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RB INYOKERN DATA CENTER

Application for Small Power Plant Exemption (SPPE)

Inyokern, Kern County, California

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Supporting Document Appendix E

Subsection(s):

- E.3 – Water Supply Assessment *(continued)*

Attachment E1

Earth Consultants International, Subsidence Report

March 2021
ECI Project No. 4009.01

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Subject: **Draft** Report Differential Interferometric Synthetic Aperture Radar (DInSAR) Study of Subsidence in the Kern County Subbasin (KCS)

Earth Consultants International (ECI) are pleased to present this report describing the scope of work, methodology, findings, and conclusions of a Differential Interferometric Synthetic Aperture Radar (DInSAR) study of the KCS. The purpose of this study was:

1. To assess the magnitude and potential drivers of land subsidence within the KCS between 2015 and 2020,
2. To assess recent DInSAR data in comparison to National Aeronautics and Space Administration/ Jet Propulsion Laboratory (NASA/JPL) subsidence data, and
3. To provide recommendations for the next steps.

DInSAR imagery for this study was obtained from Sentinel-1 radar images combined with a Short Baseline Subset (SBAS) stacking algorithm to create (1) a time series to measure subsidence and (2) for the creation of figures showing the measured average subsidence rates within the KCS) for the period April 2015 through September 2020. The project was initially intended to include radar imagery collected by the Japanese ALOS 1 & 2 satellite systems for the years between 2007 to 2011 and from 2014 to the present. Concerns about the poor quality of the raw radar images and its potential effect on data resolution prevented the use of this data.

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To achieve maximum resolution ECI downloaded, processed and analyzed a total of 172 Sentinel-1 SAR images dating from May 3, 2019. This data represents the period spanning from the end of a historic stack of Sentinel-1 interferograms created by NASA/JPL through the end of September 2020. In total the DInSAR stack generated by ECI contained 526 interferograms spanning the period of interest (i.e., 2015-2020 for this current study. The DInSAR interferometric stack created in this study was combined with the NASA/JPL stack and Line-Of-Sight (LOS) velocities were generated from the combined data using a Least-Squares processor developed by ECI.

For presentation, the processed output of the two combined interferometric stacks was converted from millimeters to inches and the subsidence was classified into 13 color coded intervals ranging from 1 to >40 inches. To the extent possible ECI utilized the same color coding as those provided on the NASA/JPL figures. For reference, and to place the findings of this current study in context, the NASA/JPL subsidence figures generated from 2015-2017 InSAR data are provided herein. (Figures 1 to 5a). These are discussed further in Section 4.1 of the report.

The raw cumulative and annual displacement (i.e., subsidence) data was used to create seven transects oriented west to east (Figure 6). Figures 7 and 8 present the current study period cumulative subsidence and annual rate of subsidence, respectively. The individual transects shown on Figure 6 are presented in detail on Figures 9a through 9g. Transect A to A′ spans the Valley approximately 4.5 miles to the north of the KCS boundary. This transect serves as a point of reference and comparison to the data within the KCS. It also provides a potential basis for SGMA-required planning and project management actions with Groundwater Sustainability Agencies (GSAs) adjacent to the KCS. The six other transects (B to B′ through G to G′) cover the entirety of the KCS. To assess interferogram stack quality, point time series data were extracted at the location of 13 continuous GPS stations. Plots were created combining data for each location, using time series data from the GPS stations, the NASA/JPL stack and the DInSAR stack created for this study (Figures 10a to 10m). The point time series plots for each GPS station were utilized to ground-truth the results of the SBAS stacking process. The time series plots exhibited a robust correlation between the vertical velocities measured by the continuous GPS stations and the velocities measured by the study InSAR stacking. As a further quality check, five point time series plots (Figures 11a to 11e) were also created for locations with subsidence known to be driven by different mechanisms (i.e., groundwater extraction versus oil field activities). These plots illustrate the difference in subsidence over time associated with extraction of oil and gas, which has a nearly linear, uniform subsidence pattern versus subsidence driven by groundwater extraction, which usually has a distinctive cyclic, seasonal subsidence pattern over time. For a baseline comparison one point was also selected in a “stable area” with nearly zero subsidence over time. Figures 12 to 34 provide cumulative subsidence and annual rate of subsidence for the study period for the individual GSAs within the KCS.

The ECI subsidence maps, point time series and subsidence transects verify the general subsidence patterns identified by earlier investigations by NASA/JPL (Farr et al 2015, 2016), TRE Altamira (2019) and the statistical study of the TRE Altamira report done by Towill, Inc (2020) commissioned by DWR.

An important preliminary finding of this study is that the short time spans (e.g. 1-3 years) used in some of the previous studies are likely overestimating the subsidence in groundwater extraction areas due to the inherent variability in short- and long-term subsidence rates. The calibrated velocities along satellite LOS in this current study is between 45 to 50% of the subsidence rates previous reports described in areas with subsidence driven by groundwater extraction. That is, previous studies may have overestimated KCS groundwater extraction related subsidence by a factor of up to 50%. By way of comparison, this does not appear to be the case for areas with subsidence driven by extraction of oil and gas, where we found the subsidence rates to be the same or somewhat larger than in previous studies. The discrepancy in the subsidence data may be affected by the cyclical nature of groundwater extraction as compared to the more steady, non-cyclical, characteristics of subsidence associated with oil production. Further assessment of this phenomenon is recommended as part of KCS SGMA project management action planning.

We hope that the information presented in the following report provides you with the data you need at this time. We appreciate the opportunity to provide these services to the KCS. Should you have any questions regarding the above, please do not hesitate to contact us at your earliest convenience.

Respectfully submitted,
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APPENDICES

Draft Differential Interferometric Synthetic Aperture Radar (DInSAR)
Study of Subsidence in the Kern County Subbasin (KCS)

1.0 INTRODUCTION

1.1 PURPOSE OF THE STUDY

Earth Consultants International (ECI) conducted a ground subsidence study for the Kern County Subbasin (KCS, subbasin, or Subbasin) area using stacked satellite-based Differential Interferometry Synthetic Aperture Radar (DInSAR). The purpose of the study was:

1. To assess the magnitude and potential drivers of land subsidence within the KCS between 2015 and 2020,
2. To assess this recent DInSAR data in comparison to National Aeronautics and Space Administration/ Jet Propulsion Laboratory (NASA/JPL) subsidence data, and;
3. To provide recommendations for the next steps.

The primary objective was to provide information to KCS stakeholders which could be utilized with regard to SGMA-required planning. A secondary goal was, to the extent feasible, to differentiate between sources of subsidence and their potential impact on critical infrastructure like canals and aqueducts within the KCS.

1.2 REGULATORY AND PRACTICAL FRAMEWORK GUIDING THE STUDY

In 2014, the State passed the California Sustainable Groundwater Management Act (SGMA), a piece of legislation comprised of three separate bills, including Assembly Bill 1739, Senate Bill 1319, and Senate Bill 1168 (State Department of Water Resources, 2015). The SGMA, which went into effect on January 1, 2015, requires the formation of local Groundwater Sustainability Agencies (GSAs) whose role is to monitor and ensure that groundwater resources in the State are used and managed sustainably. As a result of the drought that California experienced during 2010 through 2016, and the increasing number of water supply users, many of the groundwater basins in central and southern California have been, and are being pumped in excess of their natural rate of replenishment with a resultant drop in the groundwater table. In some areas this in turn has led to compaction of the geologic sediments and significant land subsidence, with concomitant damage to groundwater aquifers, utilities, public infrastructure, and some natural resources such as groundwater-fed streams and springs.

Senate Bill 1168 requires, among other things, the GSAs prepare GSPs and to regularly measure and monitor the depth to groundwater in their basin and calculate the maximum amount of water that can be pumped out of the basin in a year without causing an "undesirable result." An "undesirable result" can include any of the following: 1) chronic or persistent lowering of the groundwater level, 2) significant and unreasonable reduction in groundwater storage, 3) significant and unreasonable seawater intrusion, 4) significant and unreasonable degradation of water quality, 5) significant and unreasonable land subsidence, and 6) depletions of surface water that result in significant and unreasonable adverse impacts on beneficial uses (Water Education Foundation, 2015). The focus of this current study is land subsidence and how an integrated approach utilizing both land and satellite-based technology can be economically utilized to accurately measure and model this phenomenon.

Traditionally, the monitoring of ground surface deformation has been conducted using spirit-leveling (surveying) techniques. This method is very precise but potentially costly and time-consuming. Further, the data is often spatially and temporally sparse, as measurements are made at relatively few locations, and at temporal intervals typically measured in months or years (e.g., Poland et al., 1984). Extensometers are another method of measuring ground subsidence. These provide reliable data, but are expensive to install and maintain and, like surveying, typically provide sparse, localized data coverage.

DInSAR has been used for more than 20 years by government agencies and research institutions to assess the conditions of topographic elevation changes, to monitor groundwater basins in order to quantify potential sediment consolidation, and to monitor surface deformation resulting from the extraction and/or recharge of groundwater (for a few examples of these studies, refer to the links provided in the References Section of this report). Compared with the other direct-measurement methods briefly described above, DInSAR is considered more cost- effective, as this method can cover large areas without the need for surface access agreements and maps both the magnitude of the vertical deformation and its spatial distribution within a study area.

Provided a suitable number of satellite passes are available, DInSAR combined with a stacking algorithm can also yield changes in elevation over relatively short time intervals making it particularly useful for assessing cyclical surface changes. Finally, recent developments in the processing of interferograms to provide time-series analyses have further increased the potential value of DInSAR as a method for the monitoring of aquifers. The level of detail and broad areal coverage that DInSAR can provide make it a useful tool along with continuous GPS for local GSAs looking to adopt sustainable management plans in response to the requirements of the SGMA.

2.0 TECHNICAL BACKGROUND

2.1 DIFFERENTIAL INTERFEROMETRY SYNTHETIC APERTURE RADAR (DInSAR)

The DInSAR method relies on the processing and comparison of two Synthetic Aperture Radar (SAR) images of the same portion of the Earth's surface taken by the same satellite system on two different passes. In simple form; -in recurrent passes a satellite bounces a radar (microwave) signal off the Earth's surface and records the phase and amplitude of the reflected signal. The product resulting from the digital comparison of the phase component of two or more SAR images is called an interferogram; the resulting image illustrates and quantifies the changes in the ground surface elevation that occurred between the two satellite passes used in the analysis. The method can detect vertical changes of the ground surface of as little as 5 mm (0.2 inch) for standalone interferograms. A resolution below 5 mm can be achieved when multiple interferograms are used together with a stacking algorithm. The SAR images from the satellite platforms that ECI used for this study (discussed further below) have a surface (horizontal) pixel resolution of 25 meters (m; ~82 feet) with no space between pixels. The vertical resolution of the subsidence rates derived from this DInSAR stack is approximately 2.4mm/year or $\pm 1\sigma$ (Standard Deviation) based on comparisons with data from continuous operating GPS stations (UNAVCO and SOPAC) in the target area. For the areas with the largest subsidence this represents an error of ~1% of the annual subsidence rates.

As of September 2020, when the analysis for this study was initiated, archived satellite data from the three selected satellite systems were available for the past 10 years (2010 to 2020), as follows:

1. The Japanese Space Agency (JAXA) ALOS 1 (2006 - 2011)
2. The Japanese Space Agency (JAXA) ALOS 2 (2014 - current)
3. The European Space Agency (ESA) Sentinel-1A/B (2015 - current)

Data from all the satellite systems is available through the respective data portals for the European Space Agency (ESA) and the Japanese Space Agency (JAXA) as well as through the Alaska Satellite Facility (ASF) operated by the Geophysical Institute at the University of Alaska Fairbanks. A radar image generated by one of these satellites cannot be directly compared to an image generated by another satellite system, so the interferograms that are generated have to be based on images from the same system. The generated interferograms can be compared across satellite platforms. Data quality concerns related to the ALOS 1 & 2 systems precluded its use in the current study. This prevented extending the study period to encompass historic data for the period 2007 to 2011.

Interferometric patterns that may result from the comparison of two or more paired radar images from different time periods may be used to interpret subsurface structures defining the margins of aquifers as well as internal structures and stratigraphy, especially when combined with data from other sources like groundwater extraction records, water level data and well logs. Once a baseline is established and calibrated, yearly, biannual, or quarterly interferograms can be used as a cost-effective management tool for monitoring the conditions of the basins.

By combining the DInSAR stack from NASA/JPL with the interferometric stack generated in this study ECI identified discrepancies in the calibrated velocities along satellite LOS. The study by NASA/JPL appears to overestimate the subsidence rates for the areas with groundwater-driven subsidence by as much as 45 to 50%, though the subsidence rates for areas with subsidence driven by extraction of oil and gas are comparable between this current study and the earlier NASA/JPL data. We attribute this discrepancy to errors introduced when using linear regression on a dataset that covers a timespan that is too short (e.g. one to two years of withdrawal – recharge cycles of the aquifer) when the data contains cyclic (seasonal) changes.

Additional information on DInSAR, including the methodology used to process the data, is provided in Section 3.1 and Appendix A.

2.2 GROUND SUBSIDENCE RESULTING FROM GROUNDWATER EXTRACTION

In California, land subsidence primarily occurs as a result of groundwater extraction but can also result from tectonic activity (mountain forming and seismic events), natural consolidation of sediment, oxidation, and compaction of organic deposits, hydro compaction of moisture-deficient soil and sediments, and extraction of oil (Poland et al., 1984; Galloway and Burbey, 2011; Borchers et al., 2014). Contributing factors to subsidence caused by oil extraction activities in the KCS and their potential to impact critical infrastructure are discussed in Section 2.3 of this report.

Aquifer systems experience some degree of deformation in response to changes in hydraulic stress, which include natural (rainfall) recharge and/or artificial recharge, or withdrawals such as groundwater pumping or reinjection (Galloway and Burbey, 2011; Bawden, 2003). The seasonal cycle of discharge and recharge from unconsolidated heterogeneous aquifer systems, such as those underlying many locations in the Central and San Joaquin valleys and the Santa Clara and Antelope valleys, typically causes measurable elastic (recoverable) land subsidence and subsequent, proportionate uplift (measured in millimeters to centimeters) of the land surface. Removing water from storage in fine-grained sediments (silts and clays) interbedded in the aquifer system can cause these highly compressible sediments to compact inelastically and permanently as pore pressure is reduced. Land subsidence from inelastic (non-recoverable) compaction is a common consequence of significant groundwater level changes that can result from development of groundwater as a resource (Borchers et al., 2014; Sneed, 2016).

There are some limitations to the use of ground surface deformation data for monitoring aquifers. Specifically, for surface subsidence to occur, there must be one or more compressible layers of sufficient thickness under static conditions below the top of the saturated zone. These layers can consist of multiple stacked or interlensing fine grained layers, or a single subregional fine grained member, such as the Corcoran Clay. Additionally, the layers need to have been dewatered during extended periods of continuous pumping. All of these factors can be found in the Central Valley. Reversible (elastic) surface deformation may occur as the pore pressure within the compressible layers cyclically rises and falls during either seasonal or other forms of alternating short-period extractions and recharge. Alternatively, if the compressible layers are dewatered due to pumping without significant recharge for an extended period of time (i.e., several years), irreversible (inelastic) surface deformation will typically occur (Bawden, 2003; Borchers et al., 2014; Orange County Water District, 2016). Monitoring of surface deformation is thus primarily a useful tool if (1) the aquifers in question contain suitable compressible layers, and (2) those layers have not been previously dewatered for an extended period of time below a depth termed the "pre-consolidation stress" (e.g., prior historical low water level). Both elastic and inelastic compaction related to groundwater extraction has and is occurring in the Central Valley. For example, a large and historically propagating subsidence bowl immediately north of the KCS is attributed to dewatering of both the Corcoran Clay and fine-grained lenses to the east beyond the extent of the Corcoran Clay. The leading edges of this bowl appears to be impacting the KCS near Delano. By way of contrast, surface elevation stability or elevation increase in the KCS is also discernable in the data, due to groundwater banking activities and direct recharge via losing streams and along mountain fronts that border the KCS.

2.3 GROUND DEFORMATION RESULTING FROM EXTRACTION OF OIL AND GAS

Subsidence caused by oil field activities can be differentiated from those of seasonal agriculture. Oil field activities by their nature are long term and constant. As such they are readily discernable on DInSAR and the pattern of subsidence generally does not exhibit variability over time. Data from this current study has confirmed this phenomenon. Examples in the KCS include the Lost Hills, Cymric, Elk Hills, and Belridge oil fields, among others.

Recent technical review studies conducted on behalf of the Westside Water Authority (WDWA) have concluded that oilfield activities in the Lost Hills Oil Field (LOHF) are a contributing factor to subsidence between mileposts 195 and 215 on the California Aqueduct. In 2018, the LHOF generated approximately 13,500 acre-feet (AF) of produced water. By way of contrast, the WDWA estimates it has historically pumped only around 3,000- 5,000 AF/year for the purpose of blending the naturally poor-quality groundwater with Aqueduct water when supplies are short. Most of its irrigation water is provided by the Aqueduct (Aquilogic 2019, 2020).

Oilfield-operator aquifer exemption application materials submitted to the State document that oil extraction causes subsurface water (aka "produced water") to move up-structure due to subsurface pressure differences. According to the WDWA study, this action can withdraw subsurface water from beneath the Aqueduct, contributing to the identified undesirable subsidence results between the above referenced mileposts. The WDWA study concluded this is particularly true for areas where the Aqueduct lies adjacent to the LHOF and/or in places where the oil field geologic structure extends beneath the Aqueduct at depth (Aquilogic, 2020). A comparison of DWR Aqueduct subsidence profiles to oil field cross sections produced by the oil field operators showed a strong correlation between oil pumping and Aqueduct subsidence (Aquilogic, 2020). The WDWA study provides a basis for interpreting the DInSAR data generated by this current study. The DInSAR shows subsidence centered on the LHOF, which extends slightly to west and the east. Without the recent WDWA study this data could suggest a significant contribution from agricultural pumping to the aforementioned Aqueduct subsidence, as preliminarily reported by the DWR. However, the WDWA study indicates the irrigation well density within a five-mile radius of the Aqueduct is sparse in comparison to the number of oil wells in the LOHF (Aquilogic, 2020), and the DInSAR data produced in this current study has the characteristic signature of subsidence associated with oil field activities.

3.0 WORK COMPLETED AND METHODOLOGY FOLLOWED

Pursuant to our proposal dated June 18, 2020, ECI completed the tasks outlined below as part of this study. A more detailed description of the DInSAR method and data sources is provided in Section 2.1 and Appendix A.

3.1 QUALITY OF ALOS-1 & -2 DATA

Part of this study had intended to use historic ALOS-1 & -2 satellite data to supplement the more recent Sentinel-1 data. To assess data viability and quality ECI downloaded a total of 328 radar images from the Alaska Satellite Facility. All radar images were selected based on the geographic footprint of the study area to ensure that the whole target area was covered. ECI also ensured that the "Baseline Perpendicular Offset" of the images (Perpendicular offset between recurring orbits. See Appendix A) was within an acceptable range for successful InSAR processing. These images were then pre-processed and prepared for interferometric processing with the DInSAR processing package developed by Scripps Institute of Oceanography, Generic Mapping Tool Synthetic Aperture Radar (GMTSAR).

Results from the first processing attempt indicated potentially severe quality issues with both the ALOS -1 & -2 images. The parts of the images that were furthest in range from the satellite (SAR equipped satellites are always looking down at an oblique angle), were distorted. When these images were combined to form an interferogram it was apparent that many images also were offset along azimuth (flight path of the satellite orbit) likely due to poor control of the satellite's internal clock. Attempts at working around the problem by using a different DInSAR processing package, ROI_PAC developed by NASA/JPL, were unsuccessful due to the same quality problem. Further attempts at processing the ALOS data was thus abandoned as being non-viable and having unreliable quality, as both DInSAR processors failed with the same error. Therefore, in order to achieve maximum resolution, the ALOS data was not utilized for this current study.

3.2 INSAR PROCESSING OF SENTINEL-1 DATA, COMBINING AND STACKING INTERFEROGRAMS

A total of 172 Sentinel-1 radar images were downloaded from the European Space Agency and after pair-wise merging of neighboring images the resulting 86 SAR images were processed using the GMTSAR processor. The 86 SAR images were combined to produce 526 interferograms. By stacking this number of images ECI was able to correct for the effects of ambient moisture in the atmosphere on the interferometric data. The removal of the atmospheric effects (which can be substantial) due to moisture in clouds, transpiration and fog is important for achieving data accuracy. By using multiple interferograms created from different radar images within the same interferometric dataset, it is possible to calculate, and then subtract, the atmospheric effect on all but the first and last image in the stack. The first and the last slice in the interferometric stack can for that reason contain data outliers. However, the second step of the stacking process utilizes a least-squares method on corresponding pixels in every slice of the interferometric stack to extract a map of the surface velocities along LOS from the satellite. In so doing, the potential for data outliers to affect the final result is minimized. The initial stacking and atmospheric corrections are corrected with a Short Baseline Subset (SBAS) algorithm included in the GMTSAR package.

When re-stacking the slices after calibration to tie down the interferometric stack to stable points or to calibrate the stack to deformation recorded by continuous GPS stations, ECI applied a least-squares software package to the stacked data. Following the creation of ECI's interferometric stack, this same software package was also used when combining interferometric stacks from NASA/JPL to calculate the combined displacement rates (see Section 3.4). To remove the last traces of atmospheric interference from the interferometric stack, ECI used a process where a stable point (i.e., near zero subsidence) is identified within the footprint of the satellite images. In this case we used the CORS GPS station ISLK operated by UNAVCO, which shows long-term stability because it is located far from known sources of deformation (i.e., faults and areas with subsidence or uplift). All slices in the interferometric stack were adjusted so the value of the pixels corresponding to the location of the stable reference point is equal to zero (or in general, matching the displacement of the GPS station). The interferometric stack can then be re-processed with the least-squares software to generate maps where the displacement rates are calibrated (i.e., tied to GPS data).

3.3 Combining and post-processing the Sentinel-1 stack with NASA/JPL data

Due to the relatively short time span of the stack (i.e., April 2015 – May 2019) acquired from NASA/JPL and the short time span of the interferometric stack generated in this study (i.e., May 2019 to September 2020), it was determined that a better option was to create a combined stack spanning the full five-year period between April 1, 2015 through September 30, 2020. This was done by co-registering the ECI stack with a subset of the NASA/JPL stack and then adjusting it by adding the last slice in the NASA/JPL stack to all following slices in the ECI stack. This was possible because there was a small time overlap between the two stacks, and because one slice near the end of the NASA/JPL stack has a date matching the first slice in the ECI stack. With this process completed, we ran the merged stack through a least-squares processor and generated a velocity map for the complete period between 2015 and 2020. The ECI least squares processor also outputs a map of the R^2 ("goodness of fit") values which allows us to filter out areas where the correlation is low between the pixel values in the stack and the resulting velocity. For the maps in this report, we used an R^2 value as 0.67 as the threshold, and everything with a lower value was filtered out.

3.4 Correlating DInSAR velocities with permanent GPS (GNSS) stations

For quality control and for comparison to the NASA/JPL data we used 13 continuous GPS stations for which we downloaded available time-series data. Time series for these locations were then extracted from the corresponding location in the two DInSAR stacks and data from all three sources were then plotted together and examined. The trends of the three graphs, GNSS, NASA/JPL- and ECI DInSAR time series all show matching patterns in addition to the slopes of the DInSAR graphs matching recorded GPS data. There is too much noise (i.e., inherent atmospheric and ionospheric noise) in the NASA/JPL DInSAR time-series data to be able to recognize the fine seasonal changes in subsidence seen in the GPS data, but overall the trend and slope of the two patterns match. With the SBAS algorithm used by ECI on the Sentinel-1 data for the period between May 3, 2019 and September 30, 2020, the fine seasonal deformation patterns match the GPS data well, showing a robust correlation between DInSAR and GPS measurements. Examples for these two conditions are presented on Figures, 10a, 10b, 10d ,10e and 10h respectively.

3.5 Extraction of transects and point time series

As part of this study, we extracted seven west-to-east transects (showing annual rates and cumulative displacement), roughly equally spaced from the northern to the southern boundaries of the KCS. The placement of the transects cover critical infrastructure such as the Aqueduct and oil fields (Figure 6). For orientation purposes, markers showing the location of canals, major roads and oil fields were inserted into the transects. Extraction of transects and raster calculations for conversion between millimeters and inches were done with QGIS and the resulting text files with the cross sections were subsequently plotted with the Generic Mapping Tools (GMT). A similar technique was used when extracting data from the interferometric stacks (See the previous section 3.4). We used GMT to extract the deformation values stored in the pixels at chosen geographic locations in the raster files that makes up the interferometric stack, transferring the values to text files. These files were then plotted in GMT together with data from the continuously operating GPS stations. To illustrate the difference in subsidence patterns over time in areas with extraction of oil and gas, versus areas with groundwater extraction, five point-time series were also extracted from the stacked DInSAR data. Two point-time series from each type of area were generated with an additional point series generated in a stable area with no known subsidence.

4.0 FINDINGS AND DISCUSSION

4.1 SUBSIDENCE WITHIN THE KERN COUNTY SUBBASIN

The preliminary result of this current DInSAR study found that subsidence rates associated with seasonal groundwater extraction within the KCS over the period 2015 to 2020 are likely 45 to 50% lower than estimated by the NASA/JPL. This is because of previous studies assessed shorter time intervals that can be subject to greater variability in the raw InSAR data due to seasonal changes in the subsidence rate. Based on data from NASA/JPL (*Progress Report: Subsidence in California, 2015, 2017*), subsidence rates of between 8 and 9 inches per year are estimated for the most rapidly subsiding area at the northern border of the KCS west of Delano. Based on the longer time series utilized in this study, a subsidence rate of 2 to 3 inches per year is estimated for the same area. Similarly, the maximum subsidence rate for groundwater extraction in the subsidence bowl south of Bakersfield is estimated to be 6 to 7 inches per year for the previous shorter NASA/JPL data time series. The data for this current study estimates average subsidence rates for this same area as between 3 to 4 inches per year. A likely cause for these discrepancies lies in the changes in subsidence over time due the cyclical pumping and recharge of underlying aquifers and more long-term effects such as drought conditions. These patterns are very clear when looking at the DInSAR time series for the two GNSS stations BKR1 and BKR2, where both short, cyclical, and long-term effects are visible (Figures 10d and 10e).

We have also observed that the noise evident in the stacked data from NASA/JPL may cause problems especially when looking at shorter time spans. Though the long-term subsidence rates that can be calculated from their stacked data closely matches the subsidence rates as measured by the continuous GPS stations in the region, this noise makes it impossible to study the finer seasonal fluctuations. Furthermore, this noise significantly reduces the correlation and introduces an uncertainty in the calculated subsidence rates. Some of these effects are evident in many of the NASA/JPL figures from previous studies and present as patches of white (i.e. no color) in areas of identified groundwater extraction induced subsidence.

For the estimated subsidence rates, it is important to note that these velocities are calculated over a longer period of time, and that these will be different from the cumulative subsidence over the same time period. This is due to the large variability in subsidence rate over time, something which is evened out when doing a least-squares regression of the subsidence to calculate the average subsidence rate.

It is also important to note here that although subsidence is generally thought of as a purely vertical process, there are significant horizontal geo-mechanical stresses associated with land subsidence that are often overlooked. These stresses are known to increase over distance from the center of the source of the subsidence, reaching a maximum near the hinge line of the depression and can have deleterious consequences for linear infrastructure such as aqueducts, pipelines, canals, and rail tracks. A separate 3-dimensional analysis of the horizontal stress patterns and their potential impact on critical infrastructure in the KCS is needed for a more complete understanding of potential undesirable results.

The five identified areas of interest (AOIs) for subsidence are presented on Figure **5a**. These areas were previously identified based on NASA/JPL data for the periods 2015 to 2016 and 2015 to 2017 (i.e., 2015-2017). Below is a comparative update based on this current study utilizing DInSAR data from April 2015 to September 2020.

Friant-Kern Canal (AOI 1)

This AOI was rated by the GSAs in the KCS as high priority for monitoring between Mileposts 120 to 130, east-northeast of the City of McFarland (Figure 5a). At times, previous InSAR monitoring has detected up to 5 inches per year of subsidence in areas surrounding this segment of the Friant-Kern Canal. The current study indicates that the rate of annual subsidence in this AOI averages between 2 and 3 inches (**Figure 8**).

California Aqueduct Mileposts 196 to 215 (AOI 2)

This AOI was identified as high priority by the GSAs in the KCS. It consists of a segment of the Aqueduct where an embankment failure occurred at Milepost 208 in June of 2011 (**Figure 5a**). While additional studies to assess and monitor subsidence in this AOI are planned, a separate study by WDWA in 2019 and early 2020 has identified LOHF activities as a contributing factor to the identified subsidence (see Section 2.3). This current study shows the subsidence along this segment of the Aqueduct displays the characteristics of oil field activities, and that the LHOF is isolated by areas of generally lower annual subsidence, suggesting that agricultural groundwater extraction is minimal in this area. (**Figure 8**).

Friant-Kern Canal Mileposts 130 to 137 (AOI 3)

This AOI was identified as medium priority by the GSAs in the KCS. It is located along the Friant-Kern Canal between Mileposts 130 and 137, southwest of Famoso and Poso Creek (**Figure 5a**). Annual subsidence rates identified by this current study is estimated at between 2 to 3 inches and are a result of agricultural activity (Figure 8). An area of higher annual rate of subsidence (minimum of 3 inches) is located immediately to the west of AOI 3. That subsidence is also attributable to agricultural activities.

California Aqueduct Mileposts 267 to 271 (AOI 4)
This AOI was rated as medium priority by the GSAs in the KCS (**Figure 5a**). A review of the NASA/JPL rate of subsidence for 2015-2016 shows this area experienced between 2 and 4 inches of subsidence for that period (**Figure 5**). Data provided in this current study indicates an average subsidence rate for the period April 2015 to September 2020 was around 1 to 2 inches.

North Boundary of Subbasin (AOI 5)
The GSAs in the KCS identified this area as medium priority (**Figure 5a**). While there is reportedly no large critical infrastructure nearby this AOI there are many individual well casings that could be affected by localized subsidence. Coordinated monitoring with adjacent GSAs, both within the KCS, and those adjacent GSAs outside of the KCS is recommended. A review of the rate of subsidence for 2015-2016 presented in the 2020 NASA/JPL data shows this AOI reportedly experienced between 5 and 8 inches of subsidence for that period (**Figure 5**). Data provided in this current study indicates an average subsidence rate for the period April 2015 to September 2020 was around 2 to 4 inches, with isolated areas slightly higher. The cumulative subsidence for the current study period is approximately 5 to 10 inches versus 10 to 15 inches for the period 2015 to 2017 presented in the NASA/JPL data. (**Figure5**). It appears areas immediately to the north of the AOI outside of the KCS are experiencing significantly higher cumulative subsidence ranging from between 20 to 40 inches in places during this current study period.

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Based on the data and methodology presented above, we conclude the following:

- Sentinel-1 SAR data provides a viable method of mapping and monitoring subsidence within the KCS, especially when combined with a stacking method that reduces atmospheric noise and that allows the data set to be reliably calibrated against continuous GPS stations in the area.
- The vertical resolution of the DInSAR stack for this current study is approximately 2.4mm/year based on comparisons with data from KCS continuous GPS stations in the study area. The error rate is approximately 2.4mm/year (one standard deviation).
- Though subsidence rates identified in this study require careful future monitoring, we believe previous studies may be overestimating by 45 to 50% the subsidence rates associated with seasonal groundwater extraction within the KCS. This is due to the short time intervals related to the acquisition of available InSAR data (Confirmed by JPL, Personal communication with Dr. Zhen Liu, 2021).
- The northern boundary of the KCS is administrative and not hydraulically-based. Groundwater extraction activities to the north of the KCS should be considered in SGMA related planning and be included in future monitoring as these activities contribute to the subsidence in areas along the northern KCS boundary.

- Although subsidence is generally envisioned to be primarily vertical phenomenon, there is also a horizontal stress (3-dimensional) geomechanical component to subsidence that can have profound effects on infrastructure such as aqueducts, canals pipelines and well casings.

