Planning Act as described in Part 2.6 of Division 6 of the Water Code, commencing with Section 10610 et seq.

(ak) "Water source type" represents the source from which water is derived to meet the applied beneficial uses, including groundwater, recycled water, reused water, and surface water sources identified as Central Valley Project, the State Water Project, the Colorado River Project, local supplies, and local imported supplies.

(al) "Water use sector" refers to categories of water demand based on the general land uses to which the water is applied, including urban, industrial, agricultural, managed wetlands, managed recharge, and native vegetation.

(am) "Water year" refers to the period from October 1 through the following September 30, inclusive, as defined in the Act.

(an) "Water year type" refers to the classification provided by the Department to assess the amount of annual precipitation in a basin.

## Bulletin 118 Definitions

"Beneficial use" of water in Bulletin 118 references 23 categories of water uses identified by the State Water Resource Control Board and are listed and briefly described in Appendix E.

"Groundwater overdraft" refers to the condition of a groundwater basin in which the amount of water withdrawn by pumping exceeds the amount of water that recharges the basin over a period of years during which water supply conditions approximate average conditions.

"Groundwater in storage" refers to the quantity of water in the zone of saturation.