- DInSAR provides a useful and economical tool for siting ground-based monitoring technology (e.g. new GPS or extensometers) to enhance KCS coordination and monitoring efforts

- Discerning the difference between subsidence caused by seasonal (cyclical) groundwater extraction and non-seasonal; (i.e., long term) oilfield activities is possible utilizing DInSAR. The ability to ascertain these differences are enhanced when DInSAR is integrated with GPS or location-specific ground-based technology (e.g., extensometers, new GPS stations etc.).

5.2 RECOMMENDATIONS

As a result of this study, we recommend the following:

1. Conduct additional assessment of the apparent discrepancies between the current DInSAR results and NASA/JPL subsidence data, in areas subject to seasonal groundwater withdrawal by sharing the results of this current study with NASA/JPL.
2. Future InSAR studies should include a minimum time interval of five years' worth of InSAR data to enhance data resolution and accuracy.
3. The 3-dimensional forces associated with ground subsidence include horizontal stresses. These stresses can have expensive and long-term undesirable results on critical infrastructure such as the California Aqueduct and the Friant-Kern Canal within the KCS. The scientists at the Lawrence-Berkeley Laboratory (LBL) have demonstrated expertise in assessing the effects of vertical and horizontal geo-mechanical stress on infrastructure. It is recommended that the KCS consider engaging LBL to conduct a geo-mechanical (horizontal stress) assessment of the five AOIs with an emphasis on the critical water infrastructure (e.g., the California Aqueduct and Friant-Kern Canal).
4. LBL study partners for the purpose of cost sharing could include the DWR and Friant Water Authority, respectively. The results of the study could have significant implications on proposed or planned infrastructure rehabilitation projects, including their effectiveness, permanence, and cost.
5. Conduct a detailed analysis of the current DInSAR data and existing (2020) KCS hydrogeologic data (e.g. groundwater quality, groundwater levels and groundwater flow modeling etc.) to further refine the potential nexus between oil field activities and undesirable results to critical infrastructure in the KCS.
6. Continue coordination efforts with GSs to the north of the KCs with a focus on subsidence monitoring and reporting.

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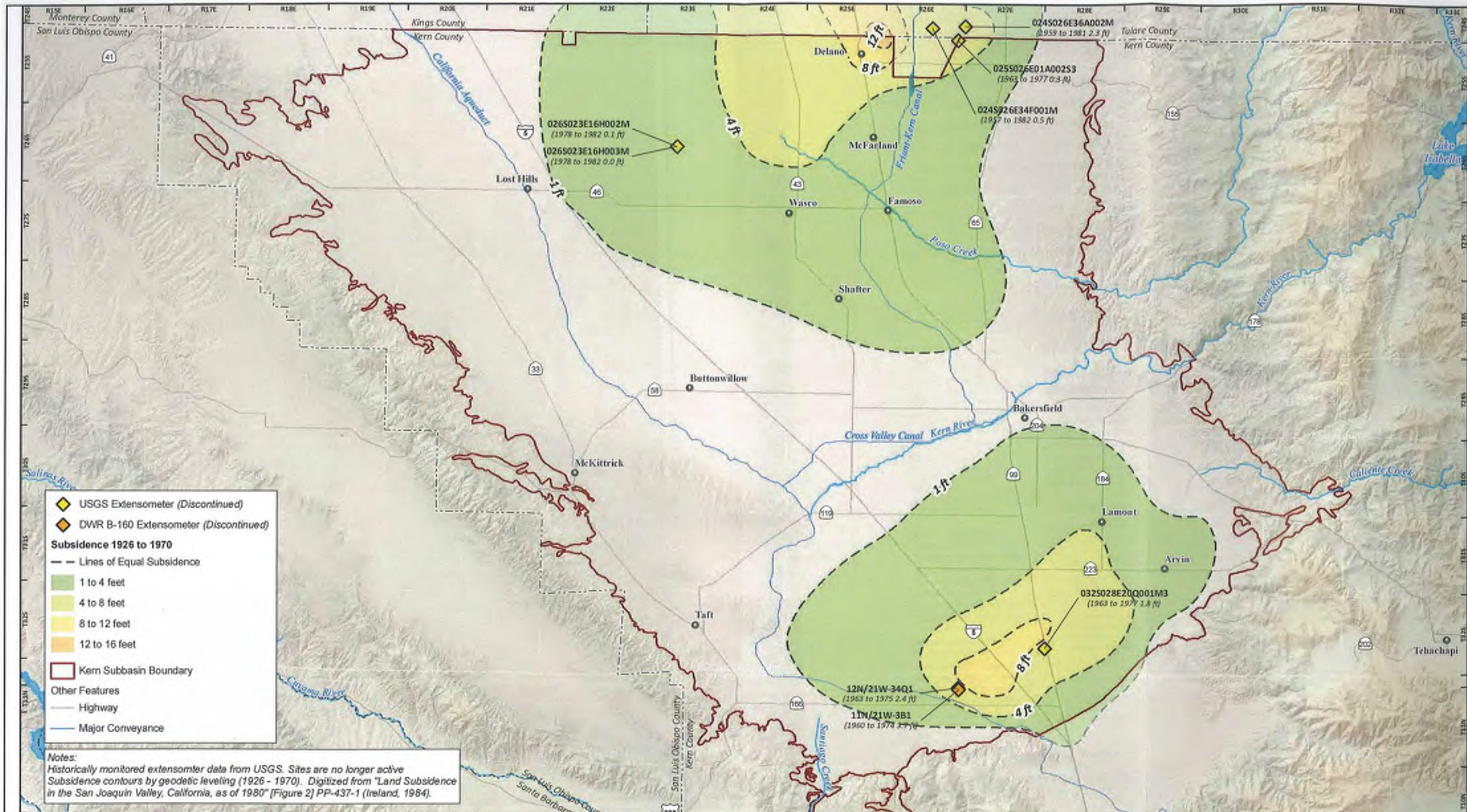

Source: GEI Consultants. (2020). Groundwater Sustainability Plan, Kern County. January.

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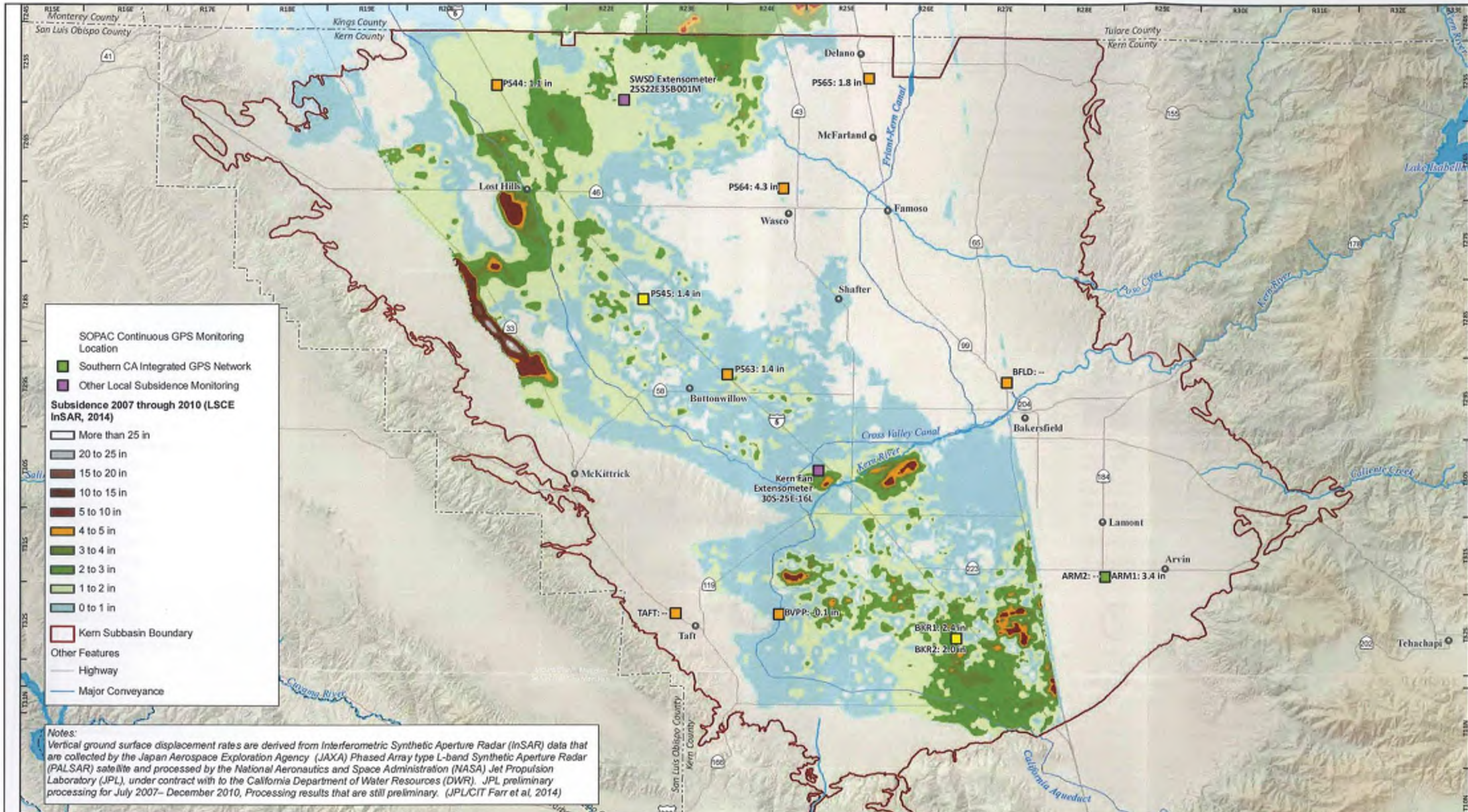
GEI, 2020 Figure 2-41
"HISTORICAL SUBSIDENCE"

Date: 2/17/2021	Project #: 043-04	Figure 1



Source: GEI Consultants. (2020). Groundwater Sustainability Plan, Kern County. January.

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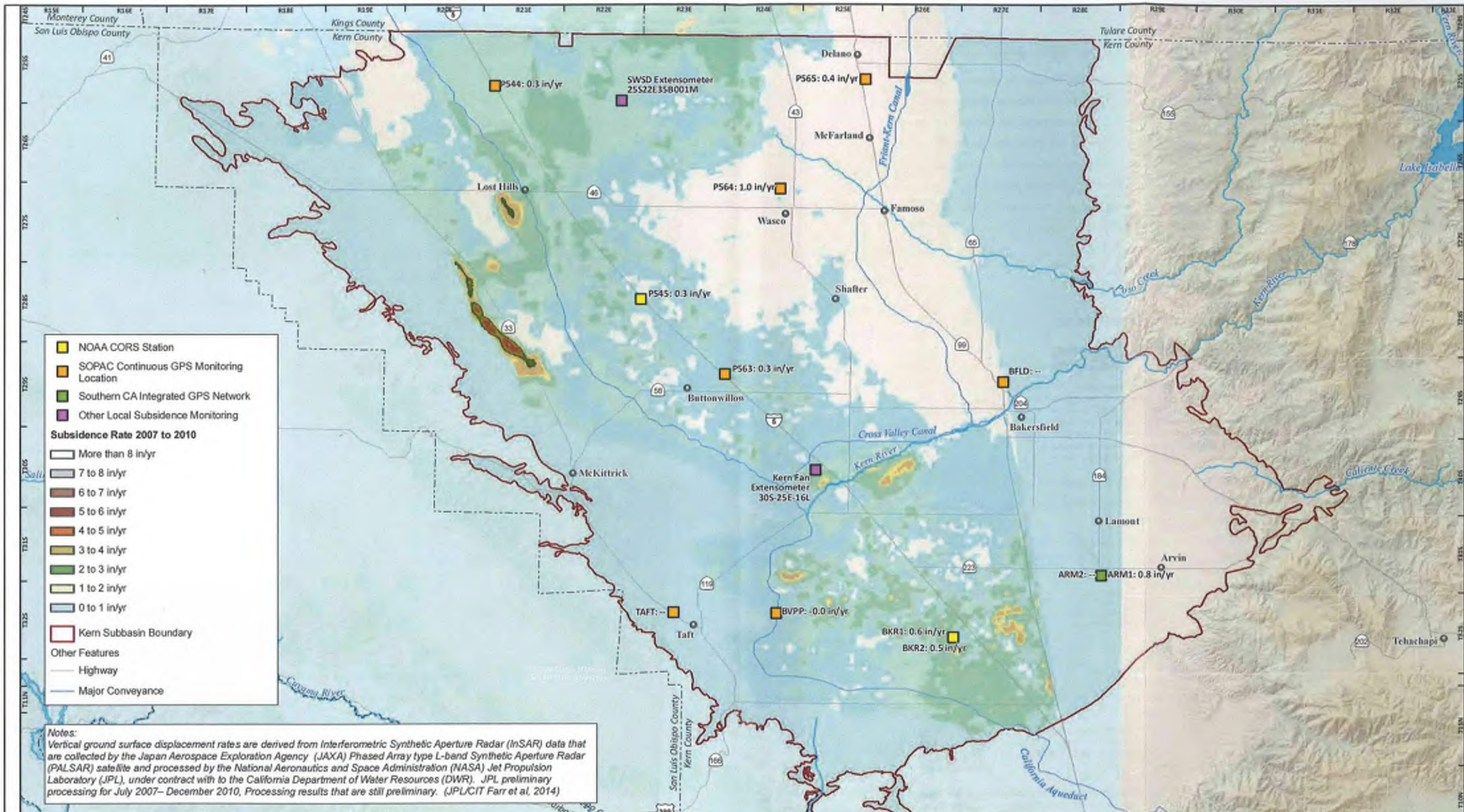
GEI, 2020 Figure 2-42 "SUBSIDENCE 2007 - 2010"

Date: 2/17/2021	Project #: 043-04	**Figure 2**



Source: GEI Consultants. (2020). Groundwater Sustainability Plan, Kern County. January.

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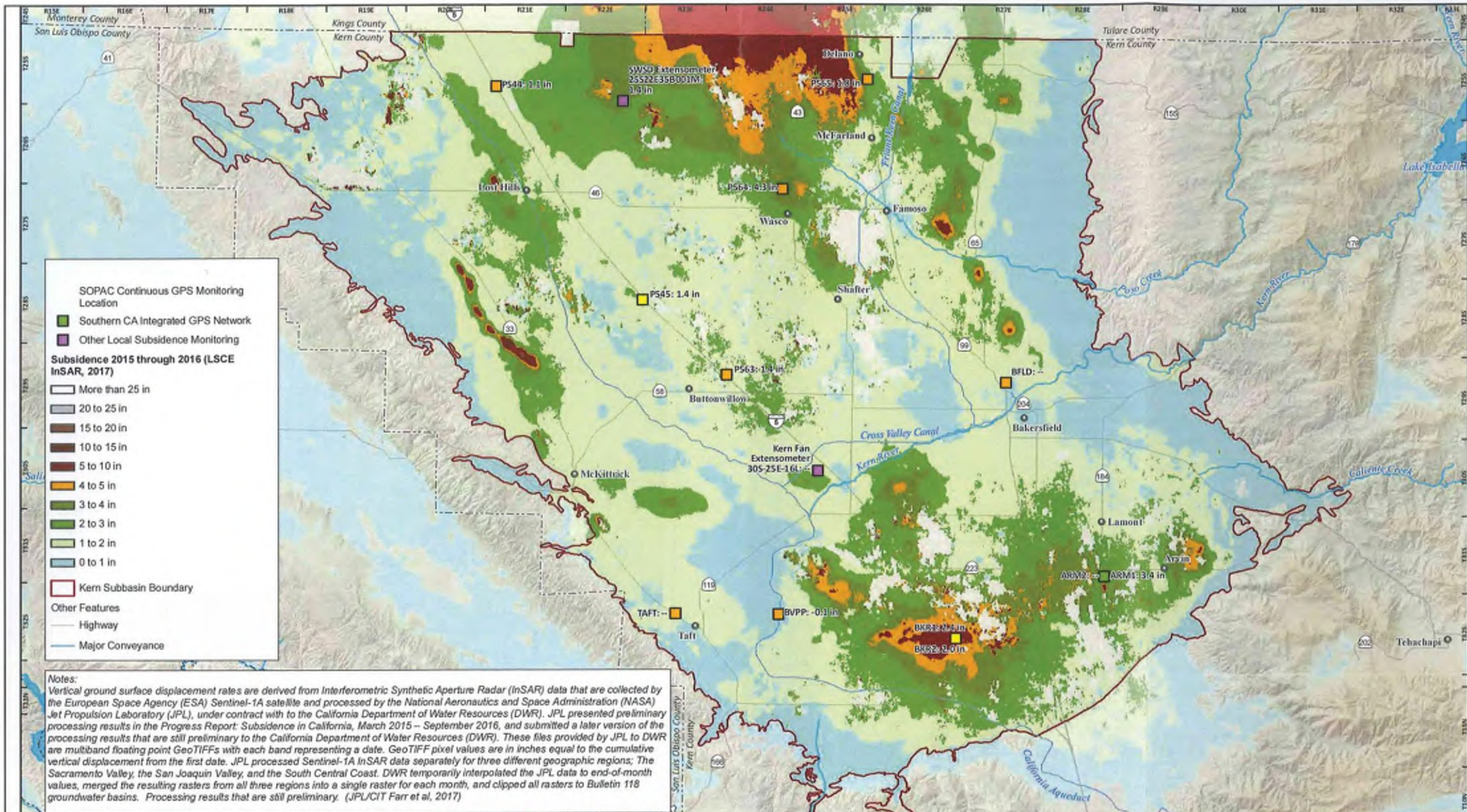
GEI, 2020 Figure 2-44
"RATE OF SUBSIDENCE 2007-2010"

Date: 2/17/2021	Project #: 043-04	**Figure 3**



Notes:
Vertical ground surface displacement rates are derived from Interferometric Synthetic Aperture Radar (InSAR) data that are collected by the European Space Agency (ESA) Sentinel-1A satellite and processed by the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL), under contract with to the California Department of Water Resources (DWR). JPL presented preliminary processing results in the Progress Report: Subsidence in California, March 2015 – September 2016, and submitted a later version of the processing results that are still preliminary to the California Department of Water Resources (DWR). These files provided by JPL to DWR are multiband floating point GeoTIFFs with each band representing a date. GeoTIFF pixel values are in inches equal to the cumulative vertical displacement from the first date. JPL processed Sentinel-1A InSAR data separately for three different geographic regions; The Sacramento Valley, the San Joaquin Valley, and the South Central Coast. DWR temporarily interpolated the JPL data to end-of-month values, merged the resulting rasters from all three regions into a single raster for each month, and clipped all rasters to Bulletin 118 groundwater basins. Processing results that are still preliminary. (JPL/CIT Farr et al, 2017)

Source: GEI Consultants. (2020). Groundwater Sustainability Plan, Kern County. January.

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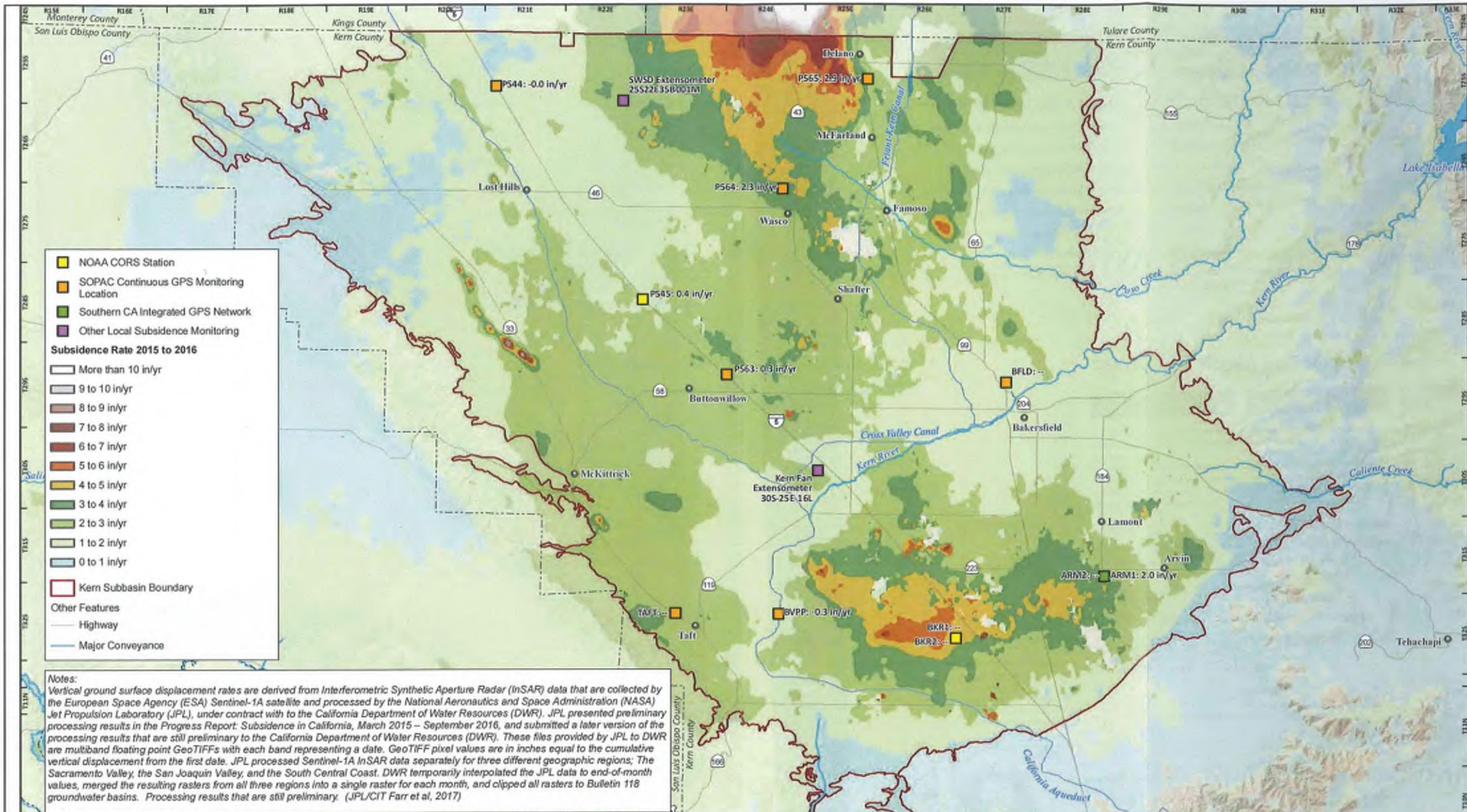
GEI, 2020 Figure 2-43 "SUBSIDENCE 2015 - 2016"

Date: 2/17/2021	Project #: 043-04	**Figure 4**



Notes:
Vertical ground surface displacement rates are derived from Interferometric Synthetic Aperture Radar (InSAR) data that are collected by the European Space Agency (ESA) Sentinel-1A satellite and processed by the National Aeronautics and Space Administration (NASA) Jet Propulsion Laboratory (JPL), under contract with to the California Department of Water Resources (DWR). JPL presented preliminary processing results in the Progress Report: Subsidence in California, March 2015 – September 2016, and submitted a later version of the processing results that are still preliminary to the California Department of Water Resources (DWR). These files provided by JPL to DWR are multiband floating point GeoTIFFs with each band representing a date. GeoTIFF pixel values are in inches equal to the cumulative vertical displacement from the first date. JPL processed Sentinel-1A InSAR data separately for three different geographic regions; The Sacramento Valley, the San Joaquin Valley, and the South Central Coast. DWR temporarily interpolated the JPL data to end-of-month values, merged the resulting rasters from all three regions into a single raster for each month, and clipped all rasters to Bulletin 118 groundwater basins. Processing results that are still preliminary. (JPL/CIT Farr et al, 2017)

Source: GEI Consultants. (2020). Groundwater Sustainability Plan, Kern County. January.

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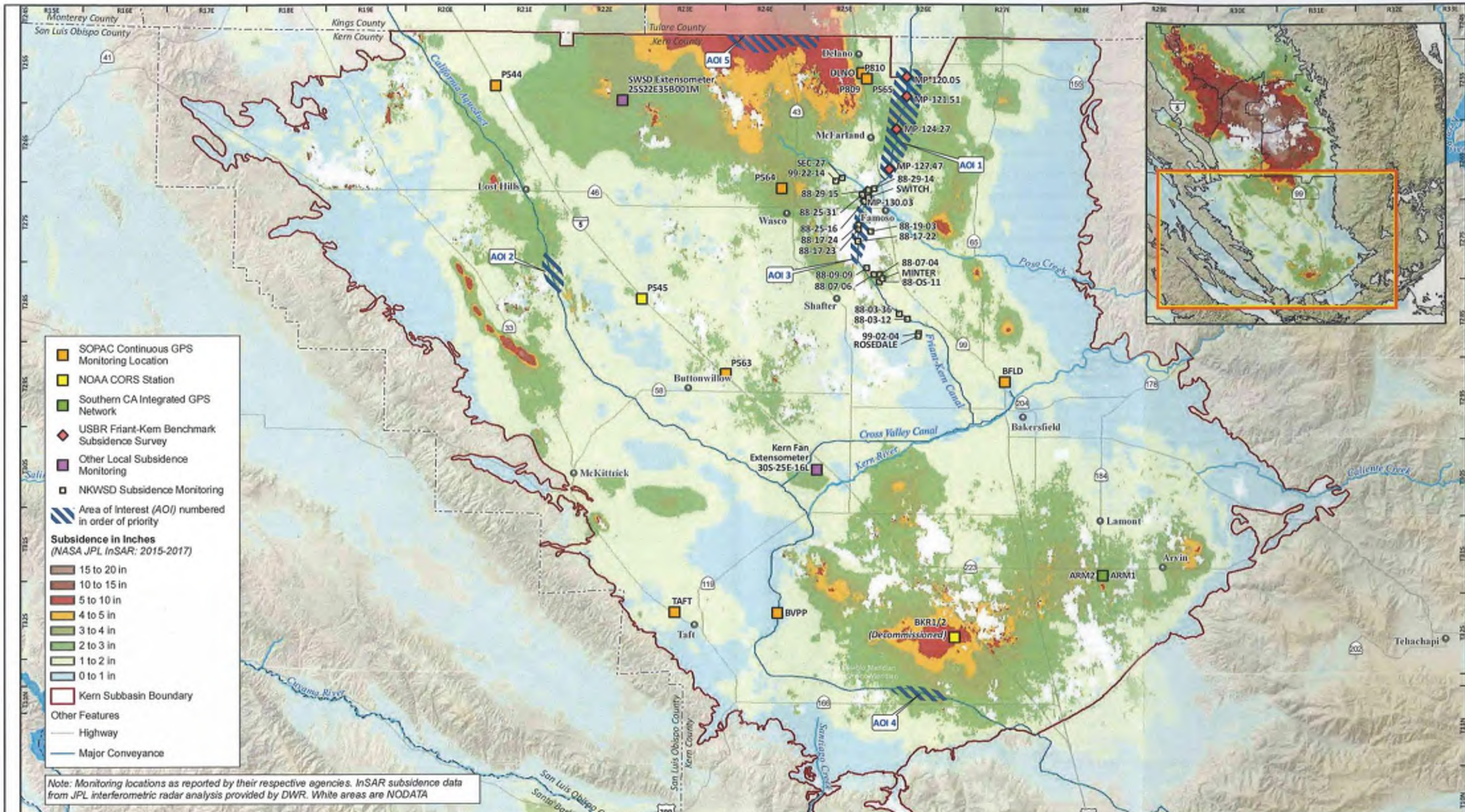
GEI, 2020 Figure 2-45
"RATE OF SUBSIDENCE 2015-2016"

Date: 2/17/2021	Project #: 043-04	**Figure 5**



Source: GEI Consultants. (2020). Groundwater Sustainability Plan, Kern County. January.

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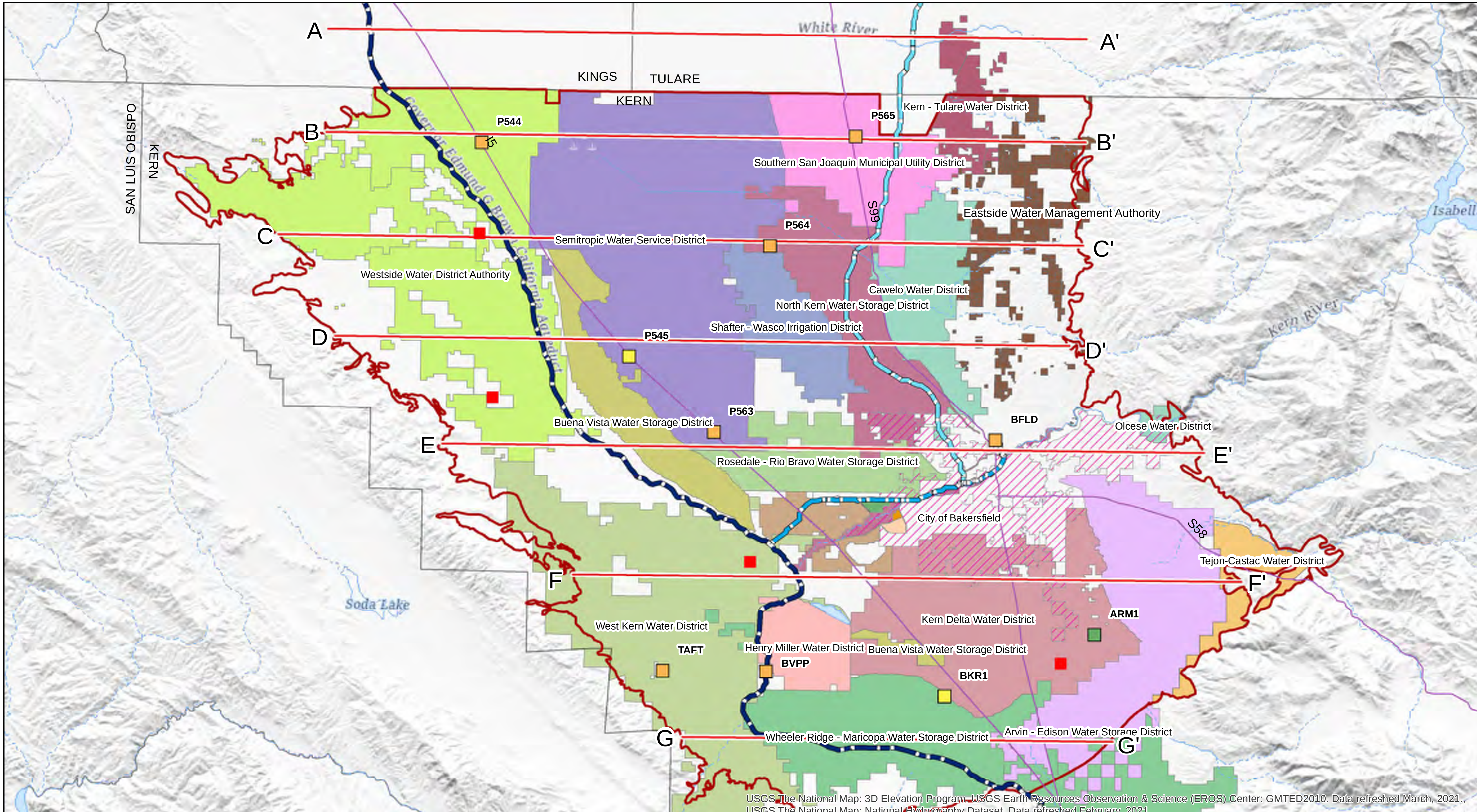
GEI, 2020 Figure 3-6 "REGIONAL MONITORING NETWORK"

Date: 2/25/2021 | Project #: 043-04 | Figure 5a



Transect location (approximate)
Kern County Groundwater Sub-basin
California Aqueduct
Cross Valley Canal
Friant-Kern Canal

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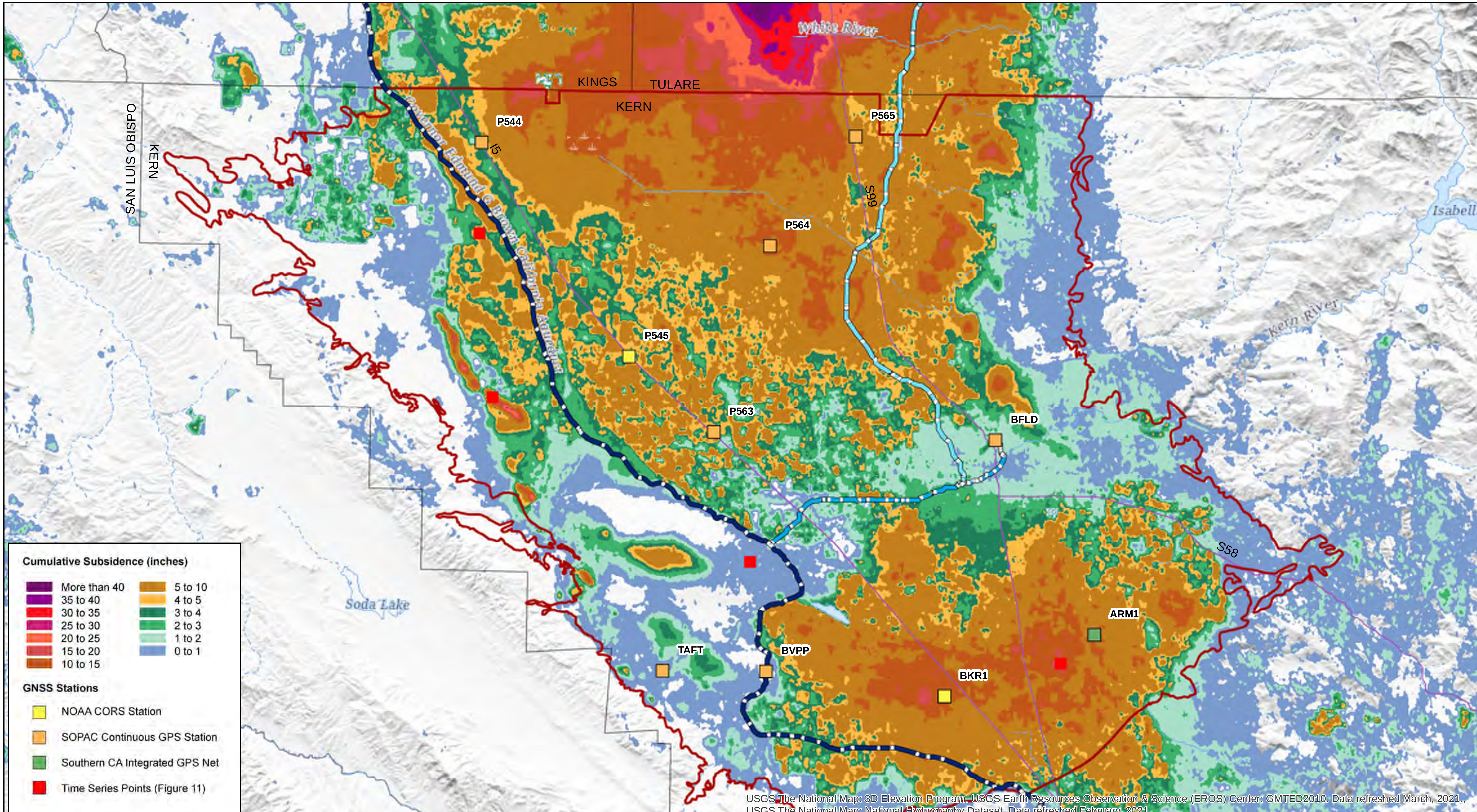
Study Area Location and Transects

Date: 4/4/2021 | Project #: 043-04 | **Figure 6**



Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

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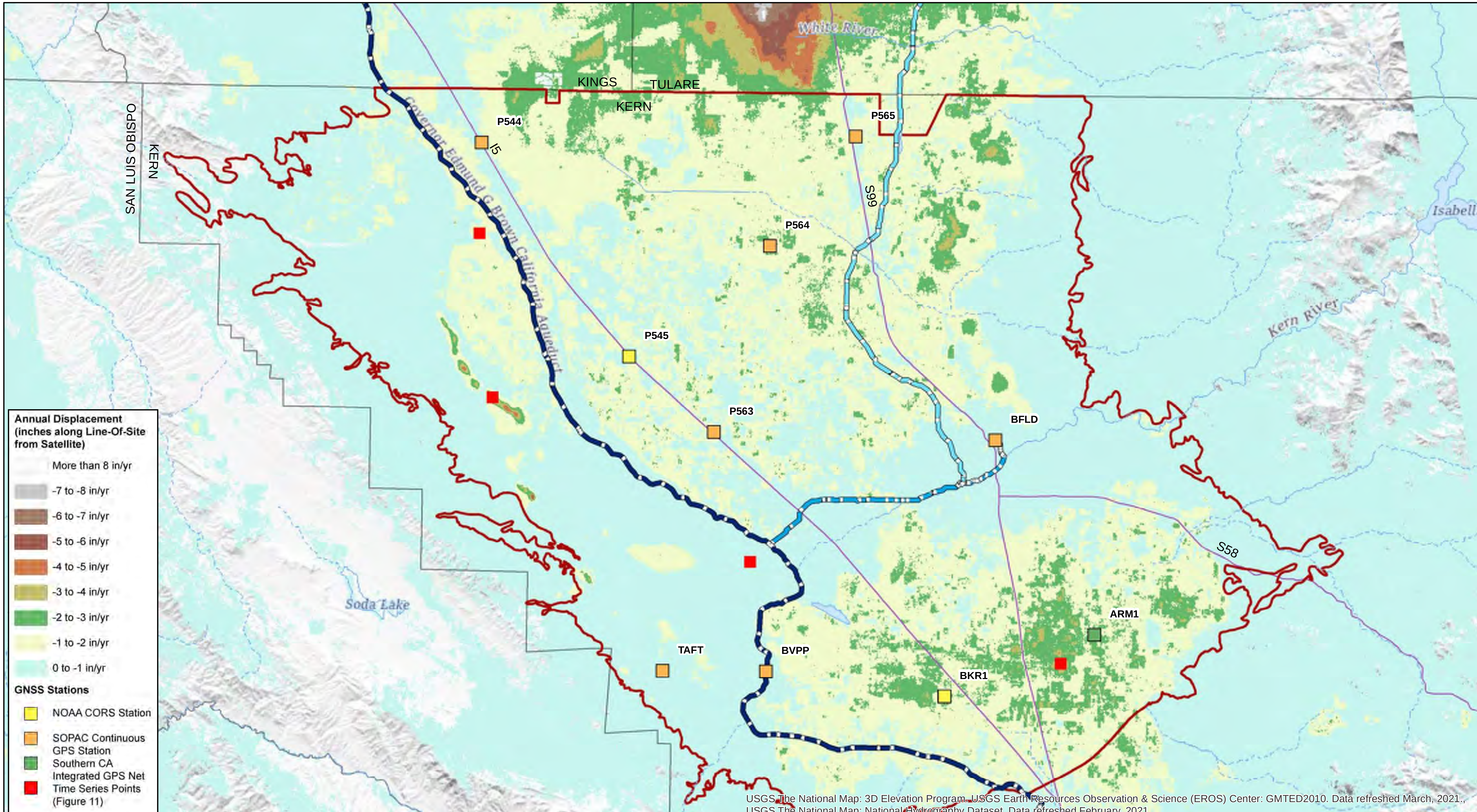
Cumulative Subsidence 1/4/2015 to 9/30/2020

Date: 4/4/2021 | Project #: 043-04 | **Figure 7**



Kern County Groundwater Sub-basin

Friant-Kern Canal

Cross Valley Canal

California Aqueduct

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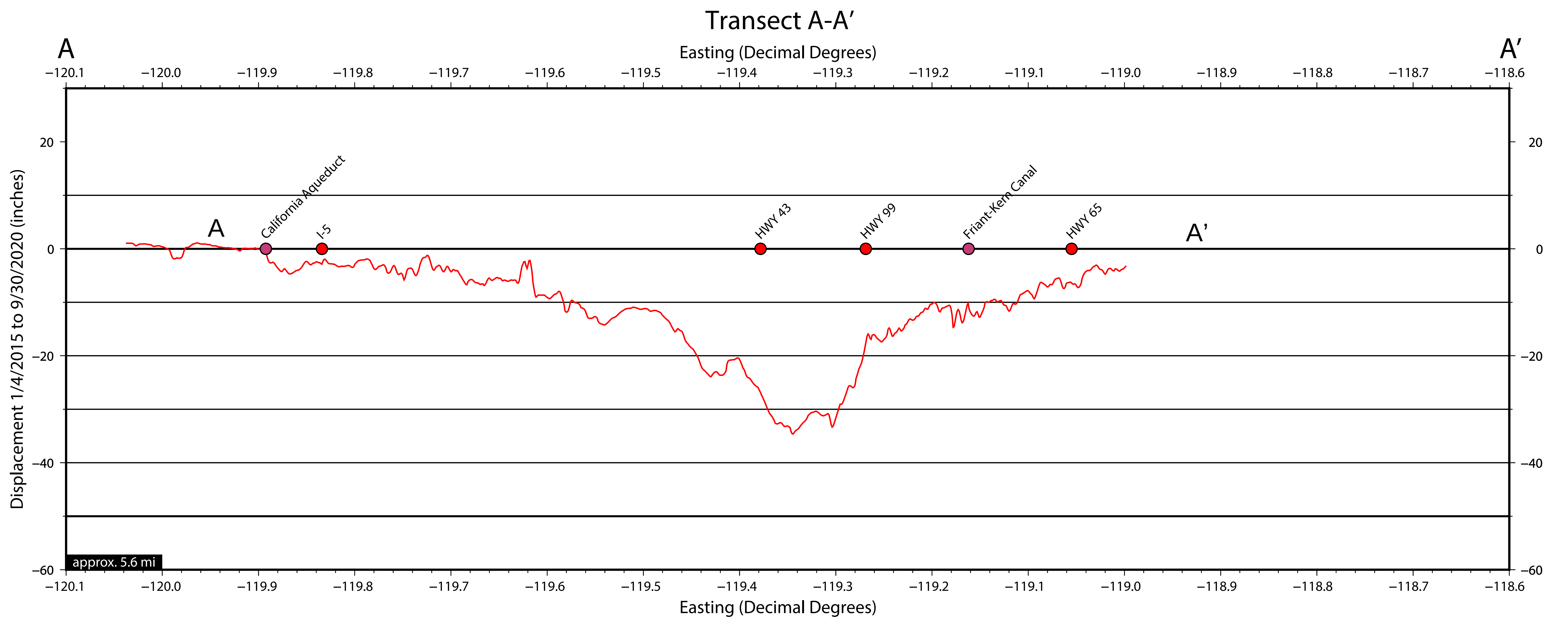
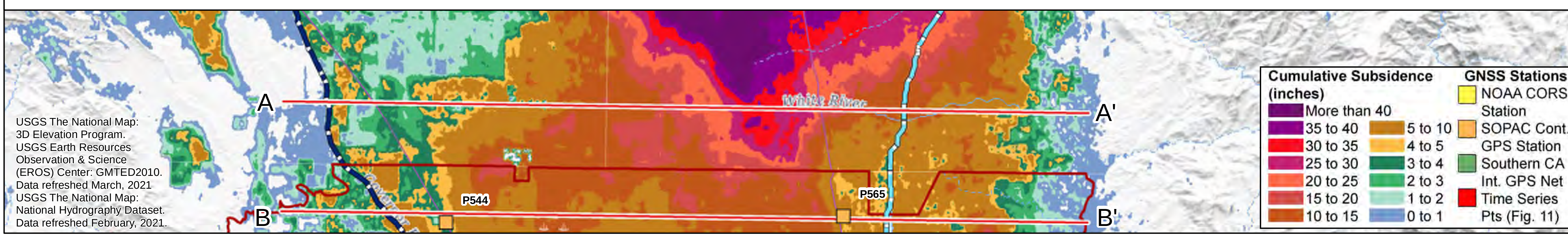
Annual Subsidence

Date: 4/4/2021 | Project #: 043-04 | **Figure 8**





Transect location (approximate)

Kern County Groundwater Sub-basin

Friant-Kern Canal

California Aqueduct

Earth Consultants International

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Miles (map)

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Transect A-A'

Cumulative Subsidence

1/4/2015 to 9/30/2020

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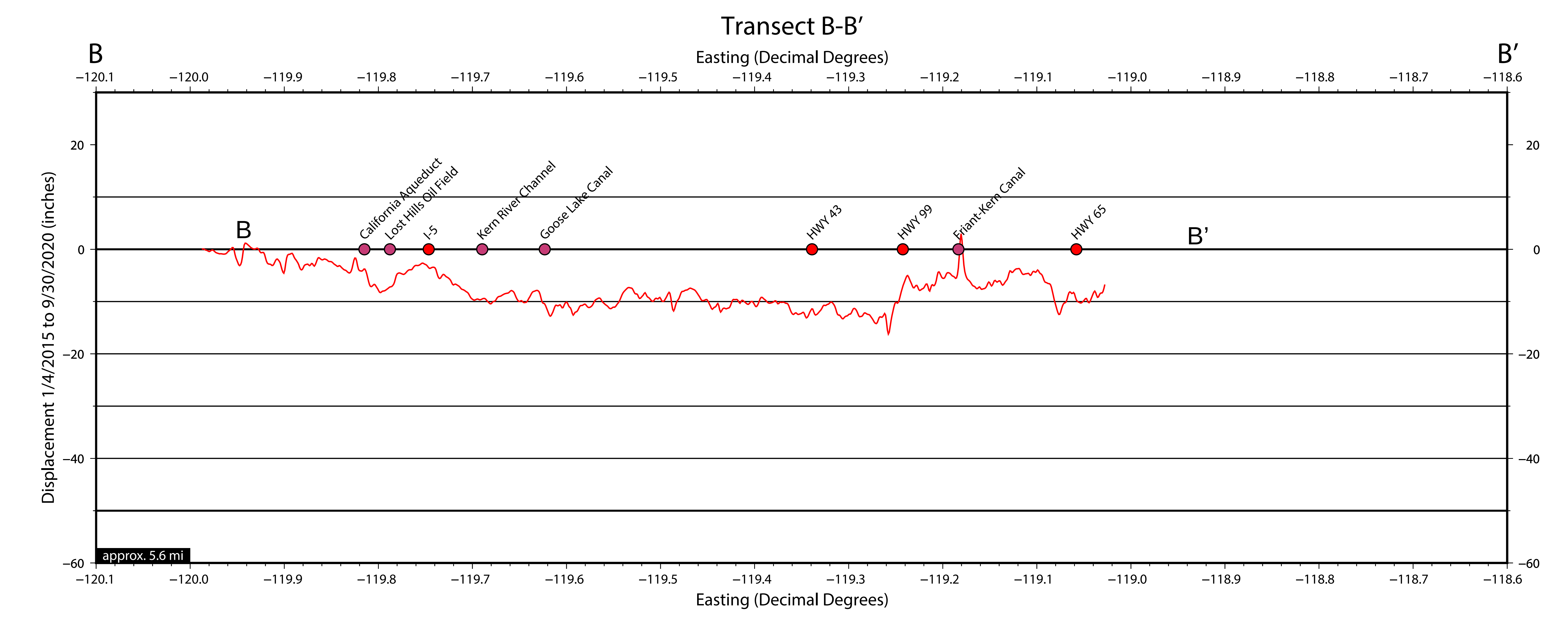
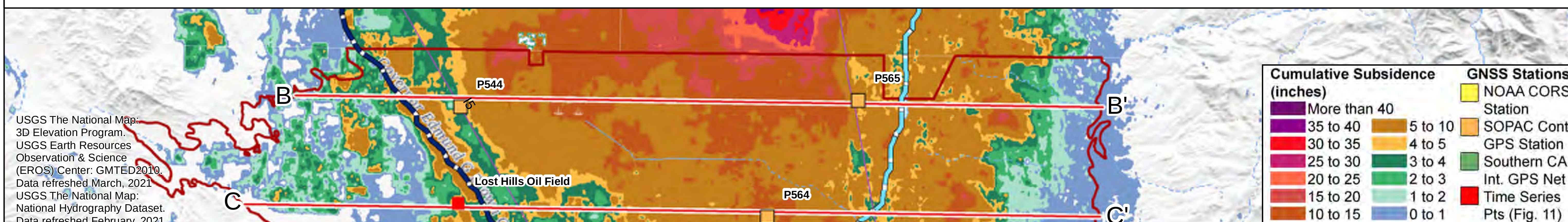
Date: 4/4/2021	Project #: 043-04	**Figure 9a**





Transect location (approximate)

Kern County Groundwater Sub-basin

California Aqueduct

Friant-Kern Canal

Earth Consultants International

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Miles (map)

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Transect B-B'
Cumulative Subsidence
1/4/2015 to 9/30/2020

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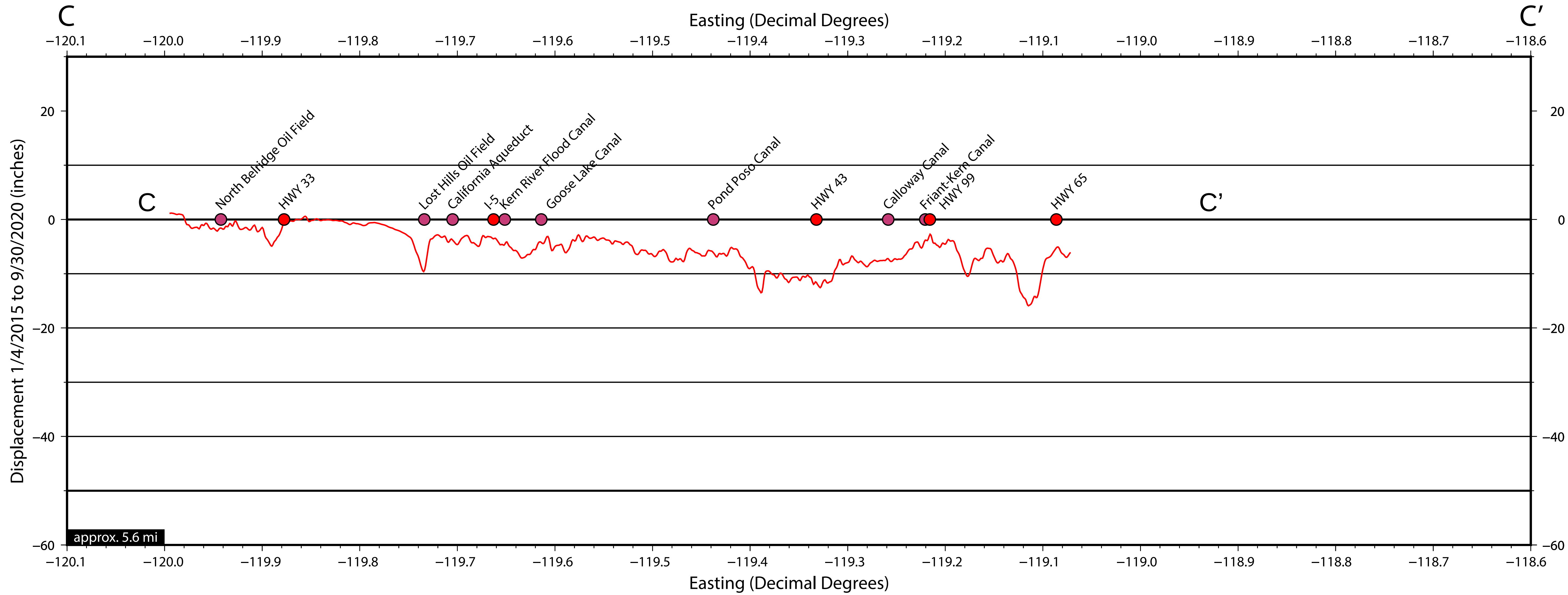
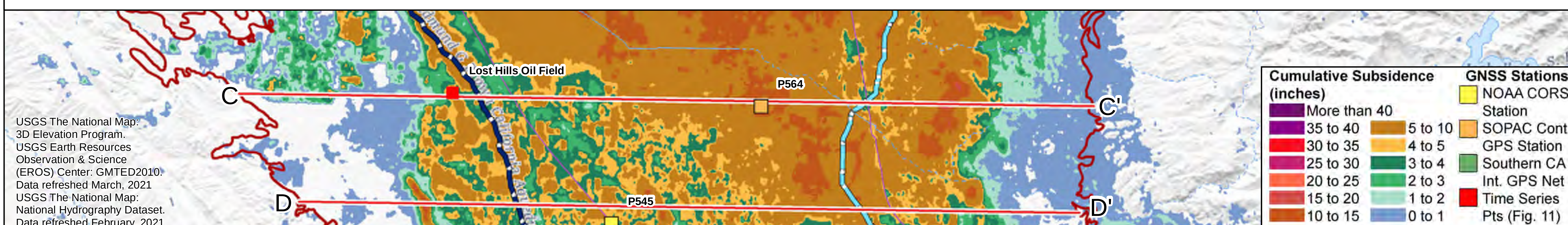
Date: 4/4/2021 | Project #: 043-04 | **Figure 9b**

Transect C-C'





Transect location (approximate)
Kern County Groundwater Sub-basin
Friant-Kern Canal
California Aqueduct

Earth Consultants International

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Miles (map)

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Transect C-C'
Cumulative Subsidence
1/4/2015 to 9/30/2020

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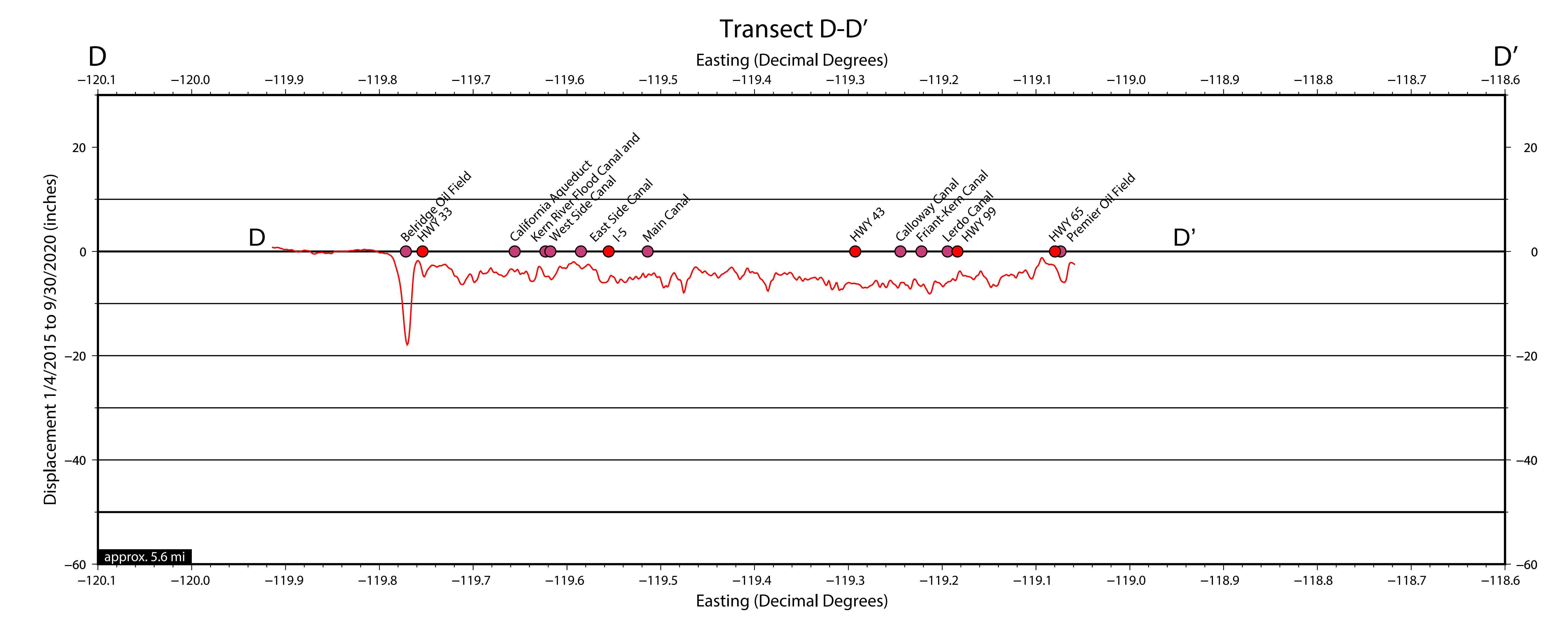
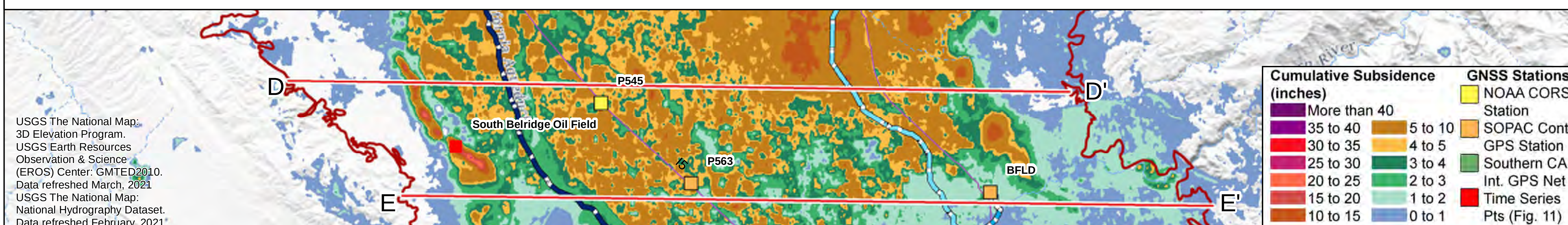
Date: 4/4/2021 | Project #: 043-04 | **Figure 9c**





Transect location (approximate)

Kern County Groundwater Sub-basin

Friant-Kern Canal

California Aqueduct

Earth Consultants International

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Miles (map)

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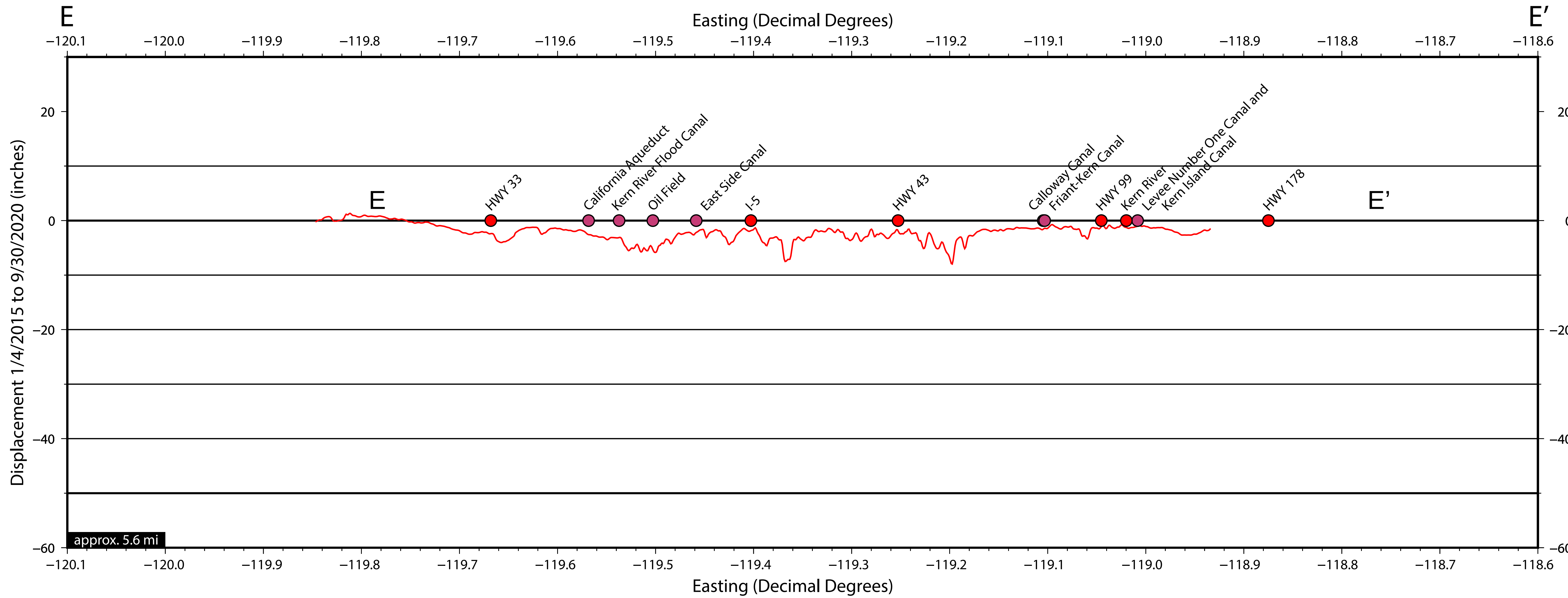
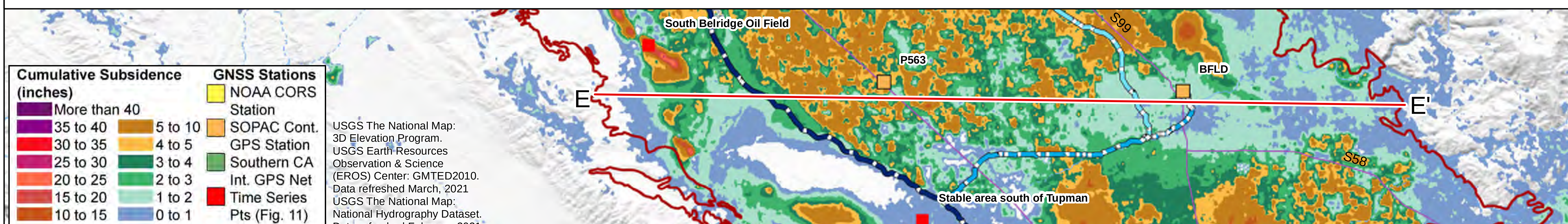
Transect D-D'
Cumulative Subsidence
1/4/2015 to 9/30/2020

DRAFT

Date: 4/4/2021	Project #: 043-04	**Figure 9d**

Transect E-E'





Transect location (approximate)
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

Earth Consultants International

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Miles (map)

aquilogic, Inc.

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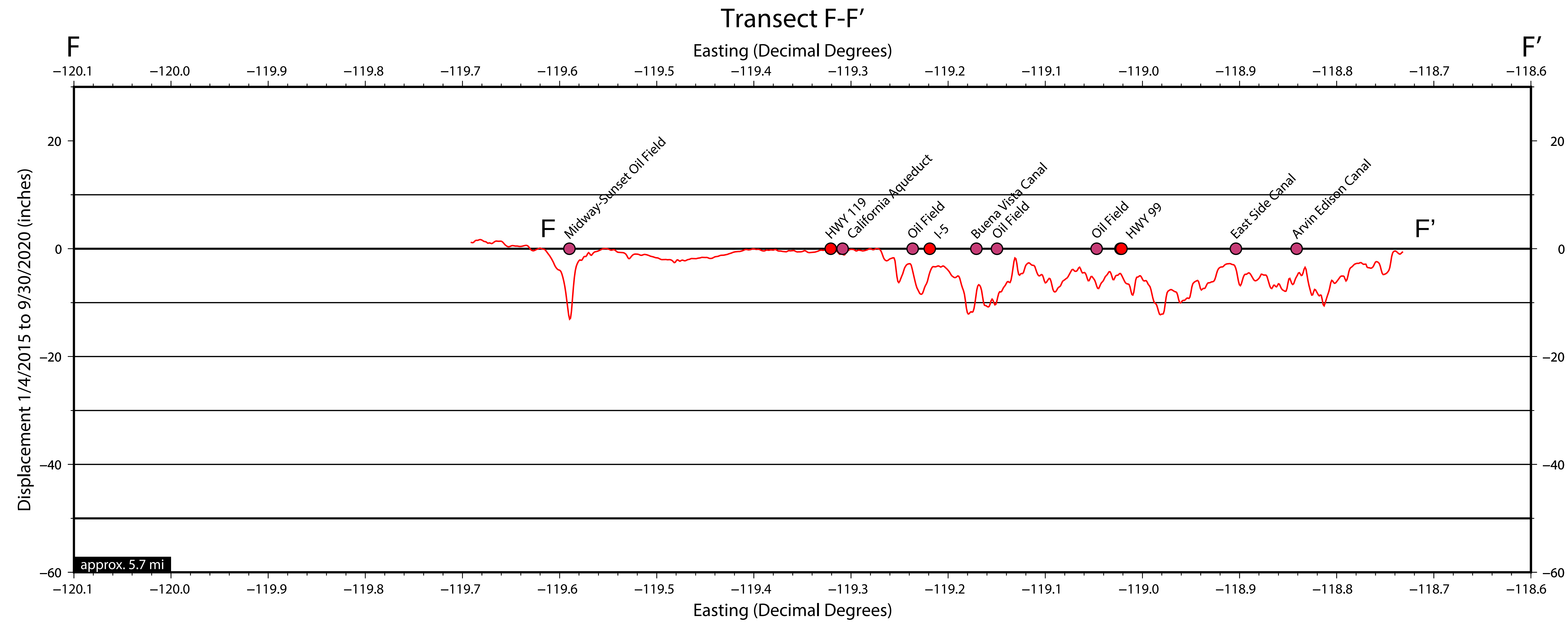
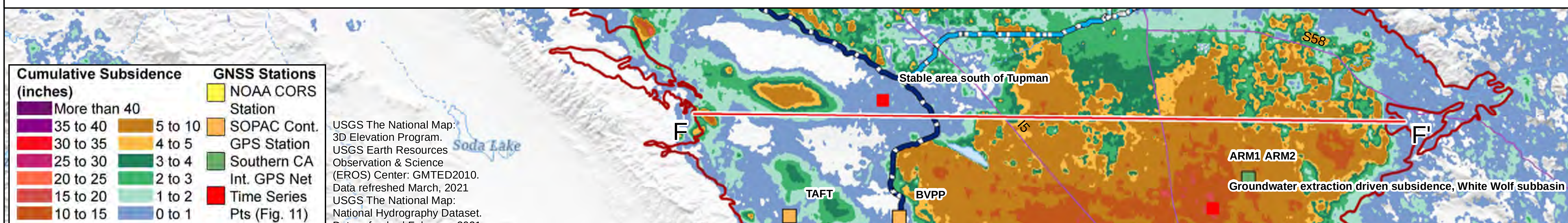
Transect E-E'
Cumulative Subsidence
1/4/2015 to 9/30/2020

DRAFT

Date: 4/4/2021 | Project #: 043-04 | **Figure 9e**





Transect location (approximate)

Kern County Groundwater Sub-basin

Friant-Kern Canal

Cross Valley Canal

California Aqueduct

Earth Consultants International

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Miles (map)

aquilogic, Inc.

Belridge WSD - WDWA - GSP

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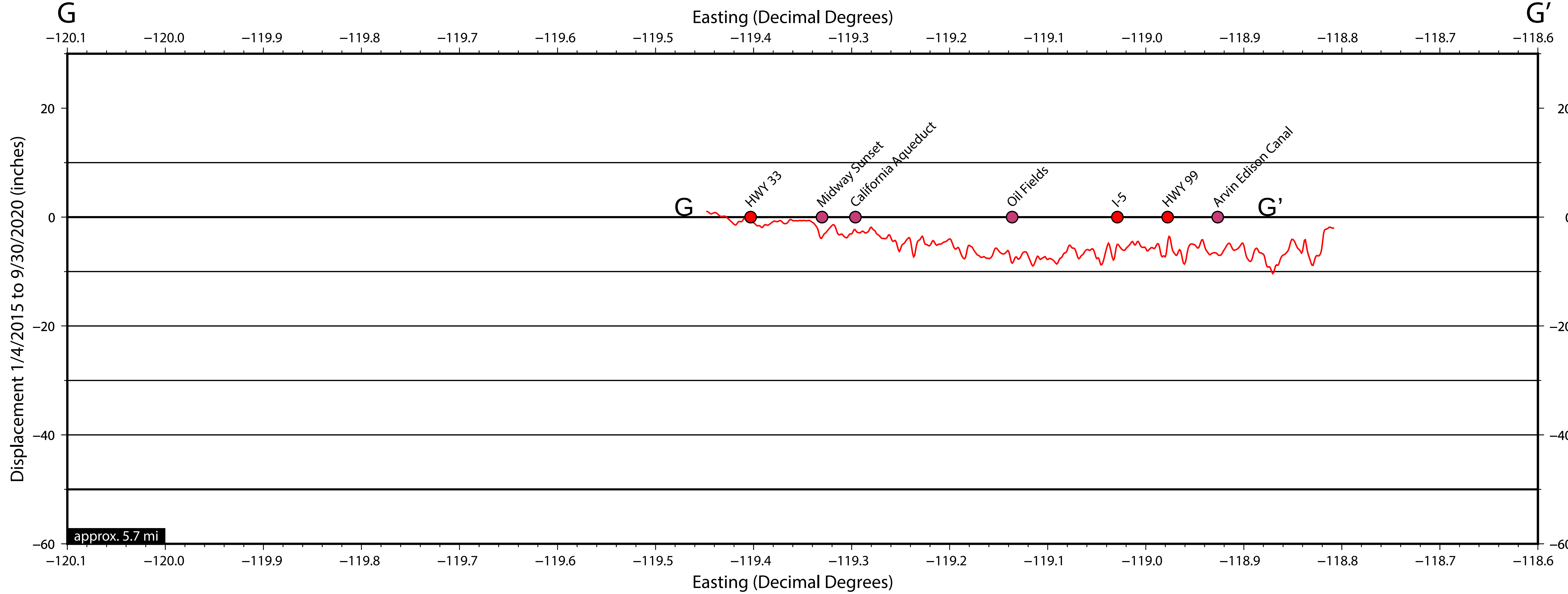
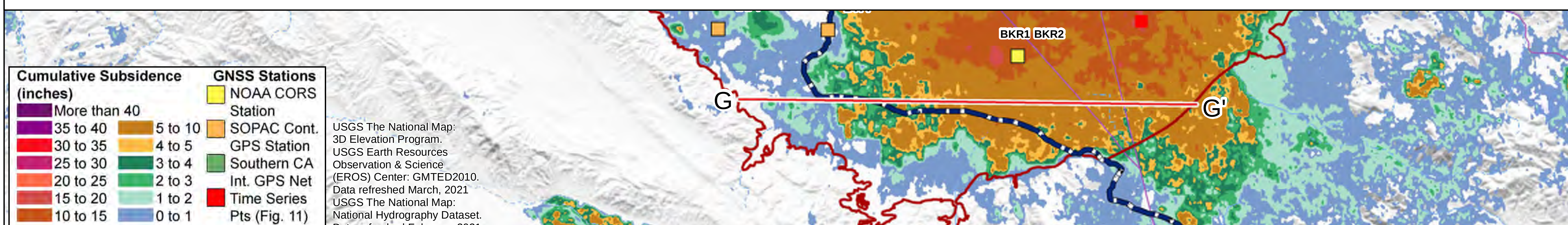
Transect F-F'
Cumulative Subsidence
1/4/2015 to 9/30/2020

Date: 4/4/2021 | Project #: 043-04 | **Figure 9f**

Transect G-G′





Transect location (approximate)
California Aqueduct
Kern County Groundwater Sub-basin

Earth Consultants International

0 7
Miles (map)

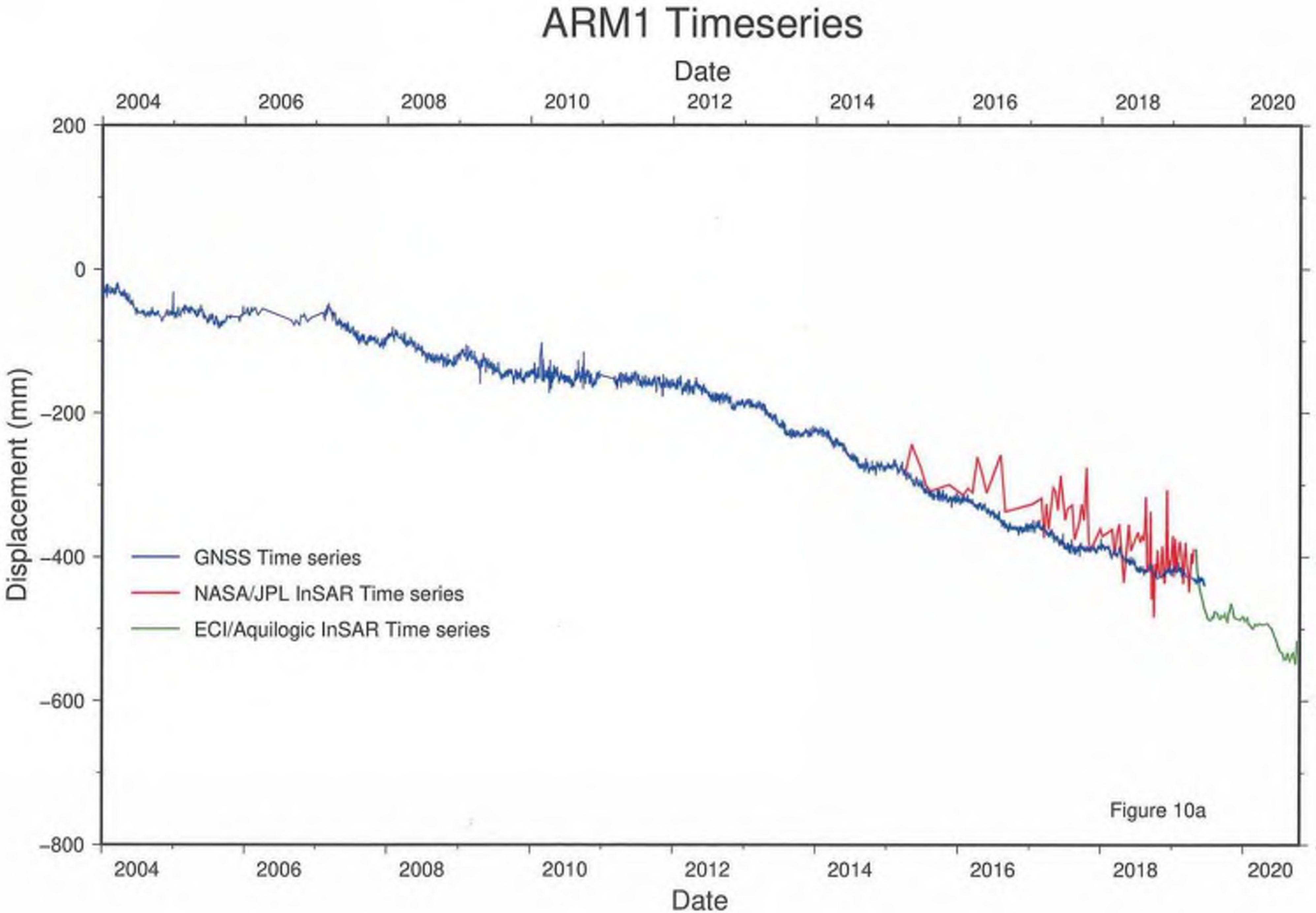
aquilogic, Inc.

Belridge WSD - WDWA - GSP

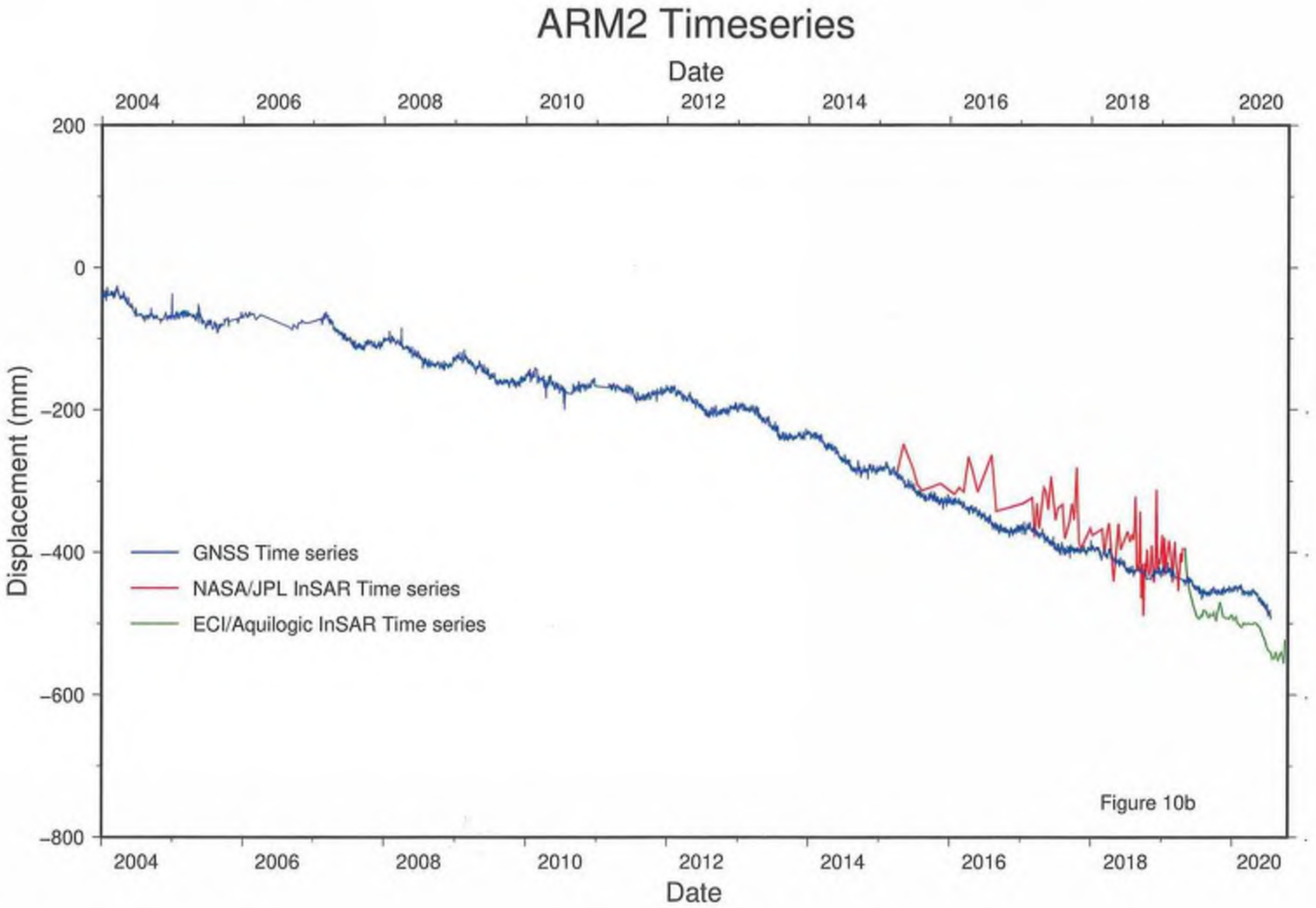
Transect G-G'
Cumulative Subsidence
1/4/2015 to 9/30/2020

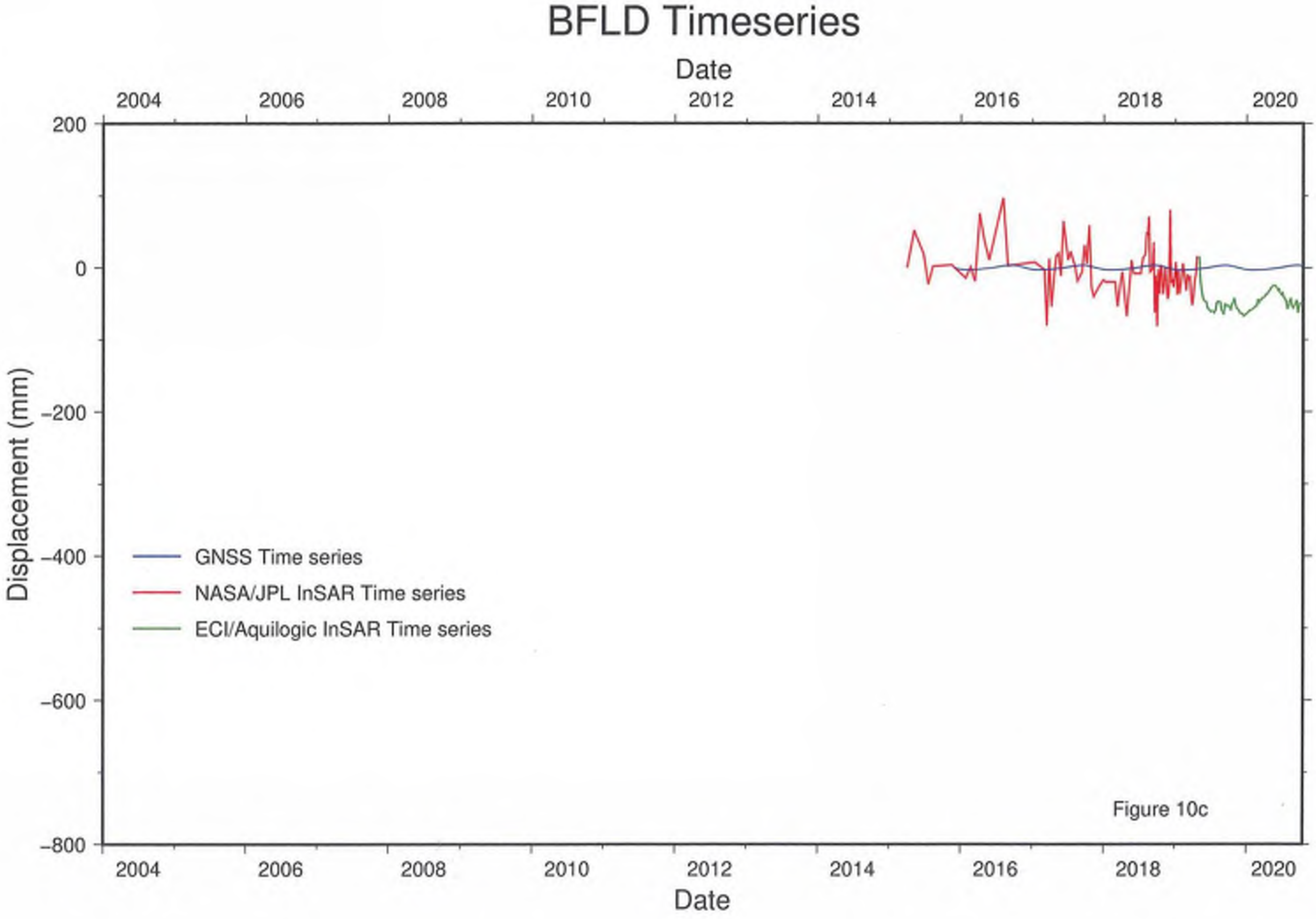
DRAFT

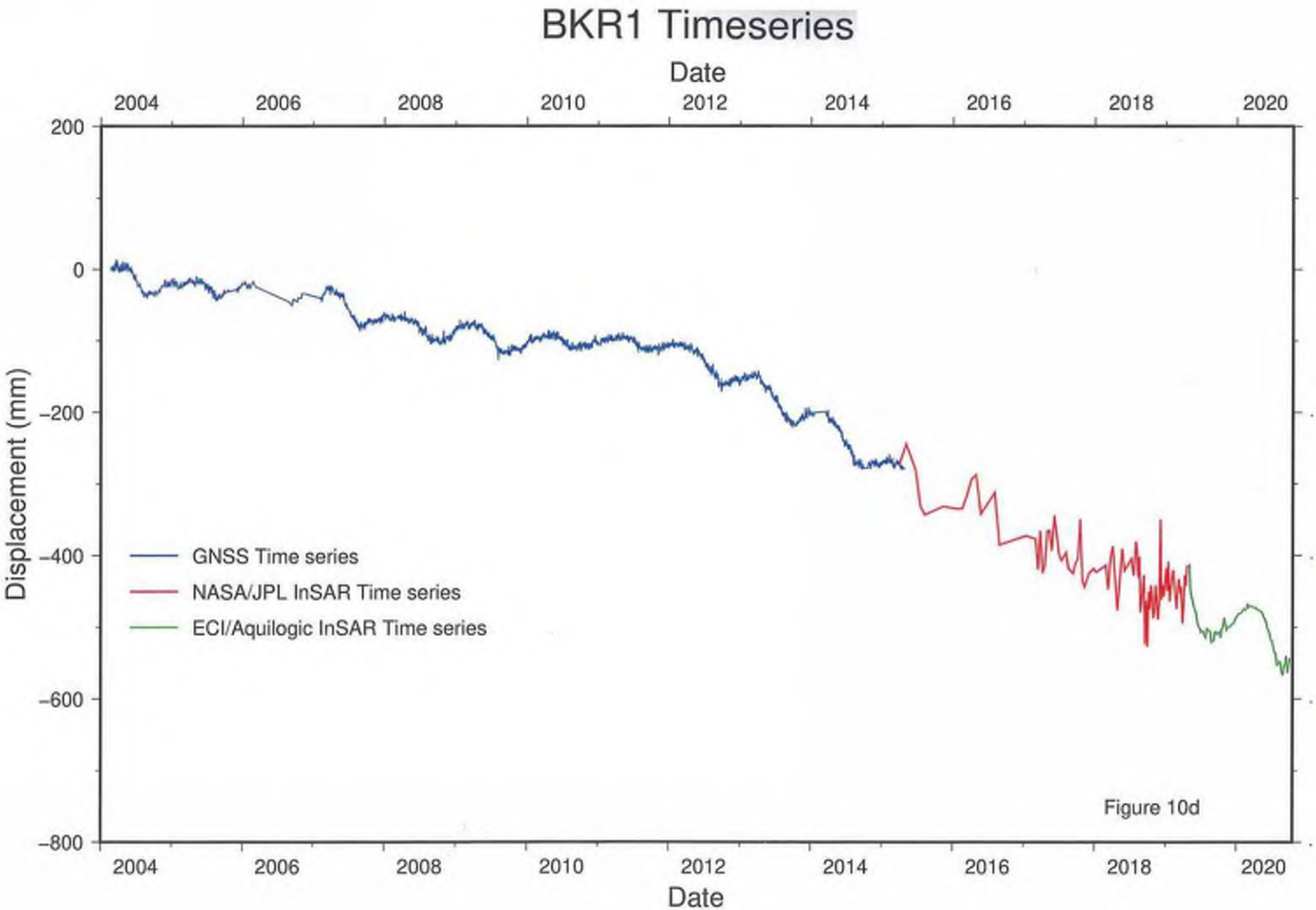
Date: 4/4/2021 | Project #: 043-04 | **Figure 9g**

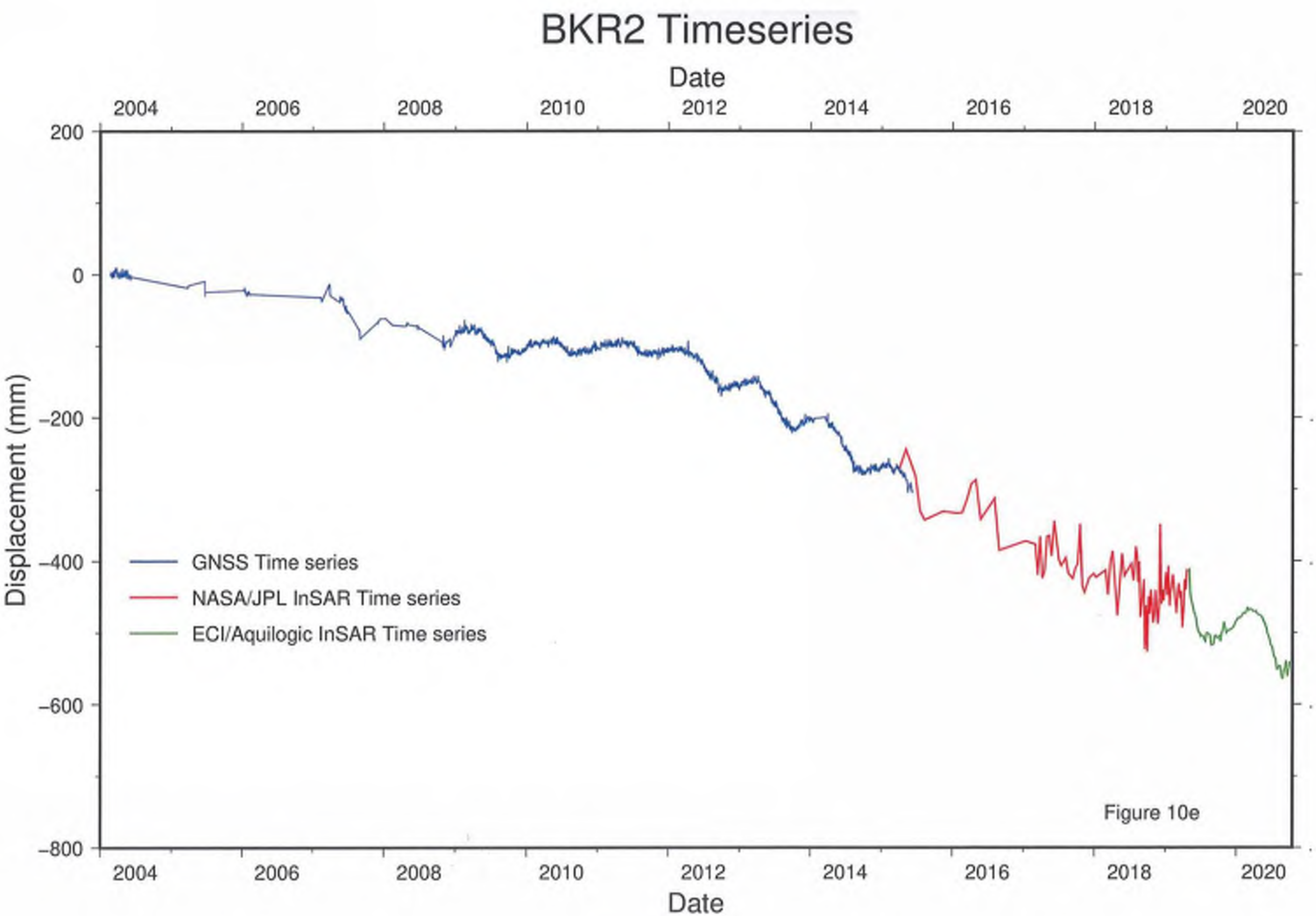


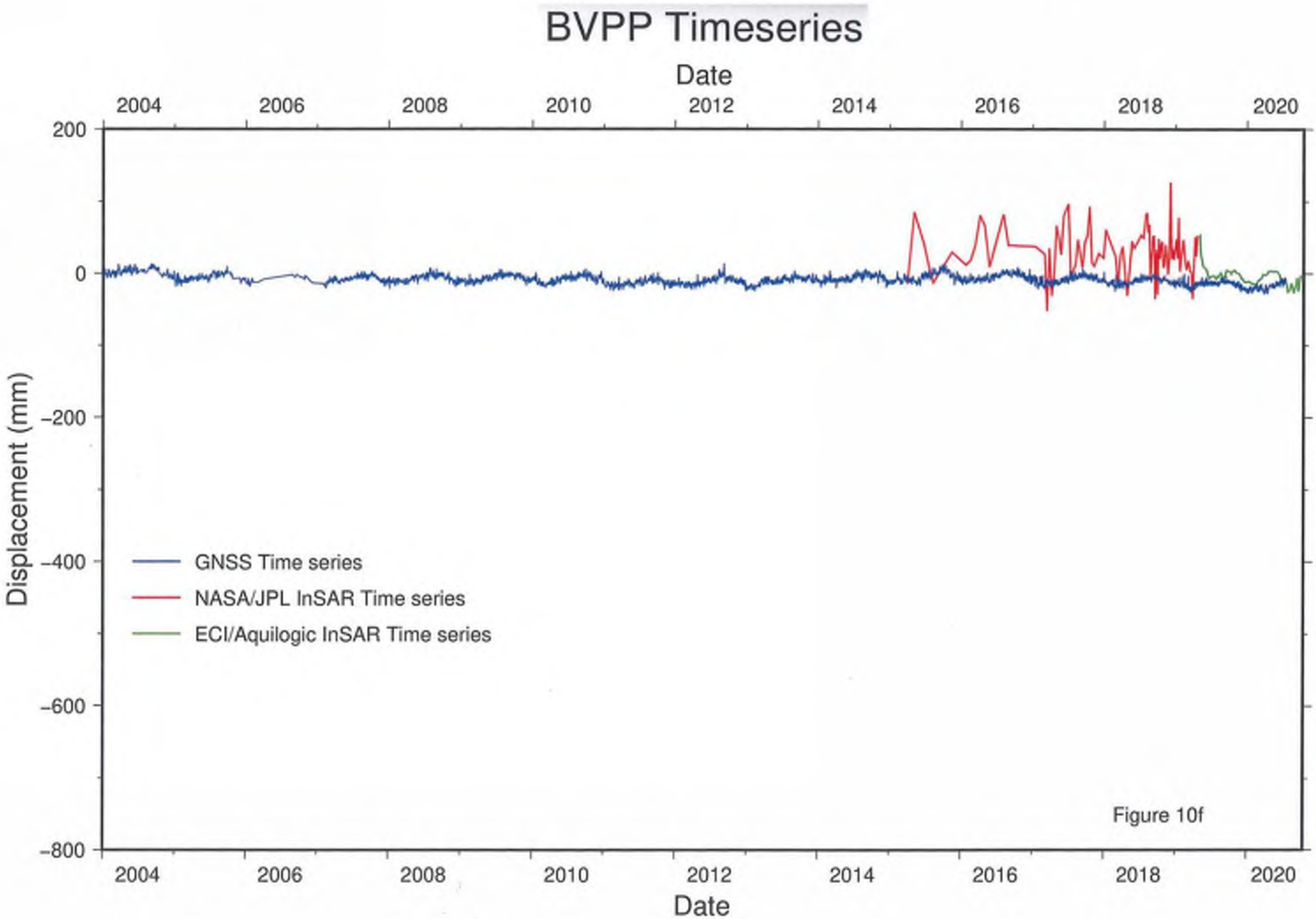
ARM1 Timeseries
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
-200
-400
-600
-800
Displacement (mm)
GNSS Time series
NASA/JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 10a

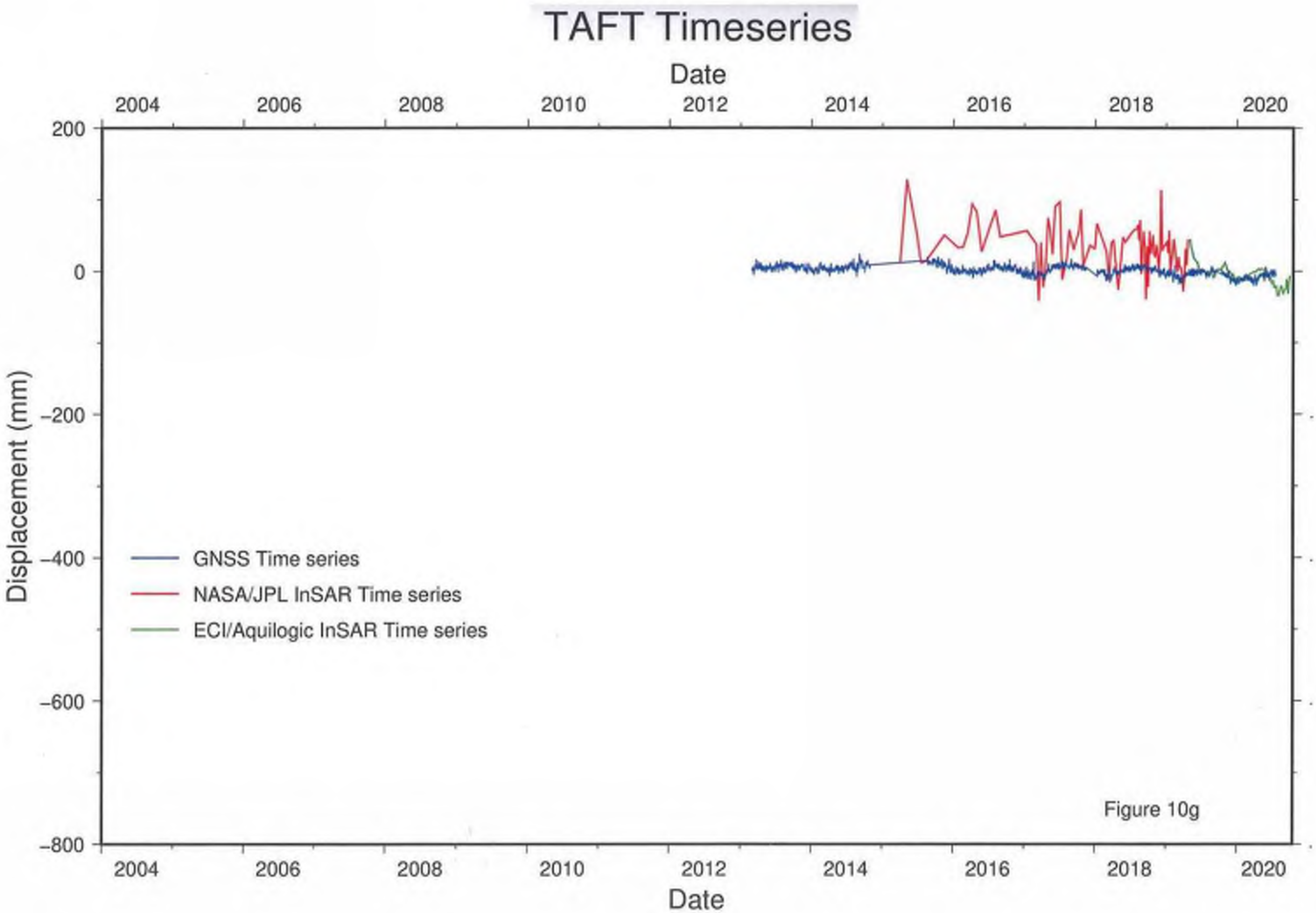

ARM2 Timeseries
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
-200
-400
-600
-800
Displacement (mm)
GNSS Time series
NASA/JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 10b
Date


BFLD Timeseries
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
-200
-400
-600
-800
Displacement (mm)
GNSS Time series
NASA/JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 10c
Date

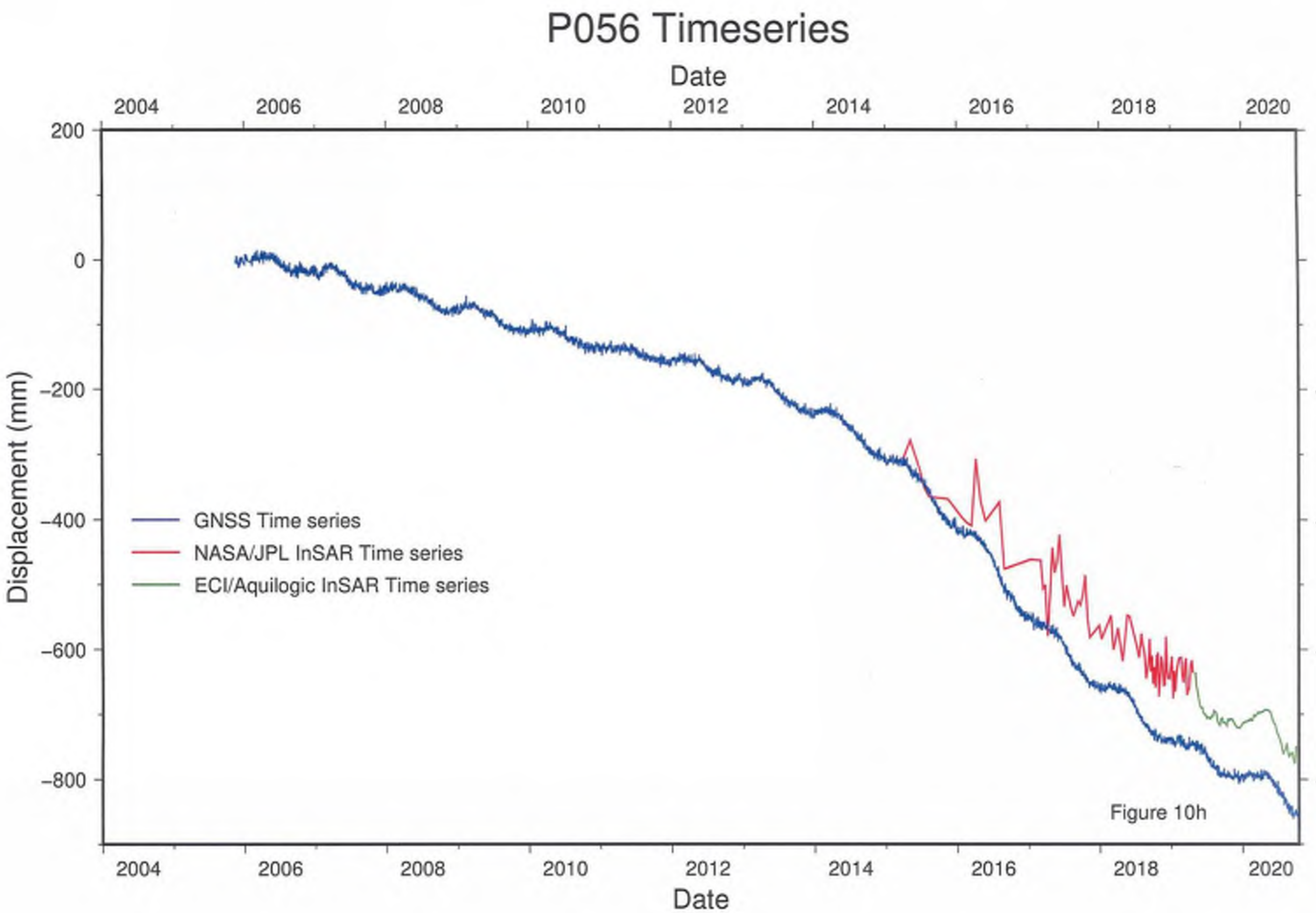

BKR1 Timeseries
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
-200
-400
-600
-800
Displacement (mm)
GNSS Time series
NASA/JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 10d
Date

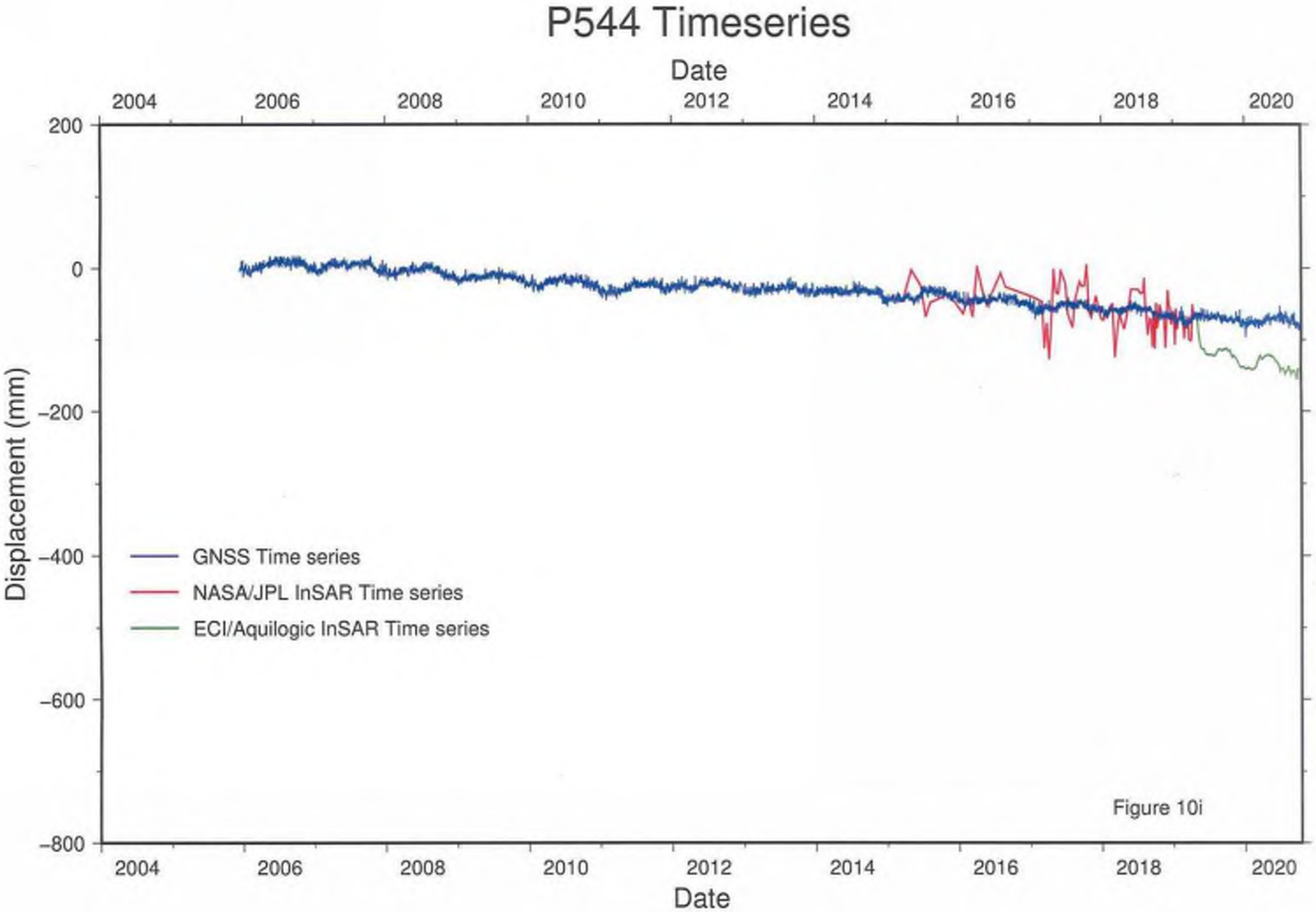

BKR2 Timeseries
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
-200
-400
-600
-800
Displacement (mm)
GNSS Time series
NASA/JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 10e


BVPP Timeseries
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
-200
-400
-600
-800
Displacement (mm)
GNSS Time series
NASA/JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 10f
Date

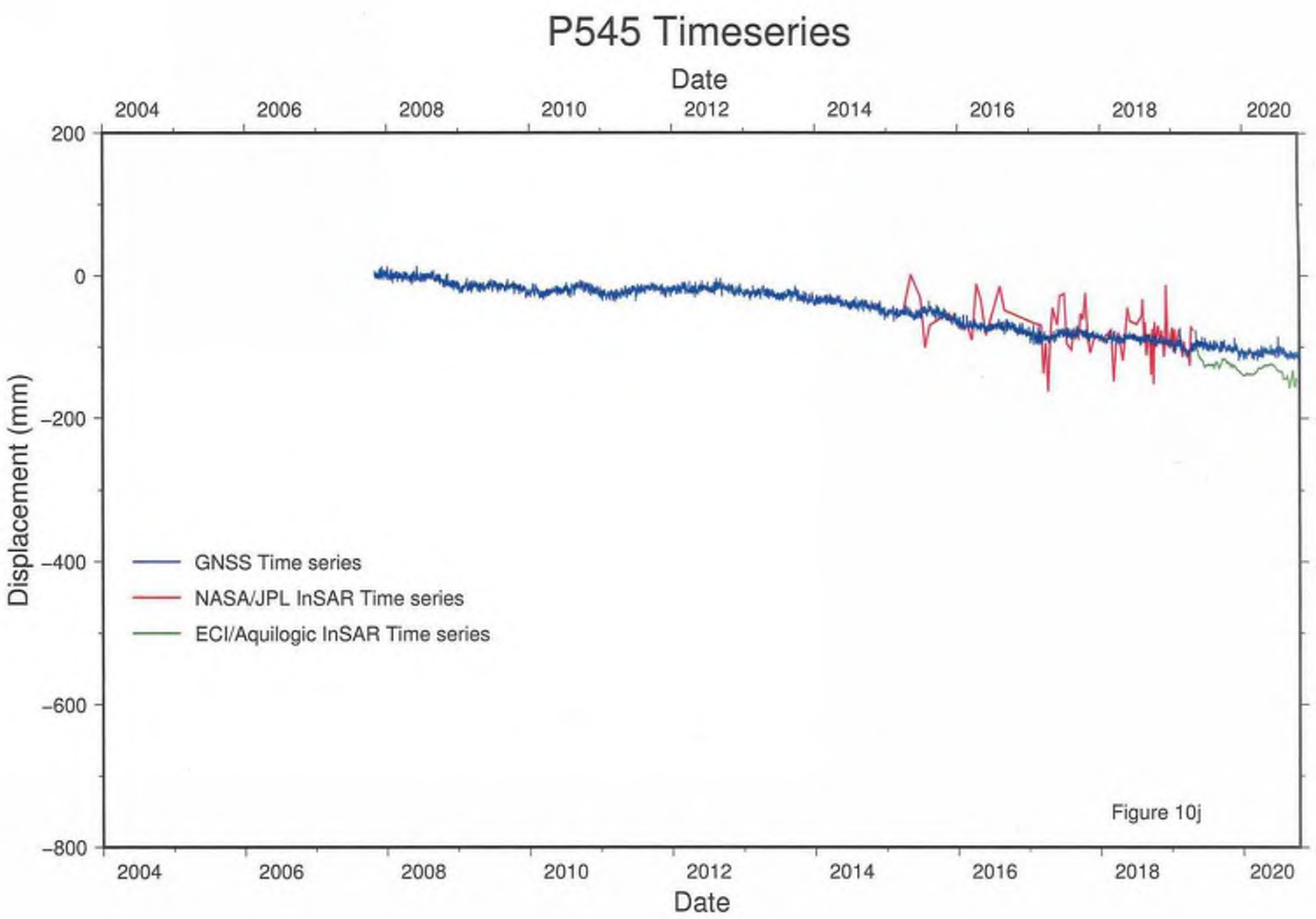


TAFT Timeseries
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
-200
-400
-600
-800
Displacement (mm)
GNSS Time series
NASA/JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 10g
Date


P056 Timeseries
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
-200
-400
-600
-800
Displacement (mm)
GNSS Time series
NASA/JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 10h
Date



P544 Timeseries
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
−200
−400
−600
−800
Displacement (mm)
GNSS Time series
NASA/JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 10i


P545 Timeseries
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
−200
−400
−600
−800
Displacement (mm)
GNSS Time series
NASA/JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 10j

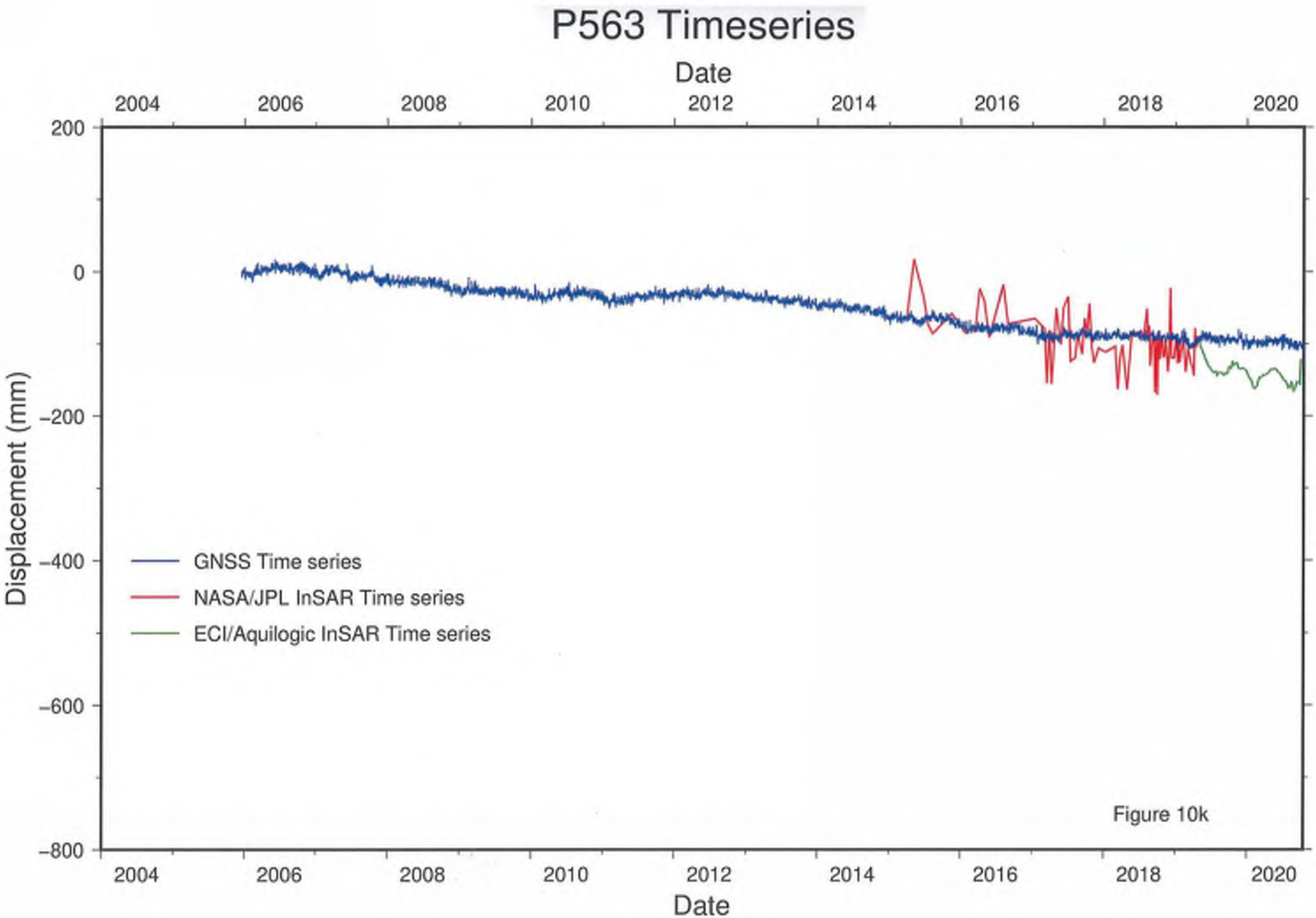
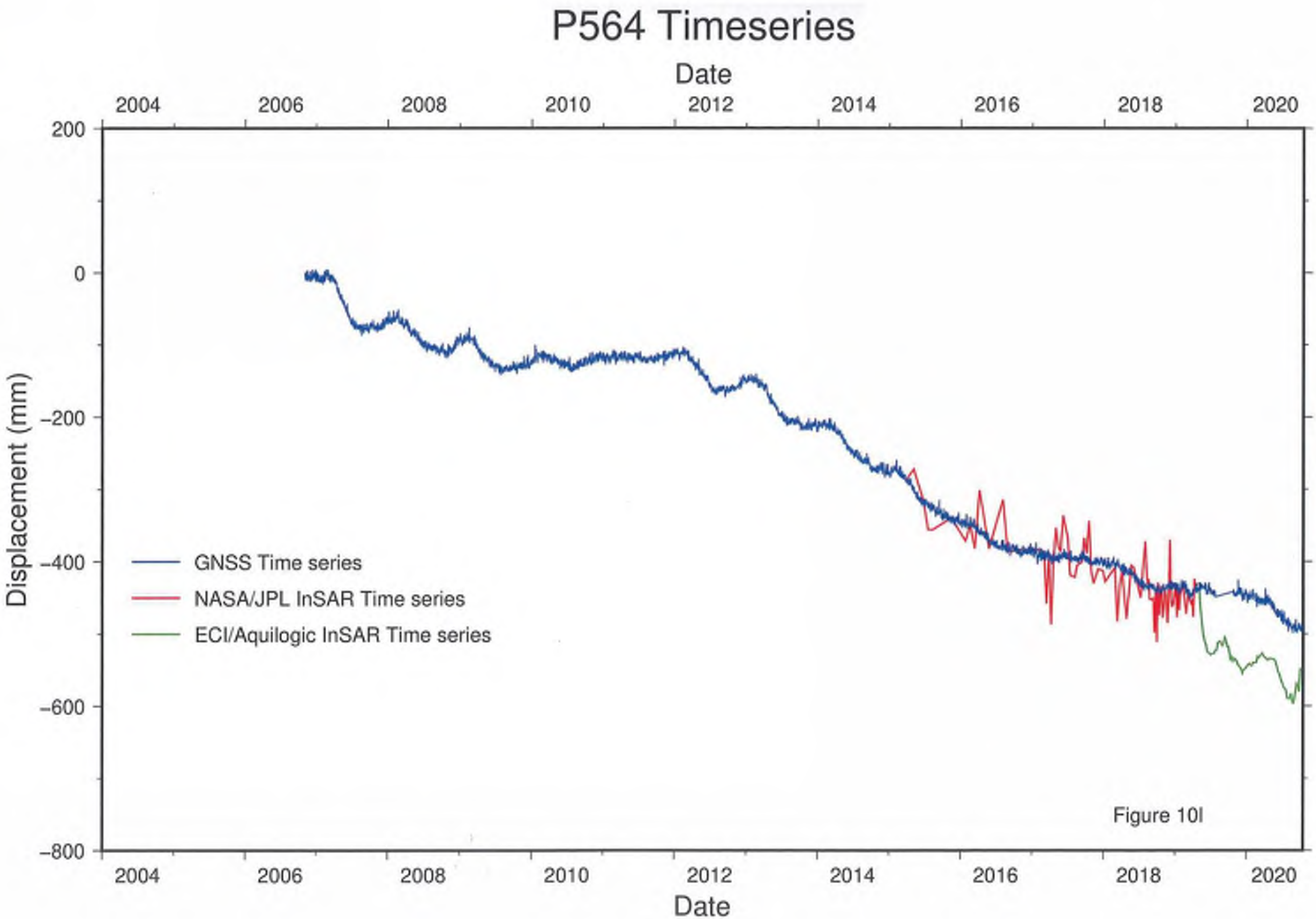
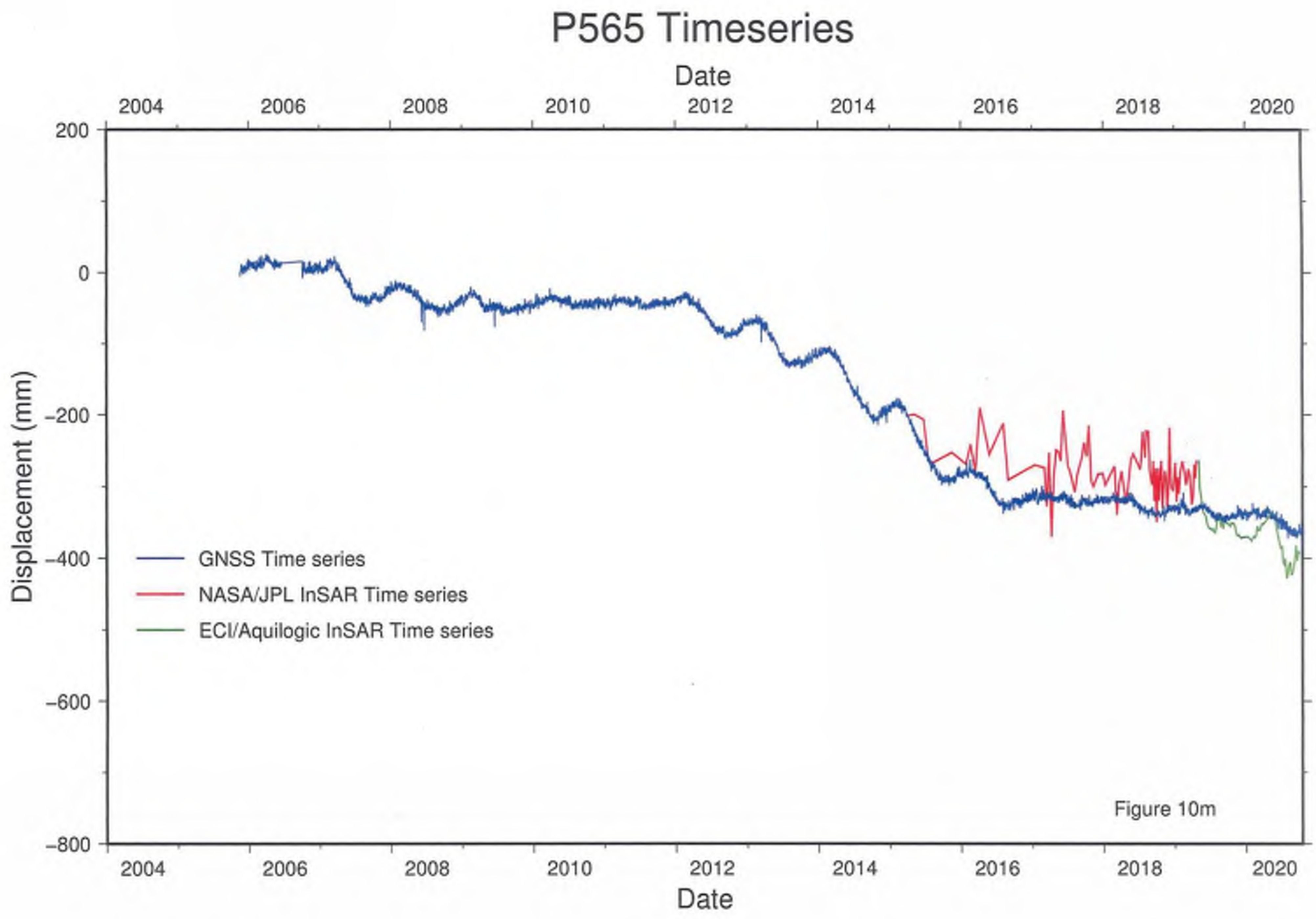
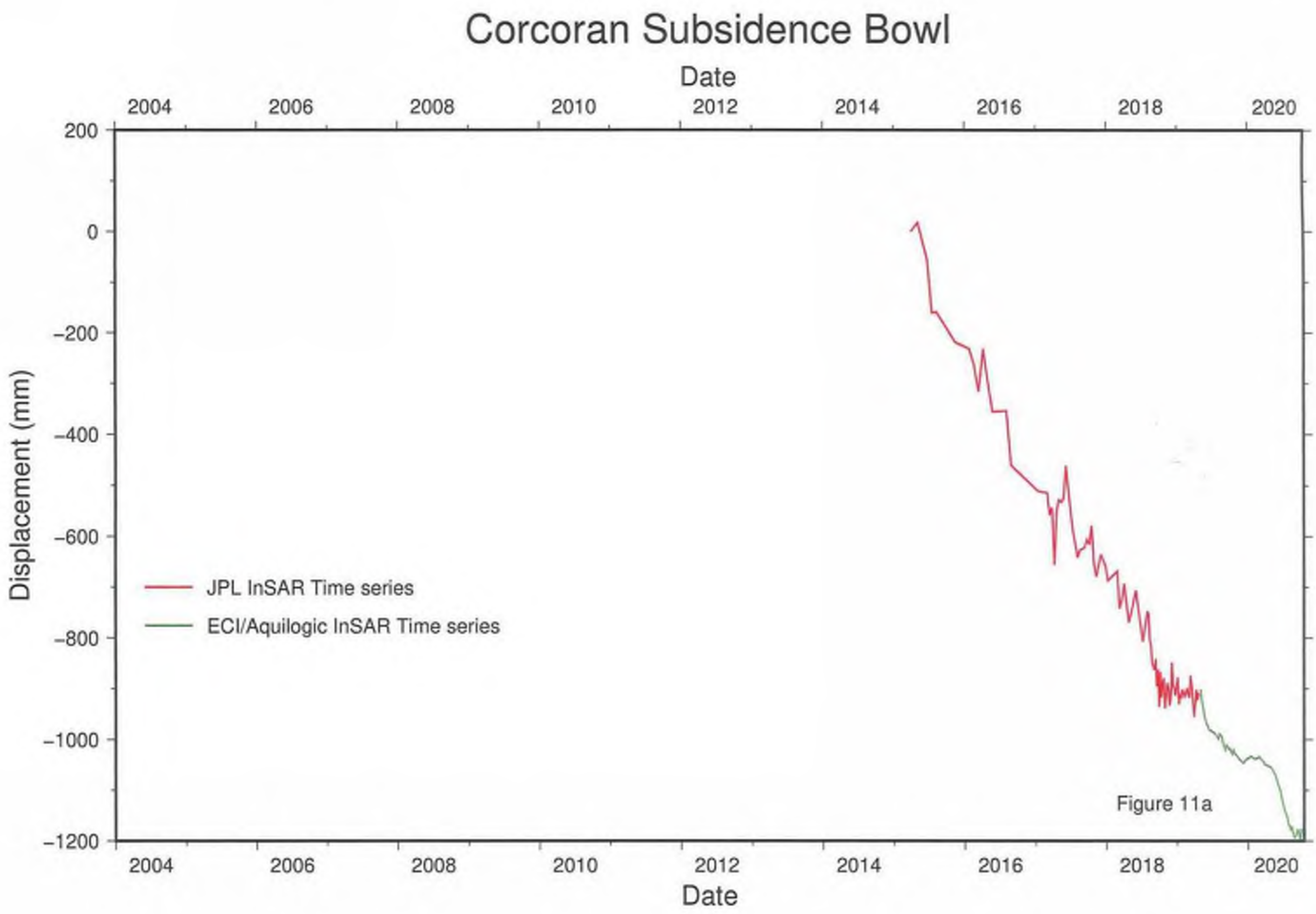

P563 Timeseries
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
-200
-400
-600
-800
Displacement (mm)
GNSS Time series
NASA/JPL InSAR Time series
ECI/Aquilogic InSAR Time series

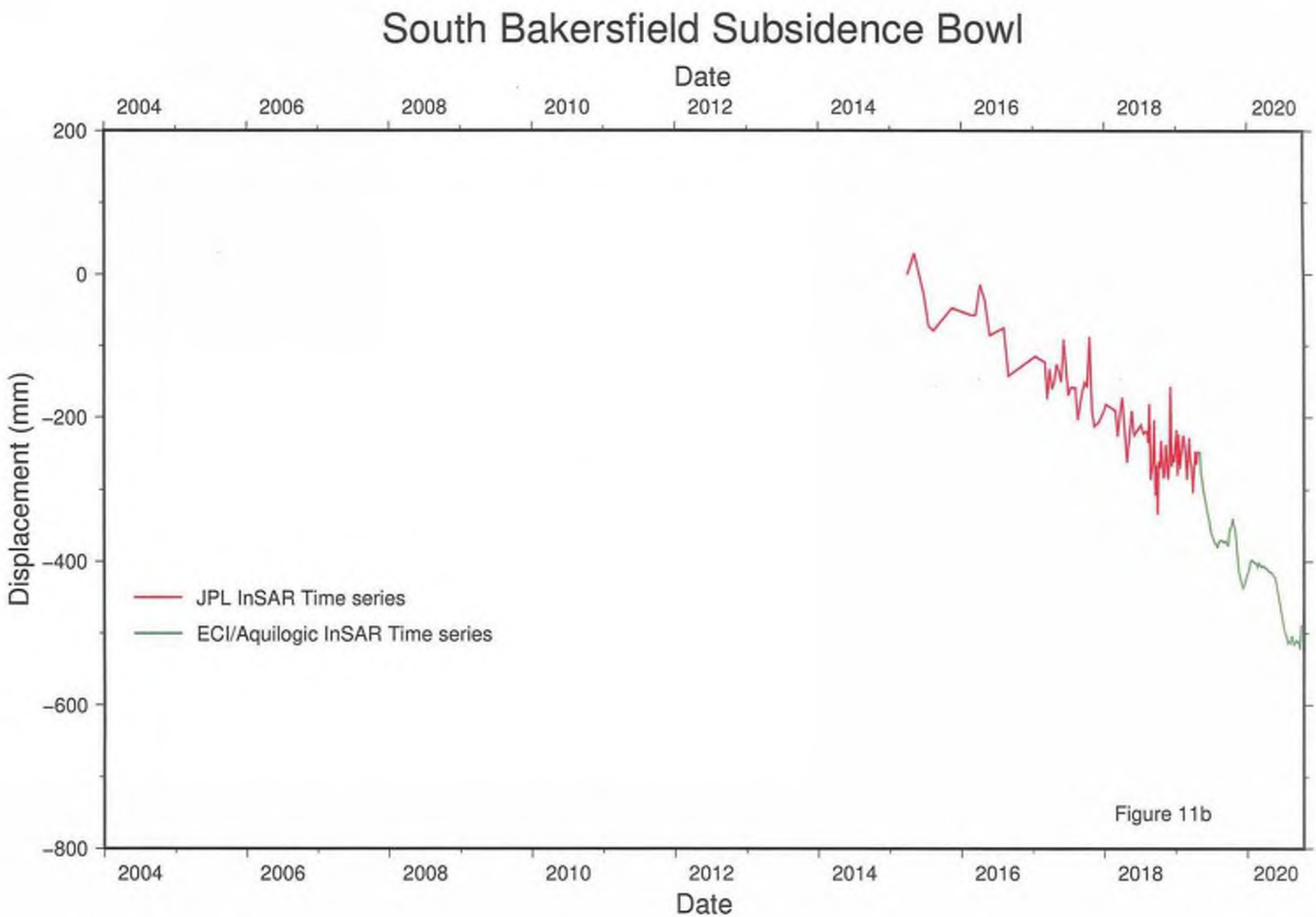
Figure 10k

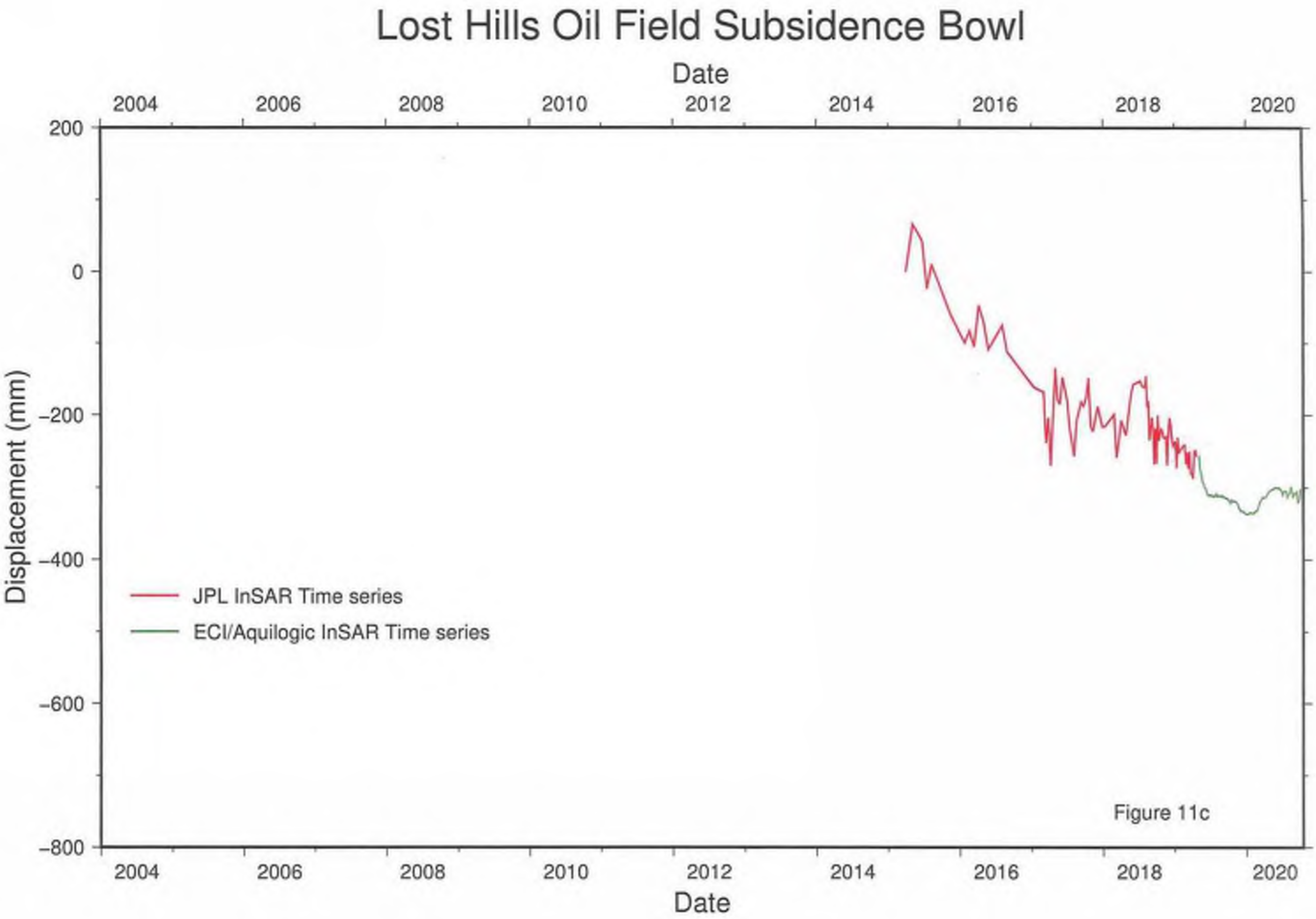

P564 Timeseries
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
-200
-400
-600
-800
Displacement (mm)
GNSS Time series
NASA/JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 10l
Date

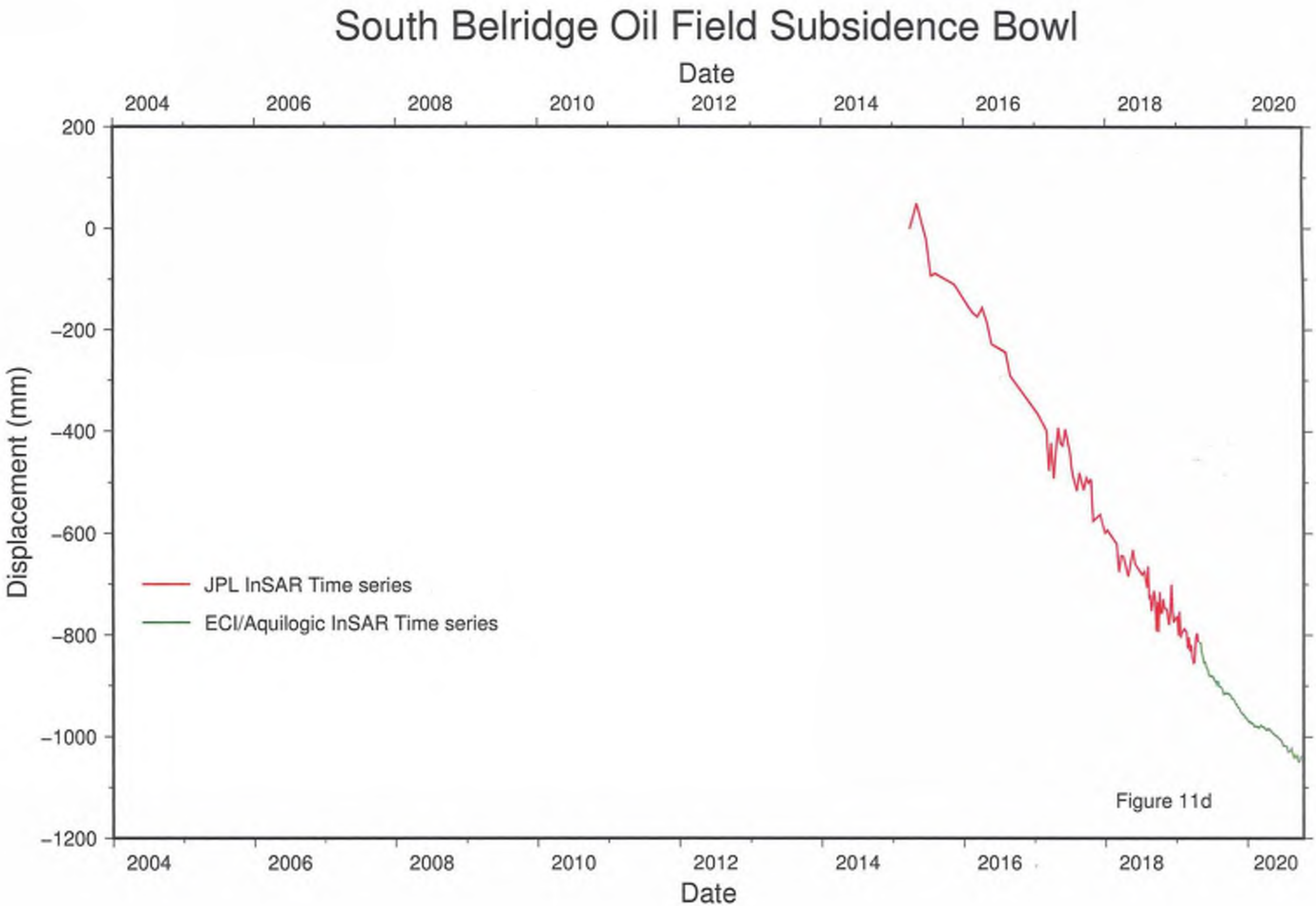


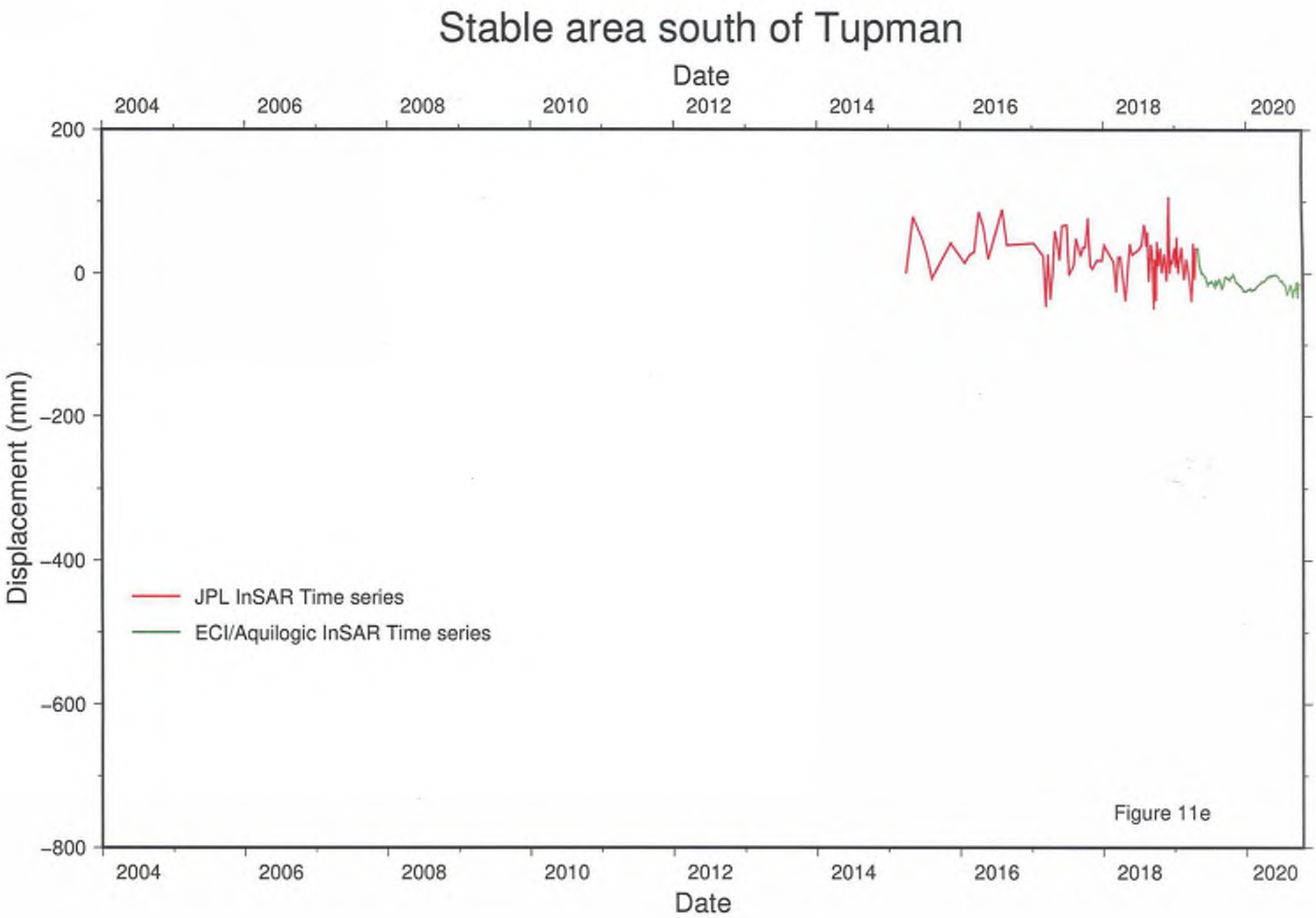
P565 Timeseries
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
−200
−400
−600
−800
Displacement (mm)
GNSS Time series
NASA/JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 10m


Corcoran Subsidence Bowl
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
−200
−400
−600
−800
−1000
−1200
Displacement (mm)
JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 11a
Date

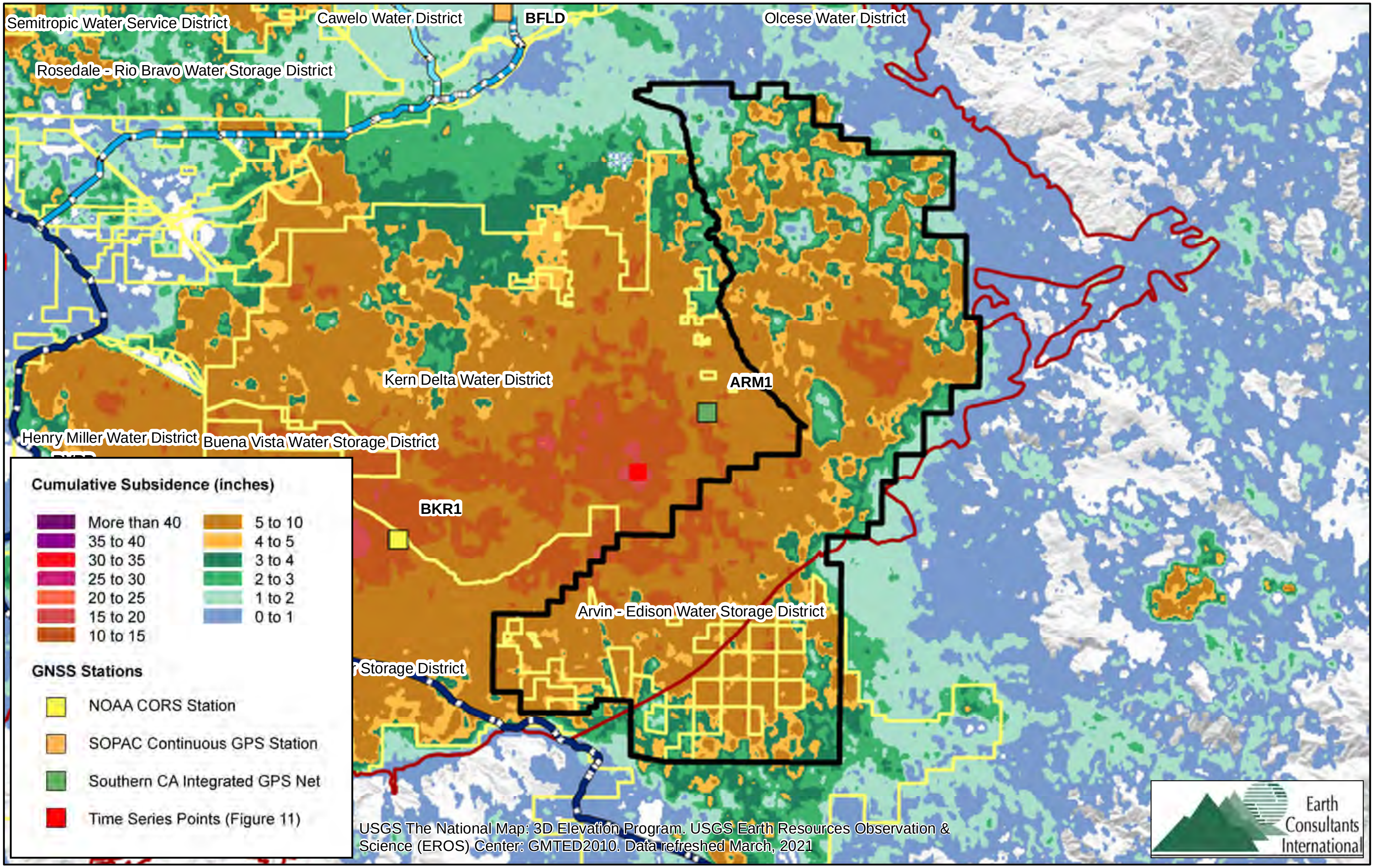

South Bakersfield Subsidence Bowl
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
-200
-400
-600
-800
Displacement (mm)
JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 11b
Date


Lost Hills Oil Field Subsidence Bowl
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
-200
-400
-600
-800
Displacement (mm)
JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 11c
Date


South Belridge Oil Field Subsidence Bowl
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
Displacement (mm)
200
0
-200
-400
-600
-800
-1000
-1200
JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 11d
Date



Stable area south of Tupman
Date
2004
2006
2008
2010
2012
2014
2016
2018
2020
200
0
−200
−400
−600
−800
Displacement (mm)
JPL InSAR Time series
ECI/Aquilogic InSAR Time series
Figure 11e
Date



Arvin Edison Water Storage District
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

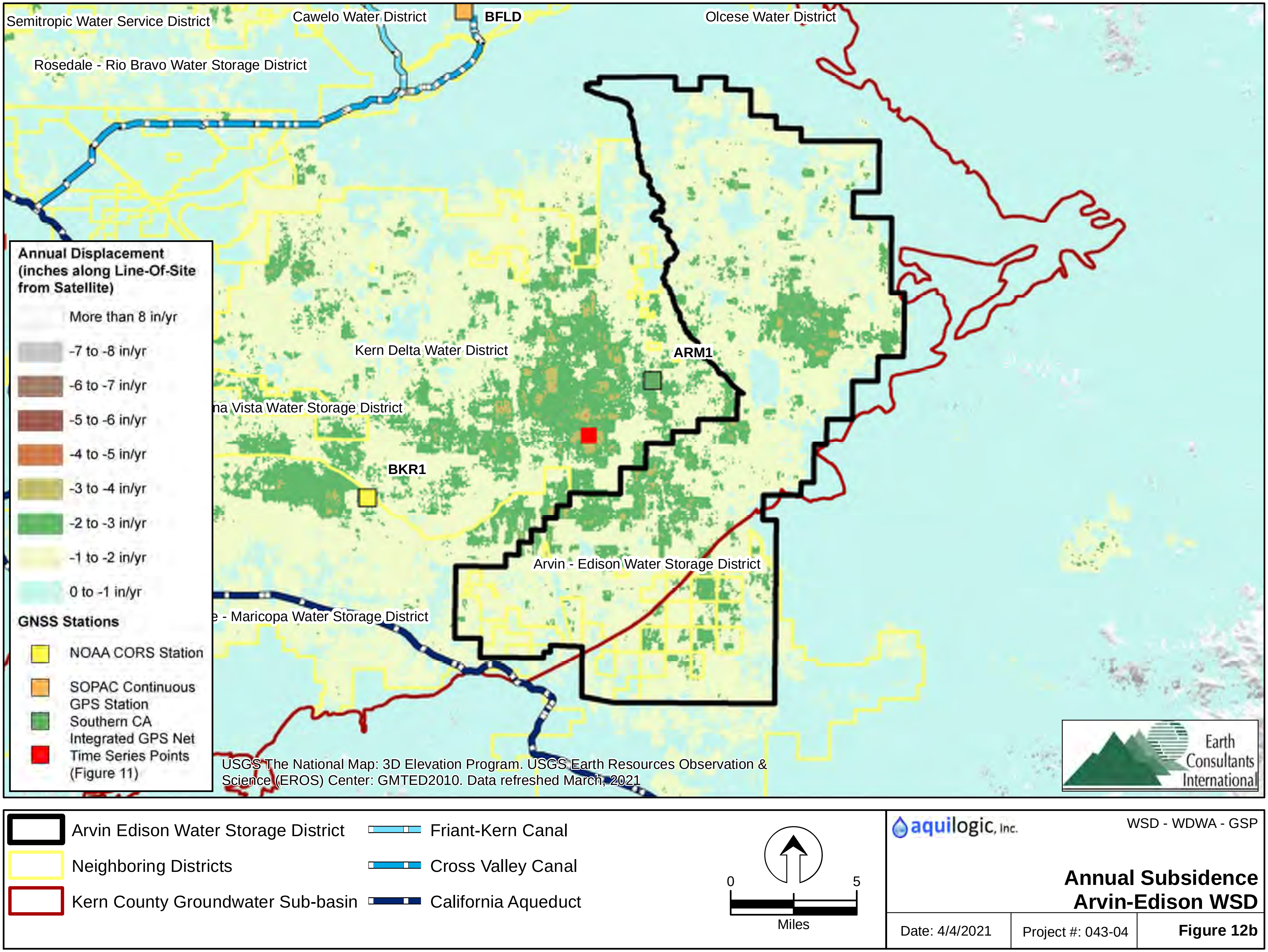
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Arvin-Edison WSD

Date: 4/4/2021	Project #: 043-04	**Figure 12a**

DRAFT



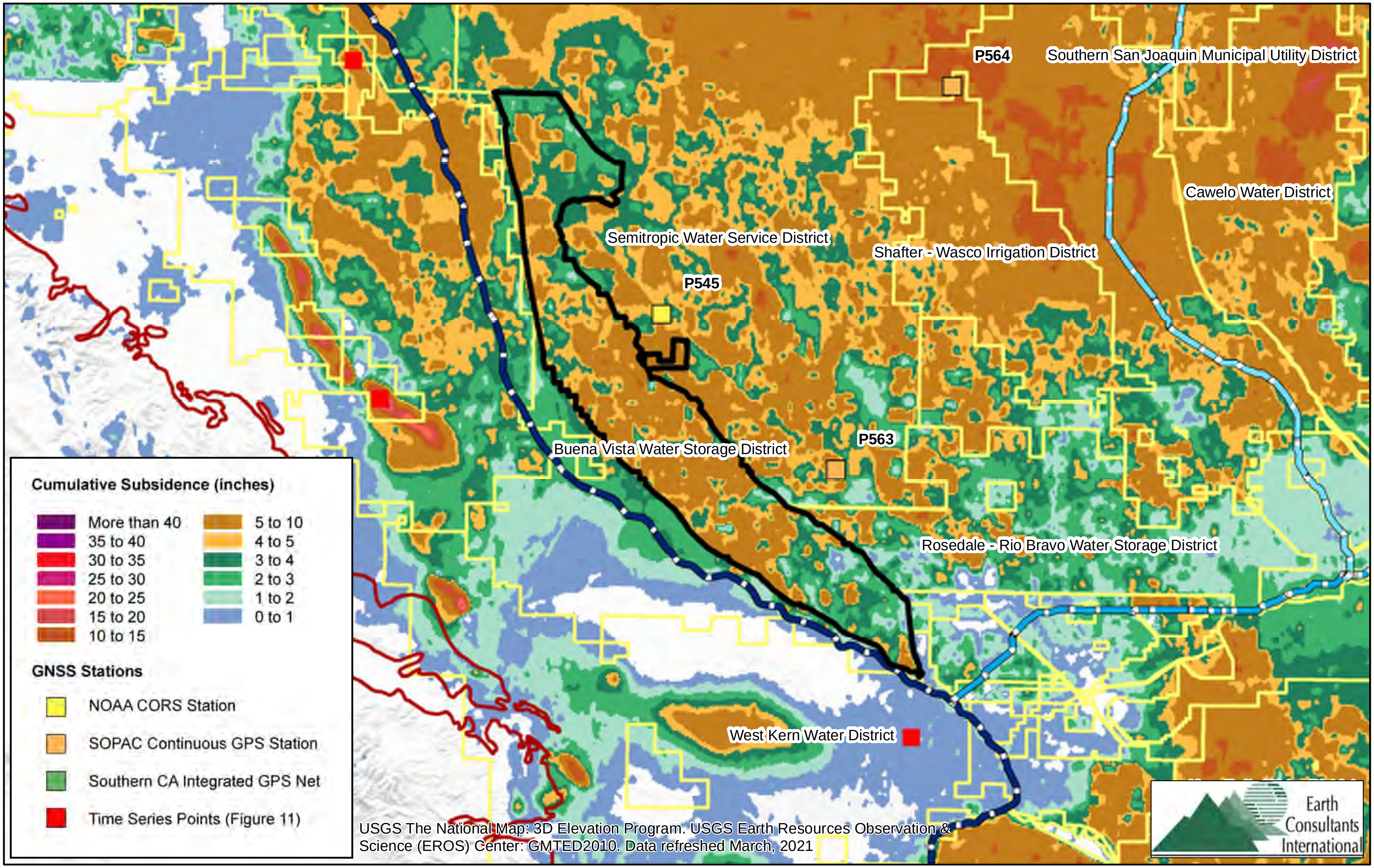
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Arvin-Edison WSD

Date: 4/4/2021	Project #: 043-04	**Figure 12b**

DRAFT



Buena Vista WSD
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

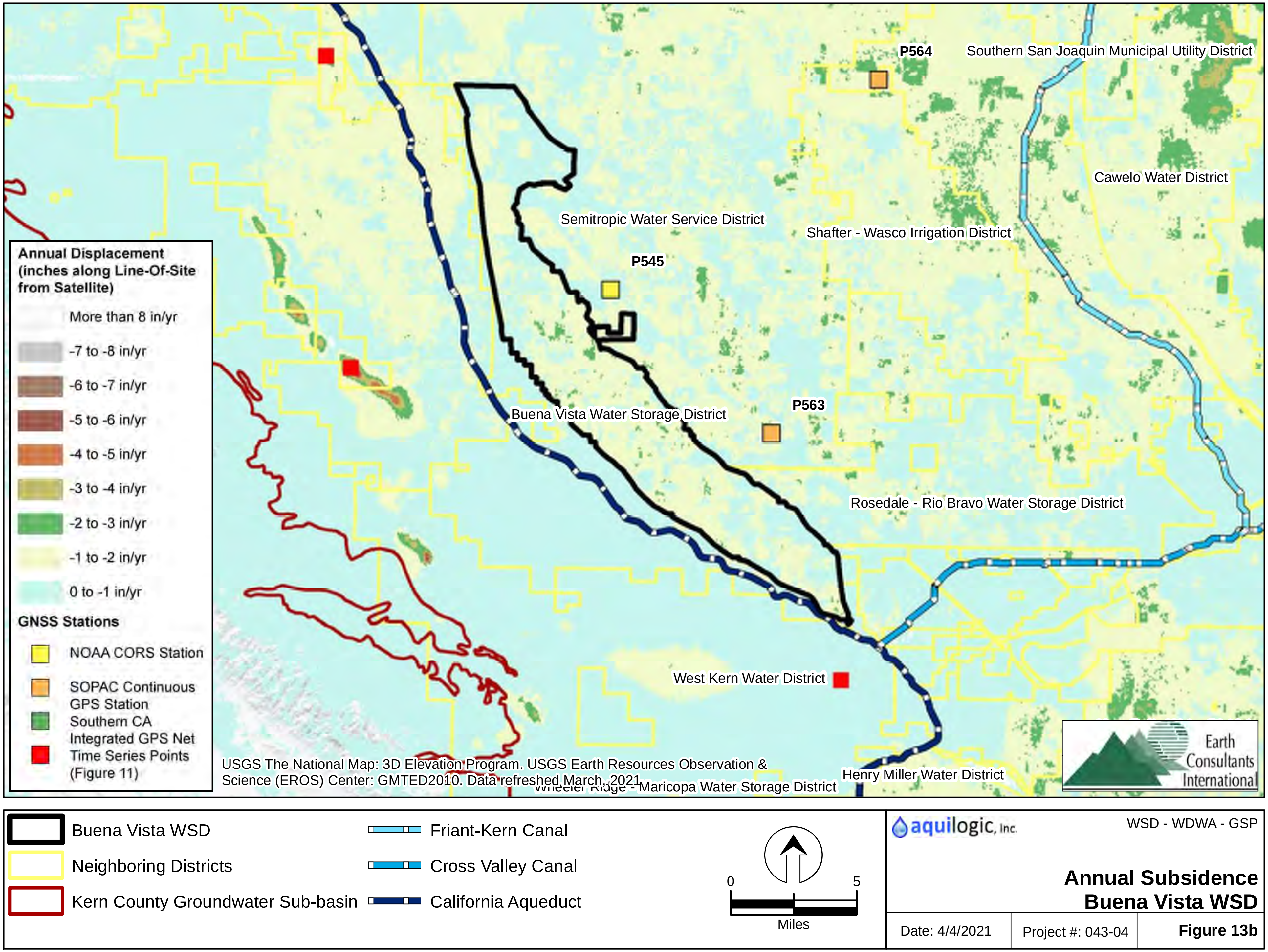
aquilogic, Inc.

WSD - WDWA - GSP

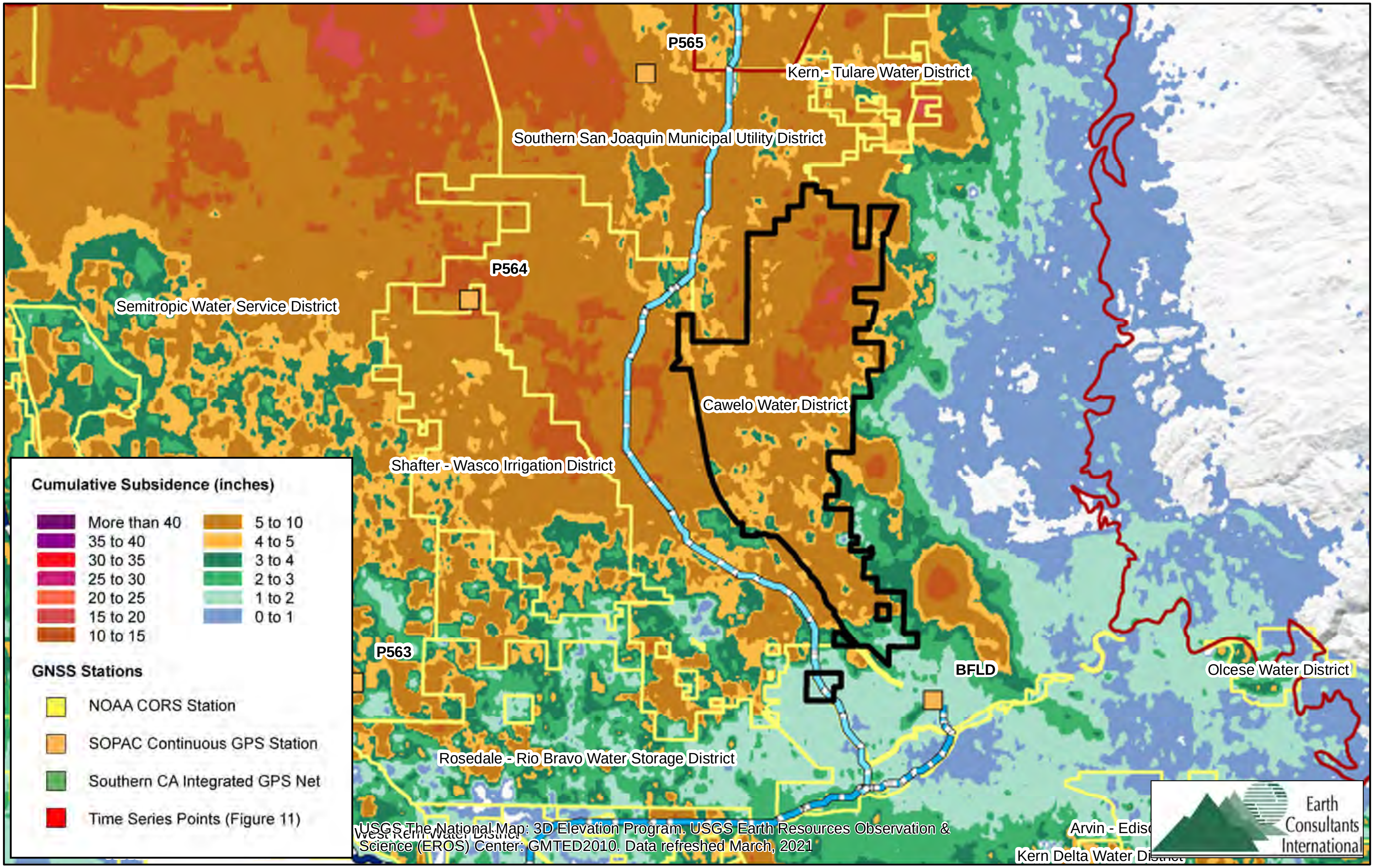
Cumulative Subsidence
1/4/2015 to 9/30/2020
Buena Vista WSD

Date: 4/4/2021	Project #: 043-04	**Figure 13a**

DRAFT


P564
Southern San Joaquin Municipal Utility District
Cawelo Water District
Semitropic Water Service District
Shafter - Wasco Irrigation District
P545
P563
Buena Vista Water Storage District
Rosedale - Rio Bravo Water Storage District
West Kern Water District
Henry Miller Water District
Wheeler Ridge - Maricopa Water Storage District
Annual Displacement (inches along Line-Of-Site from Satellite)
More than 8 in/yr
-7 to -8 in/yr
-6 to -7 in/yr
-5 to -6 in/yr
-4 to -5 in/yr
-3 to -4 in/yr
-2 to -3 in/yr
-1 to -2 in/yr
0 to -1 in/yr
GNSS Stations
NOAA CORS Station
SOPAC Continuous GPS Station
Southern CA Integrated GPS Net
Time Series Points (Figure 11)
USGS The National Map: 3D Elevation Program. USGS Earth Resources Observation & Science (EROS) Center: GMTED2010. Data refreshed March, 2021.
Earth Consultants International
Buena Vista WSD
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct
0
5
Miles
aquilogic, Inc.
WSD - WDWA - GSP
Annual Subsidence
Buena Vista WSD
Date: 4/4/2021
Project #: 043-04
Figure 13b

DRAFT



Cawelo Water District
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

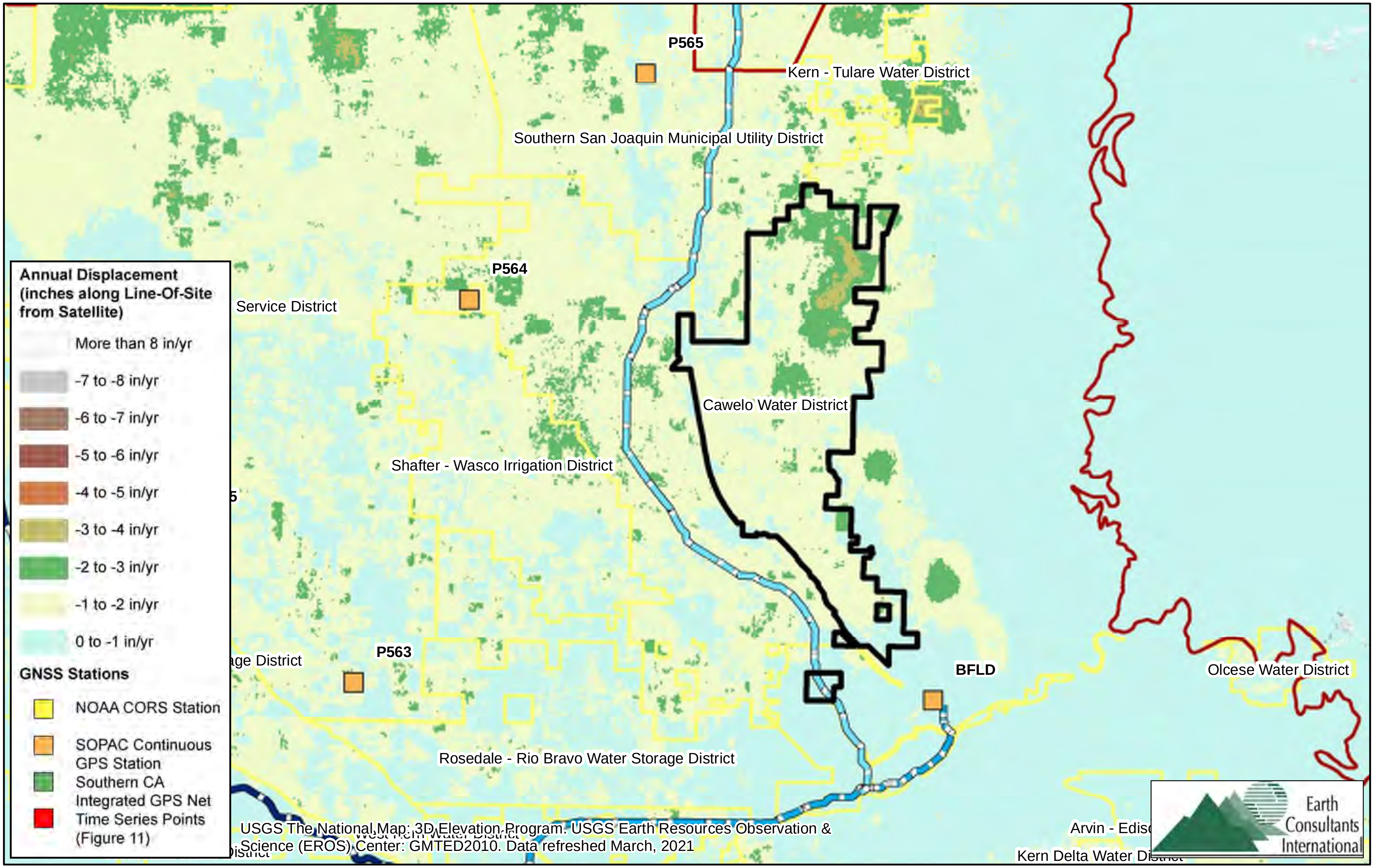
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Cawelo Water District

Date: 4/4/2021	Project #: 043-04	**Figure 14a**

DRAFT



Cawelo Water District
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

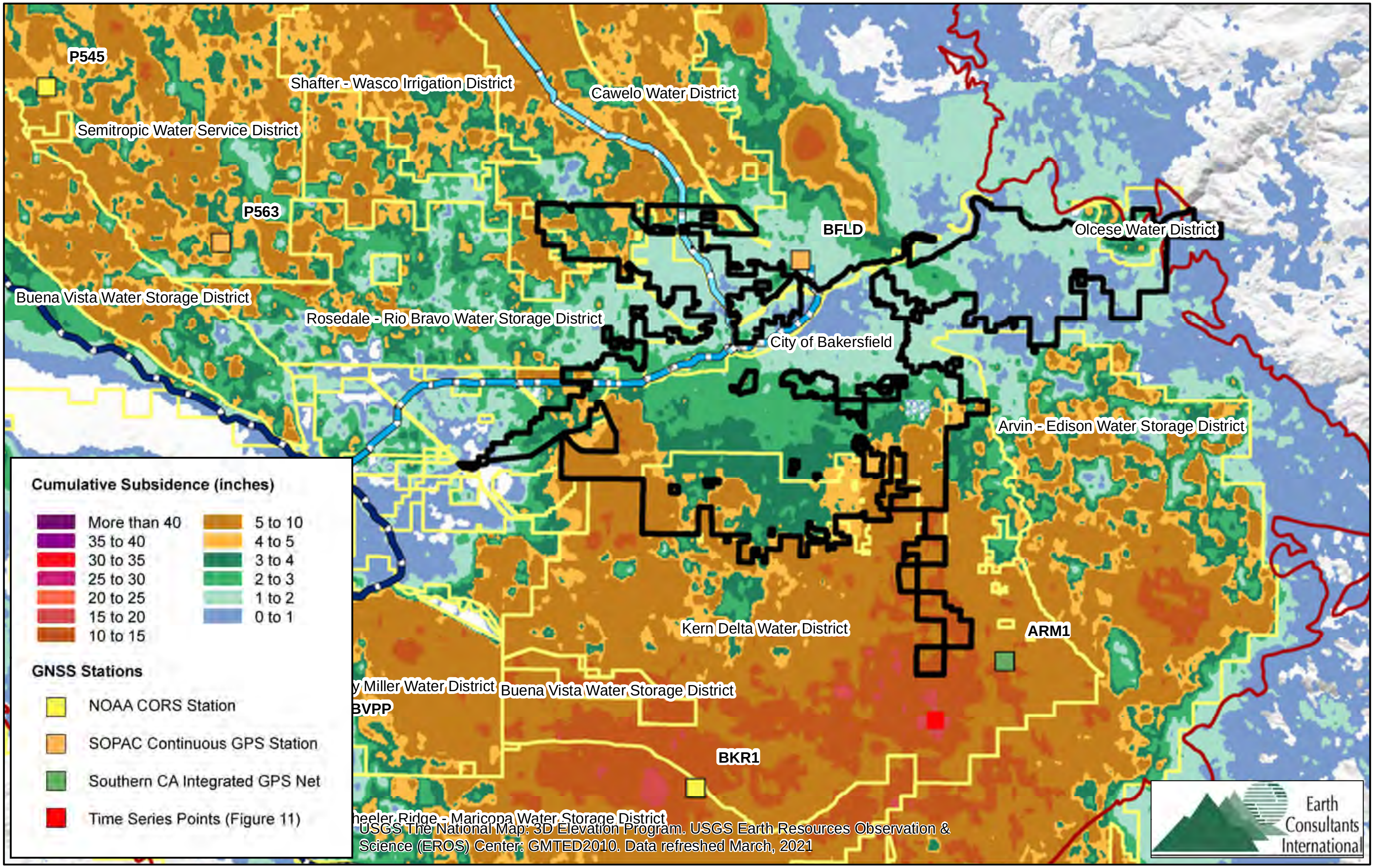
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Cawelo Water District

Date: 4/4/2021	Project #: 043-04	**Figure 14b**

DRAFT



City of Bakersfield
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

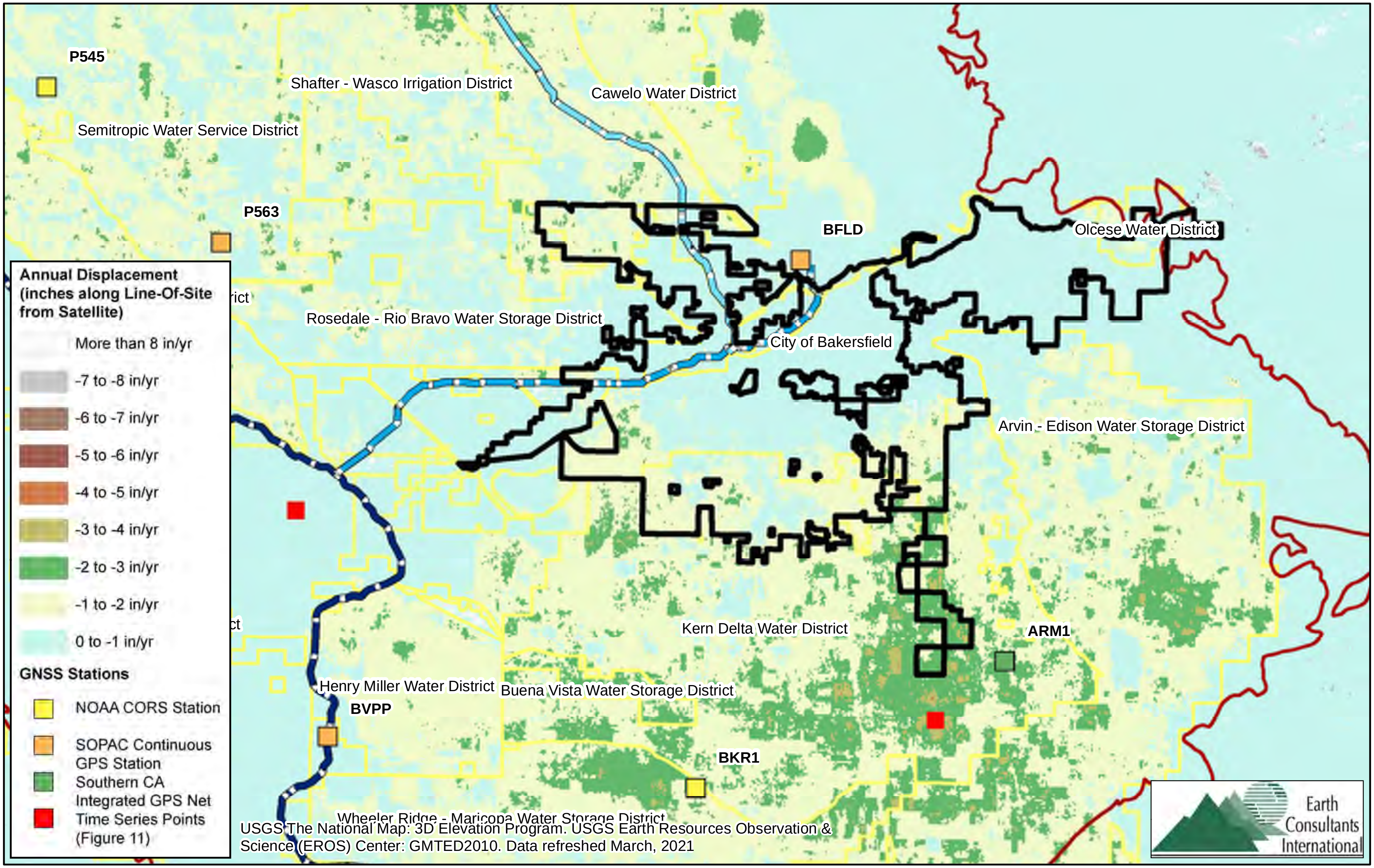
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
City of Bakersfield

Date: 4/4/2021	Project #: 043-04	**Figure 15a**

DRAFT



City of Bakersfield
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

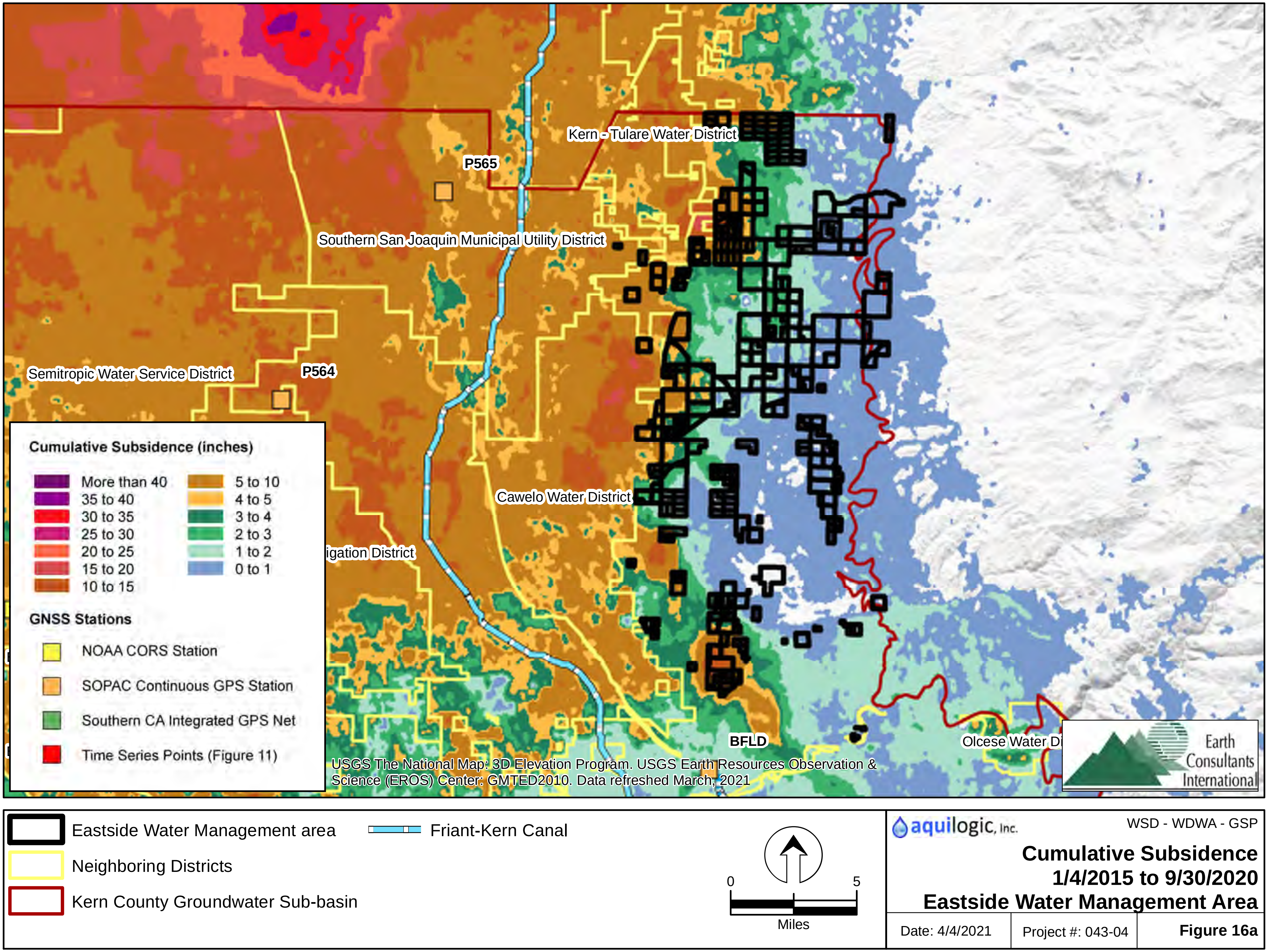
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
City of Bakersfield

Date: 4/4/2021	Project #: 043-04	**Figure 15b**

DRAFT



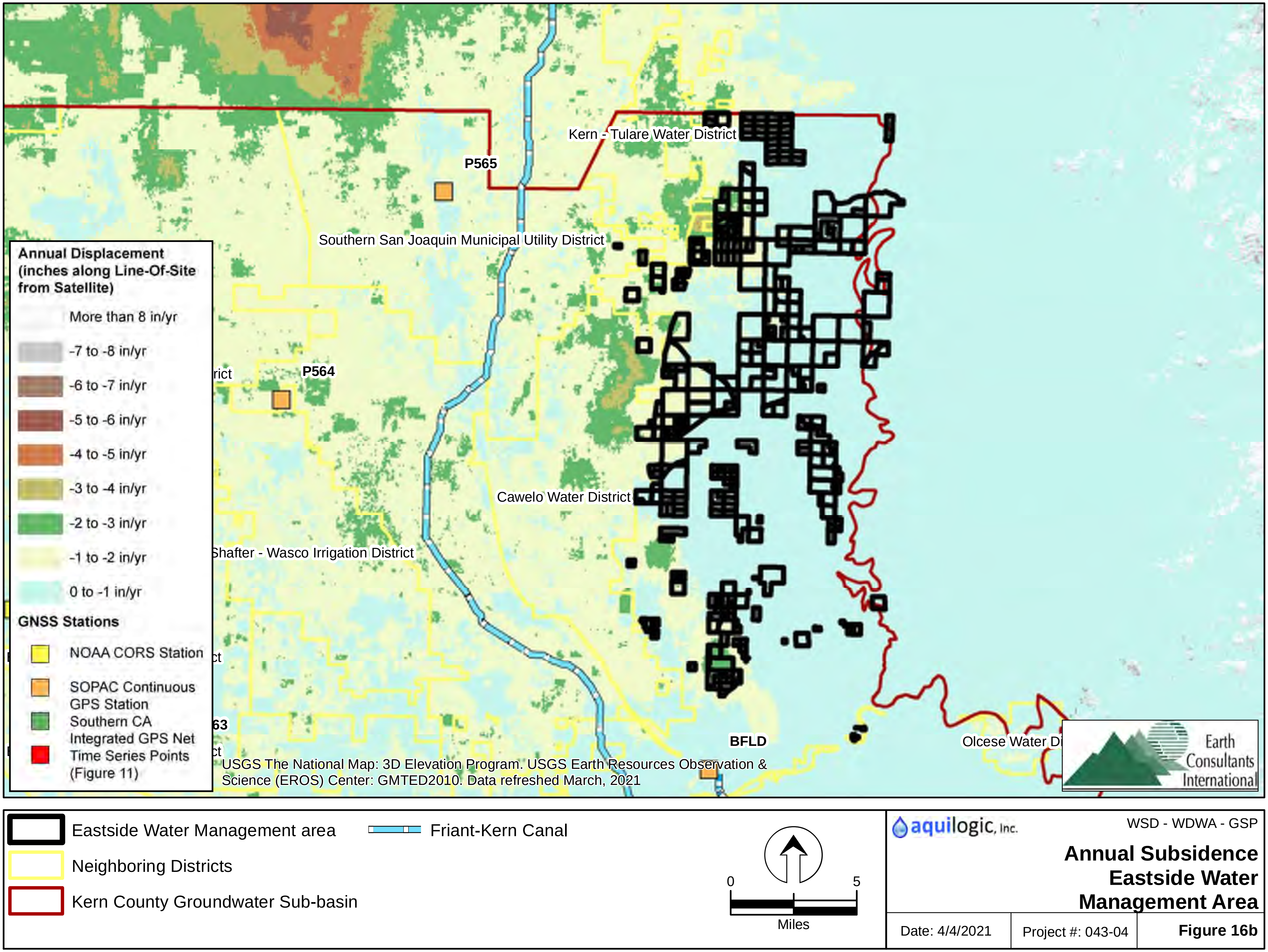
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Eastside Water Management Area

Date: 4/4/2021	Project #: 043-04	**Figure 16a**

DRAFT



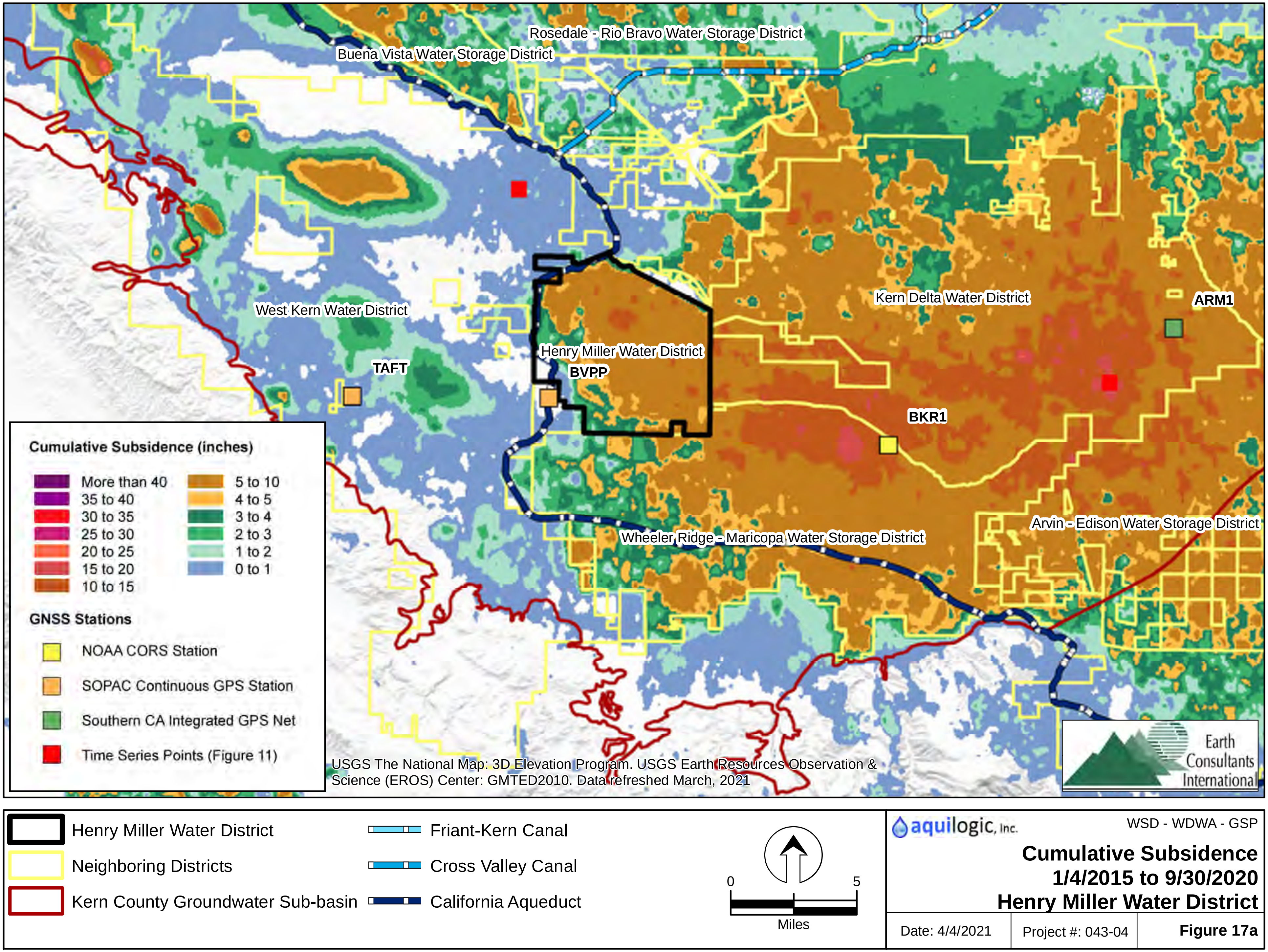
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence Eastside Water Management Area

Date: 4/4/2021	Project #: 043-04	**Figure 16b**

DRAFT



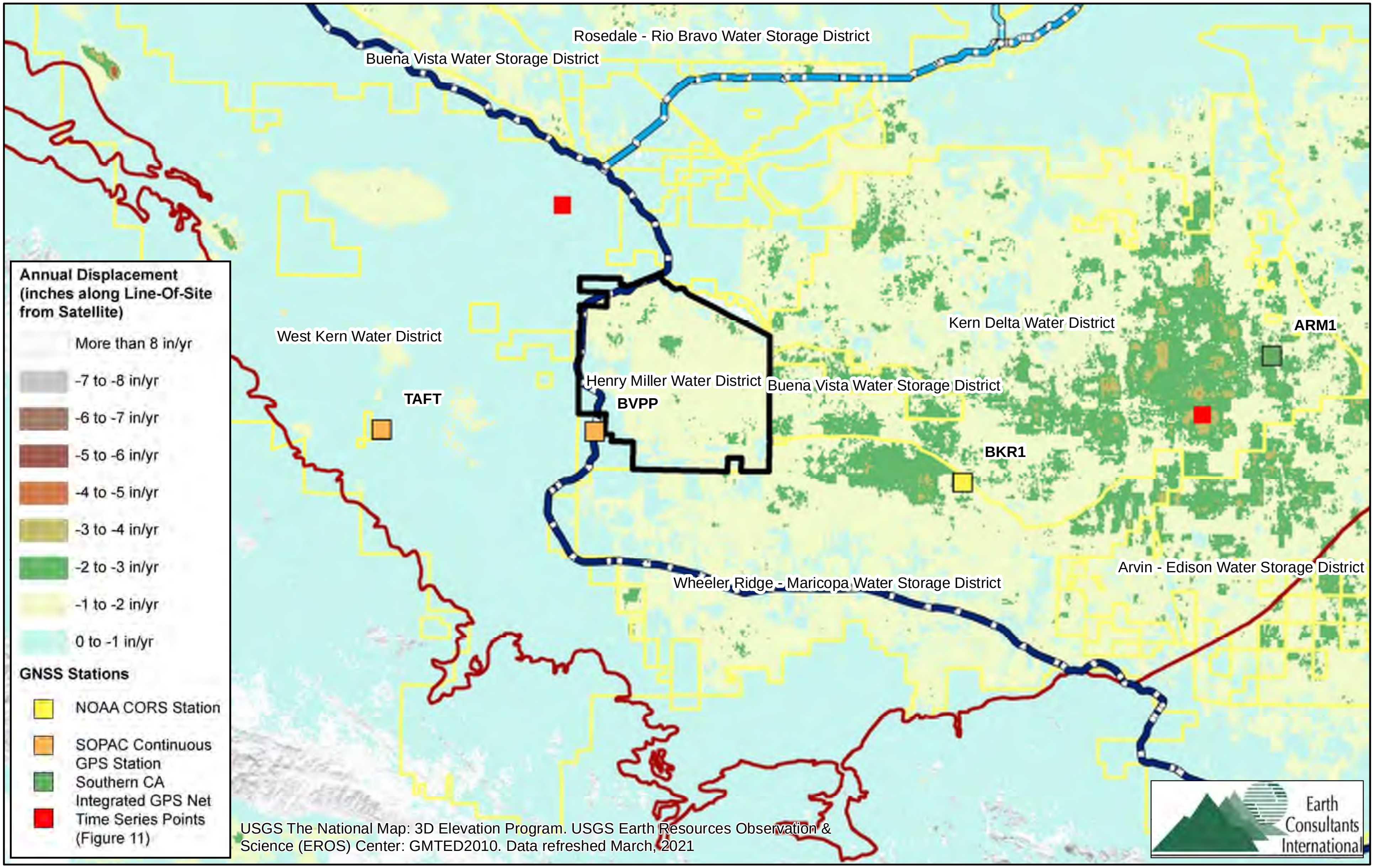
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Henry Miller Water District

Date: 4/4/2021	Project #: 043-04	**Figure 17a**

DRAFT



Henry Miller Water District
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

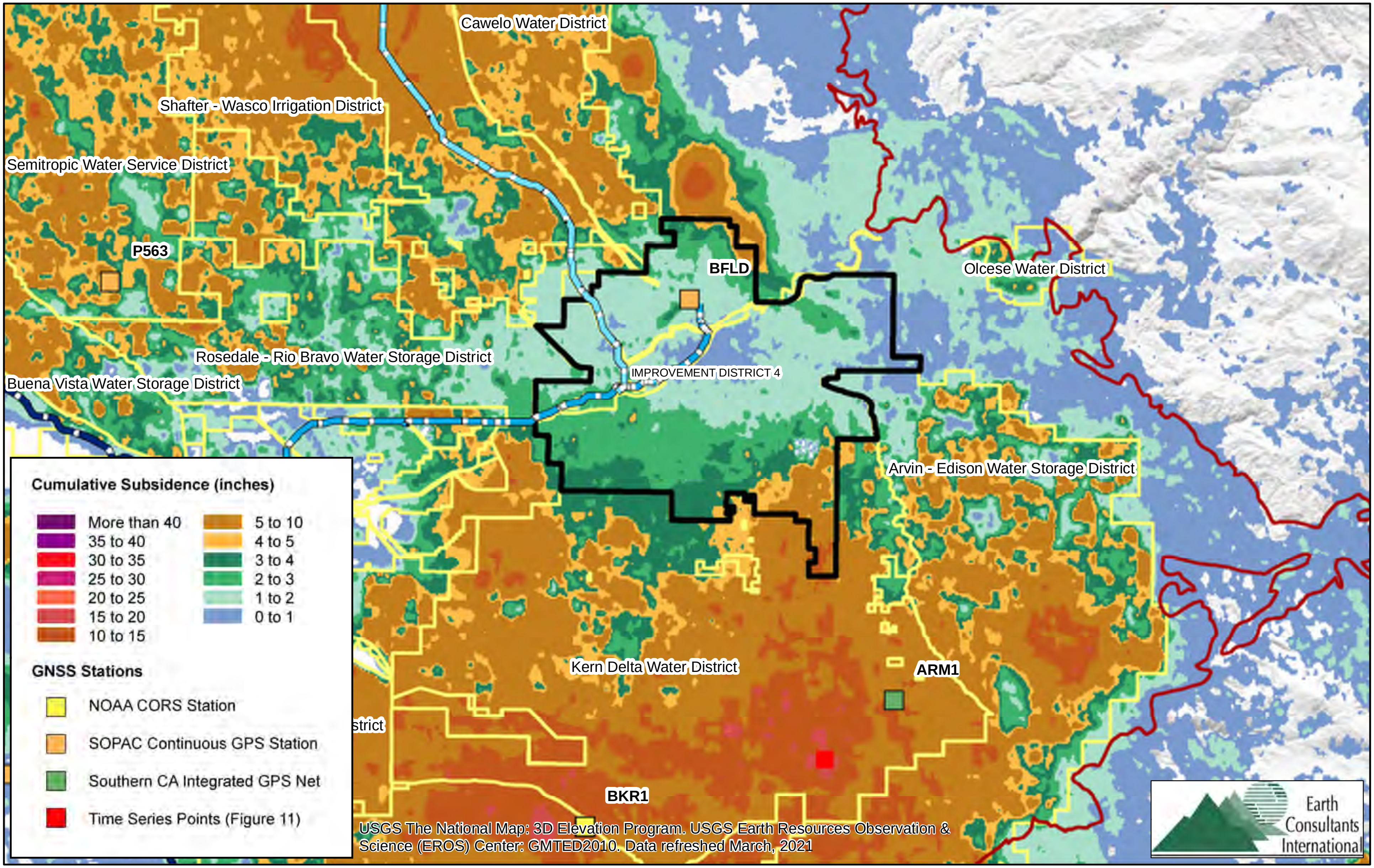
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Henry Miller Water District

Date: 4/4/2021	Project #: 043-04	**Figure 17b**

DRAFT



Improvement District 4
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

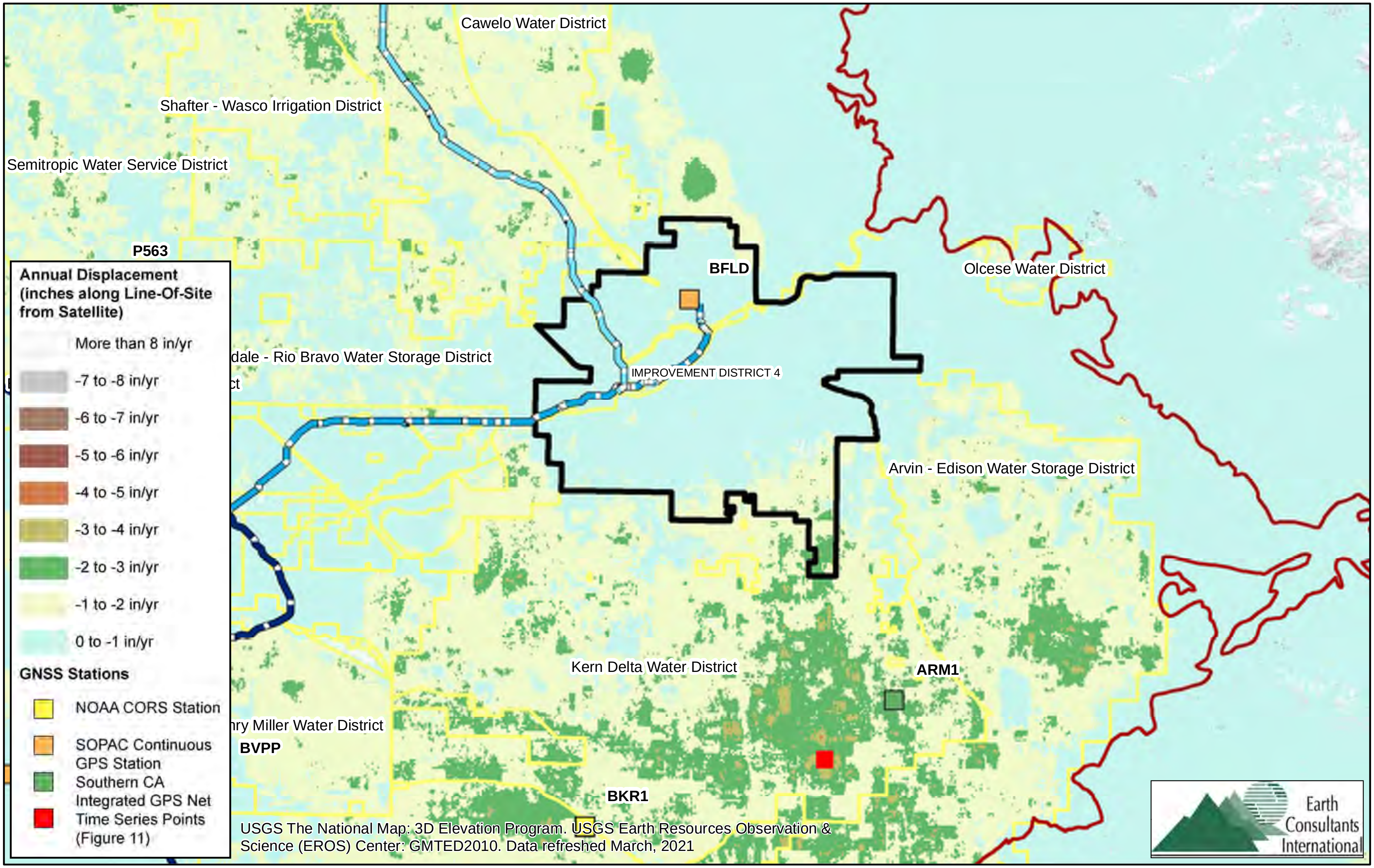
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Improvement District 4

Date: 4/4/2021	Project #: 043-04	**Figure 18a**

DRAFT



Improvement District 4
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

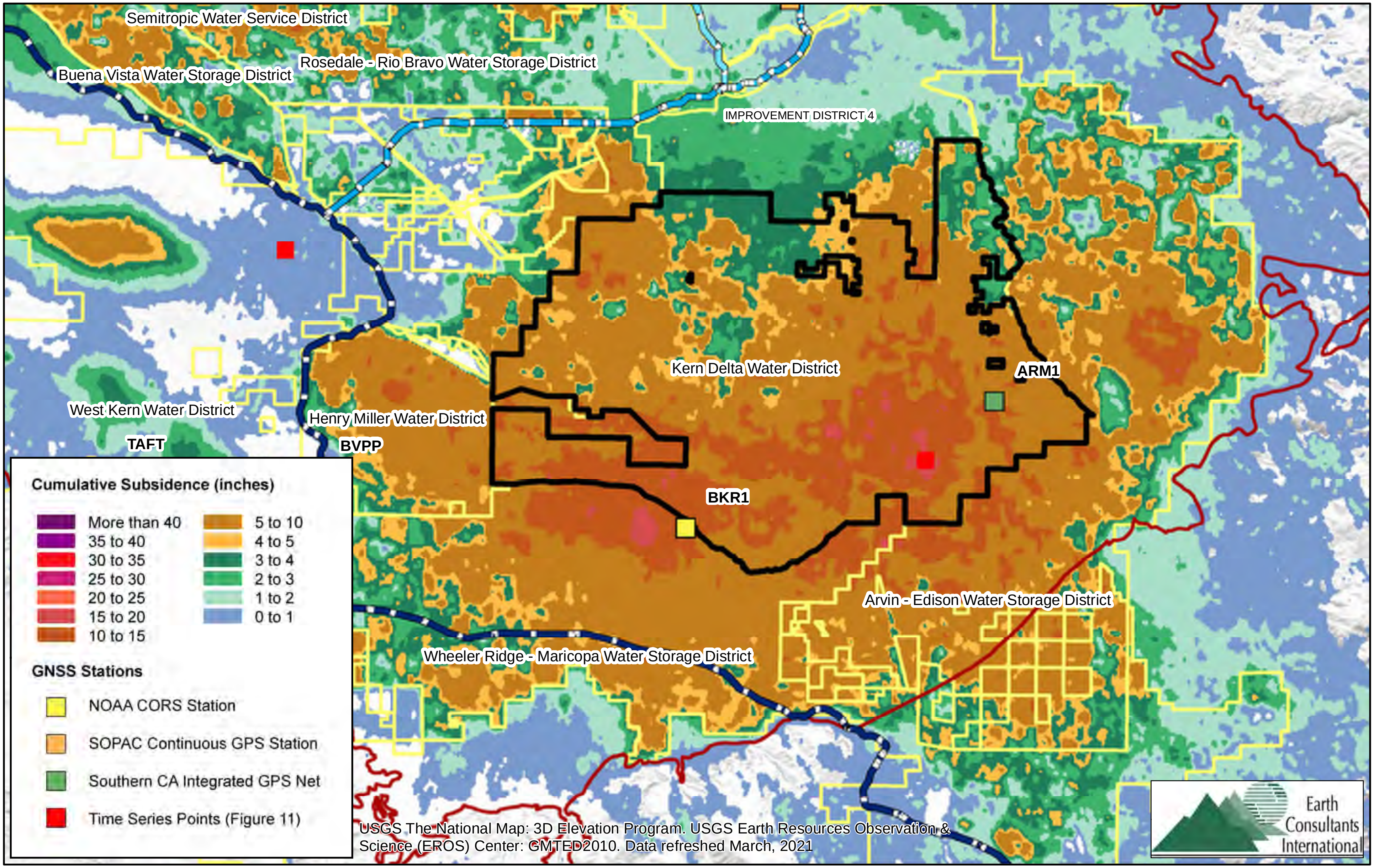
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Improvement District 4

Date: 4/4/2021	Project #: 043-04	**Figure 18b**

DRAFT



Kern Delta Water District
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

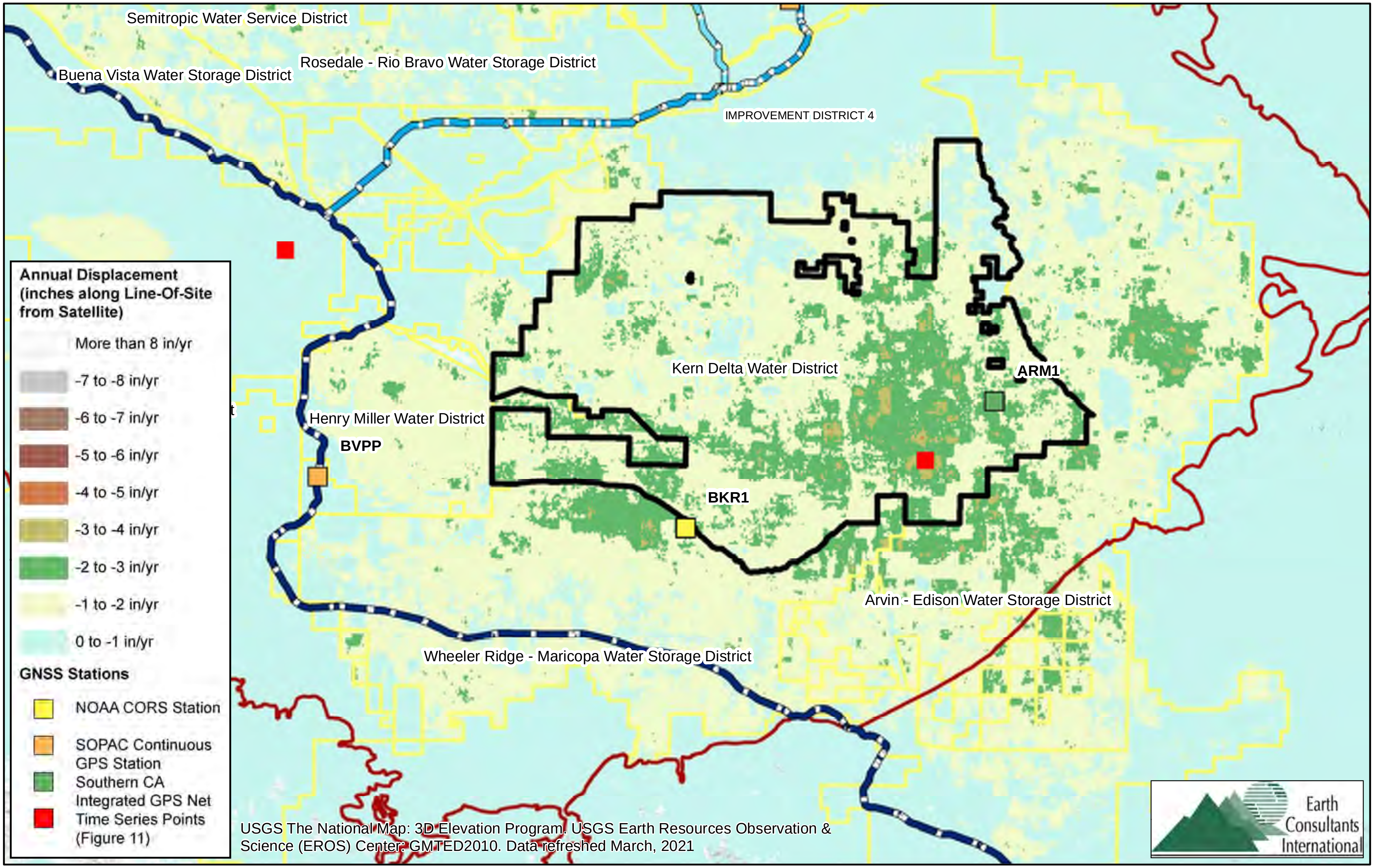
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Kern Delta Water District

Date: 4/4/2021	Project #: 043-04	**Figure 19a**

DRAFT



Kern Delta Water District
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

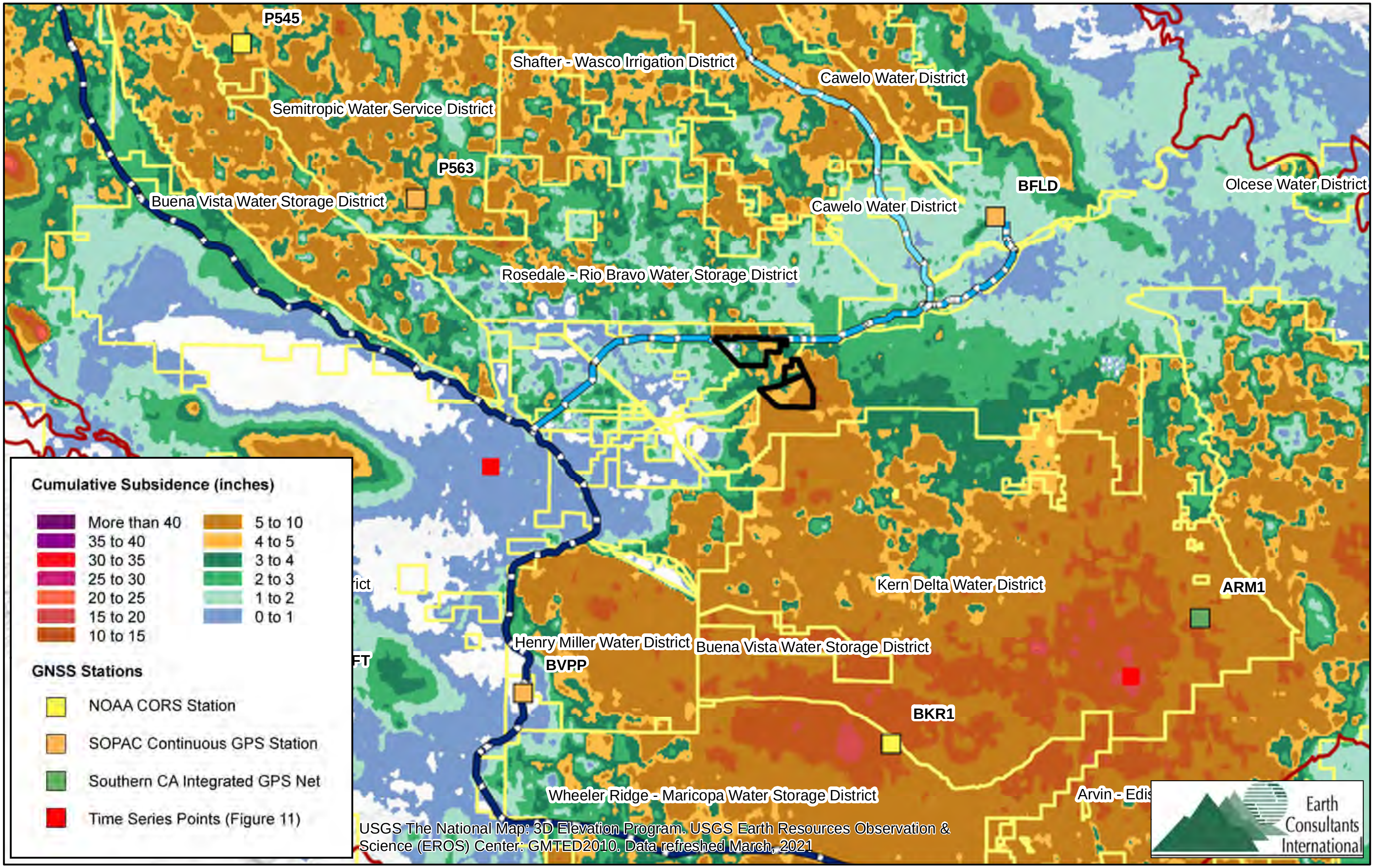
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Kern Delta Water District

Date: 4/4/2021	Project #: 043-04	**Figure 19b**

DRAFT



Kern County Water Agency - Pioneer Project

Neighboring Districts

Kern County Groundwater Sub-basin

Friant-Kern Canal

Cross Valley Canal

California Aqueduct

0 5

Miles

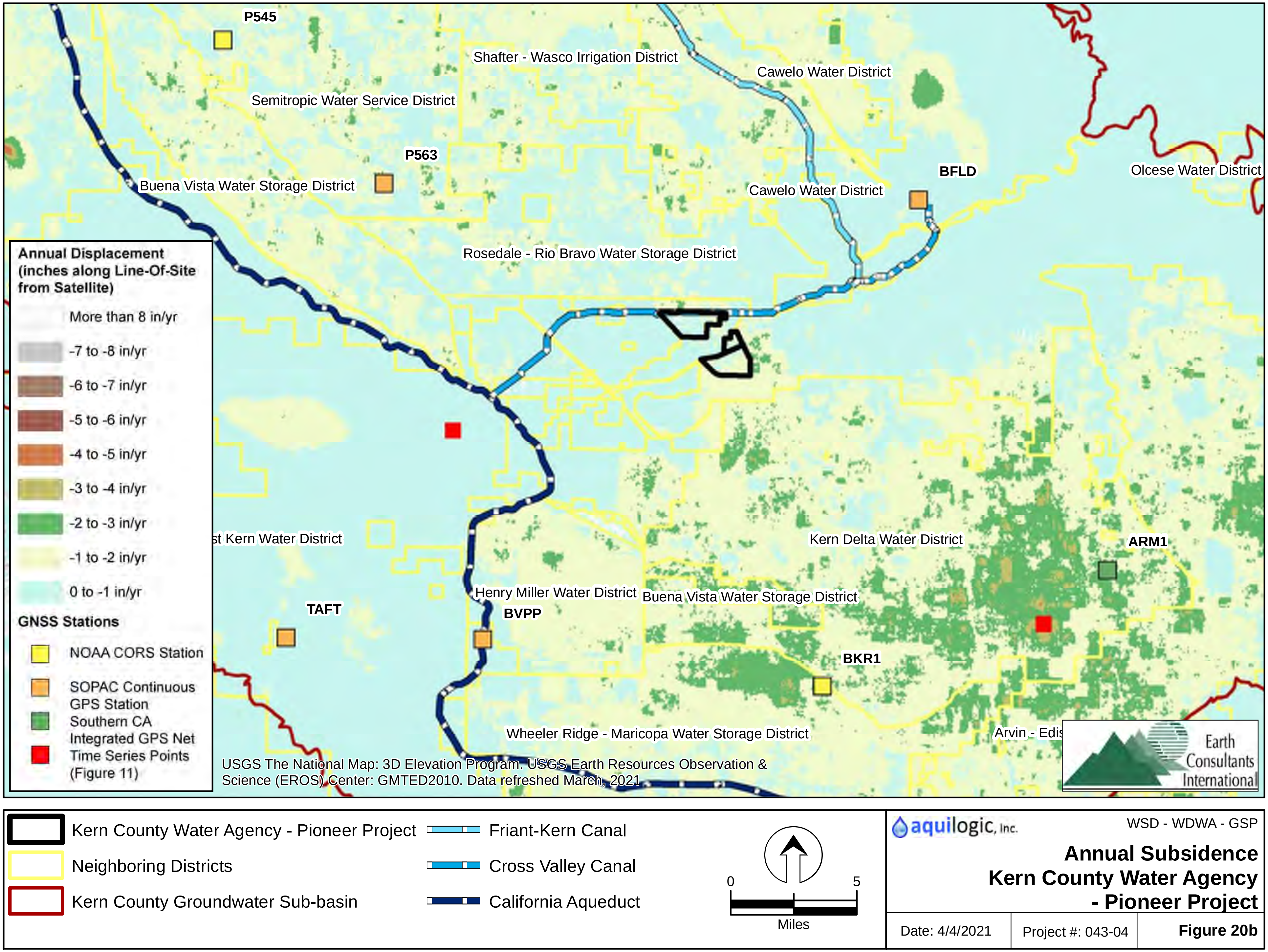
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence 1/4/2015 to 9/30/2020 Kern County Water Agency - Pioneer Project

Date: 4/4/2021	Project #: 043-04	**Figure 20a**

DRAFT



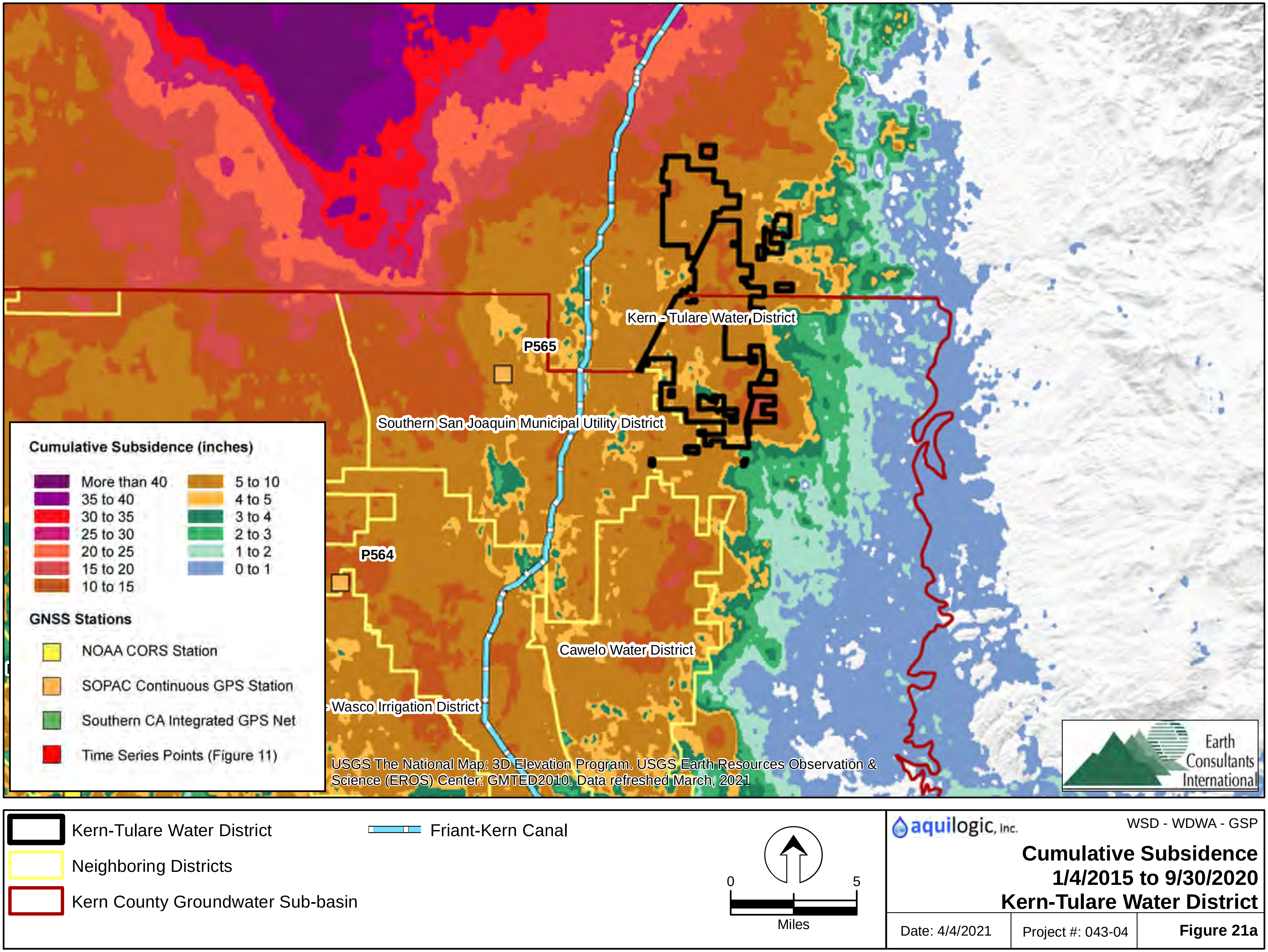
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence Kern County Water Agency - Pioneer Project

Date: 4/4/2021	Project #: 043-04	Figure 20b

DRAFT



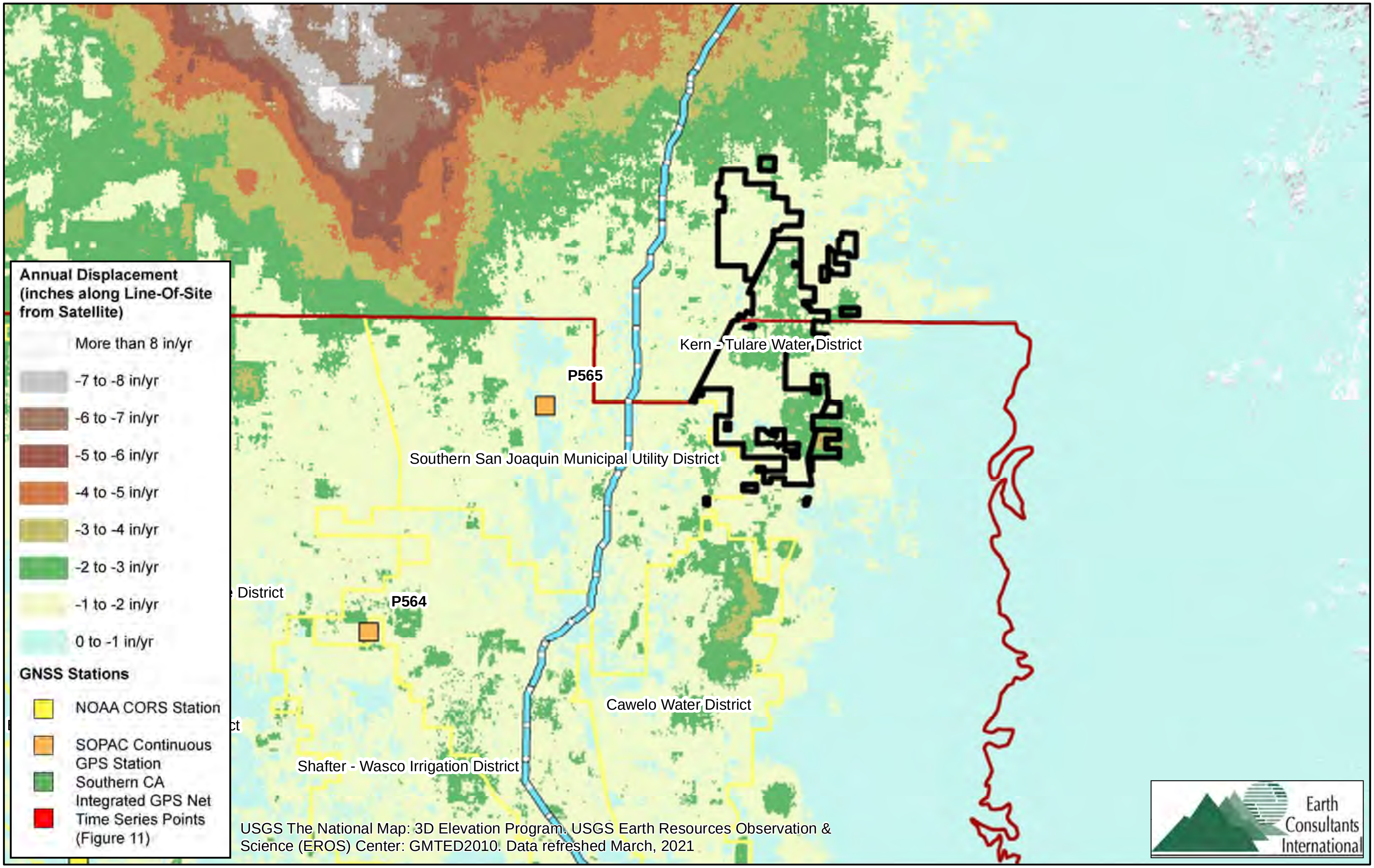
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Kern-Tulare Water District

Date: 4/4/2021	Project #: 043-04	**Figure 21a**

DRAFT



Kern-Tulare Water District
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal

0 5
Miles

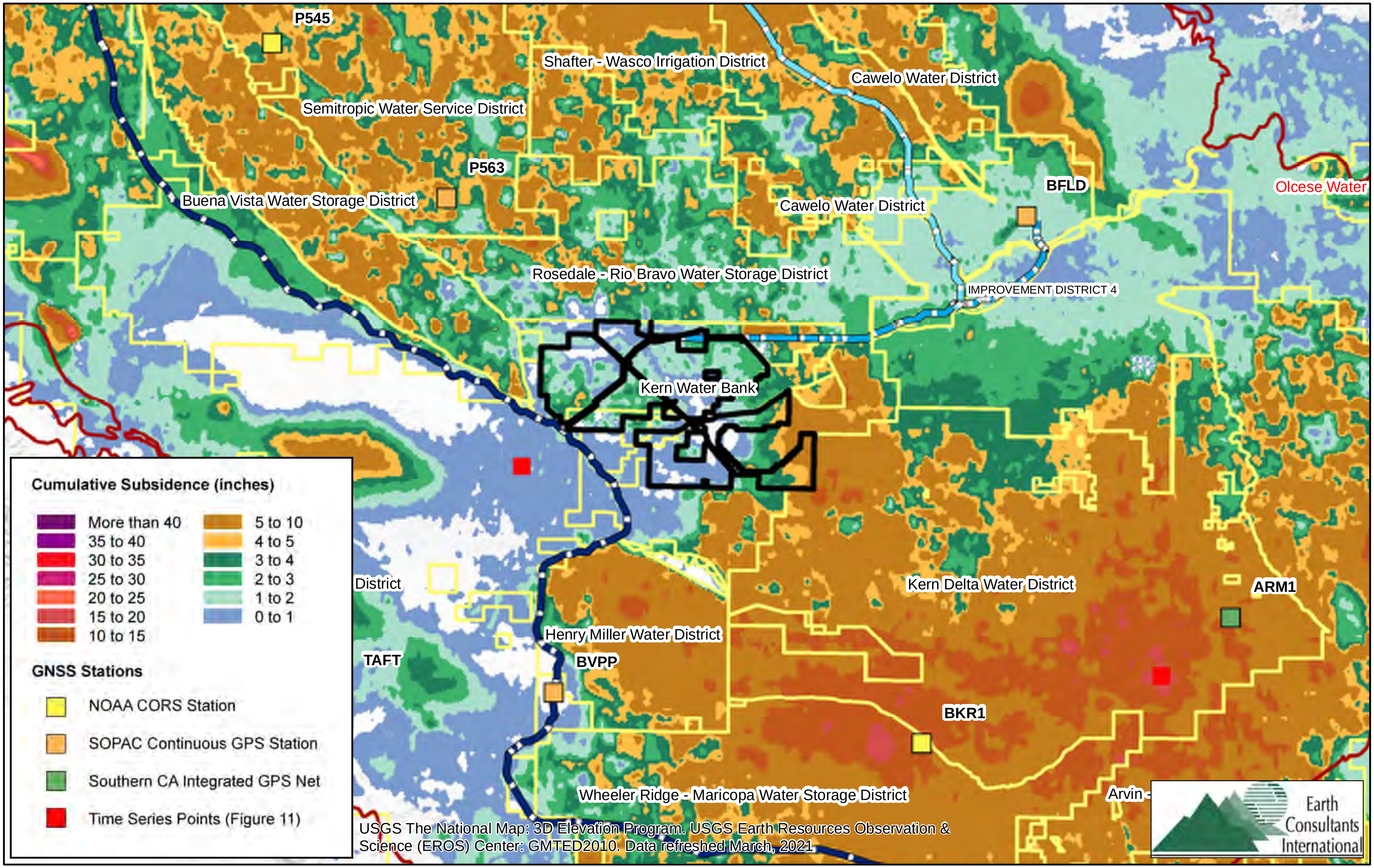
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Kern-Tulare Water District

Date: 4/4/2021	Project #: 043-04	**Figure 21b**

DRAFT



Kern Water Bank
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

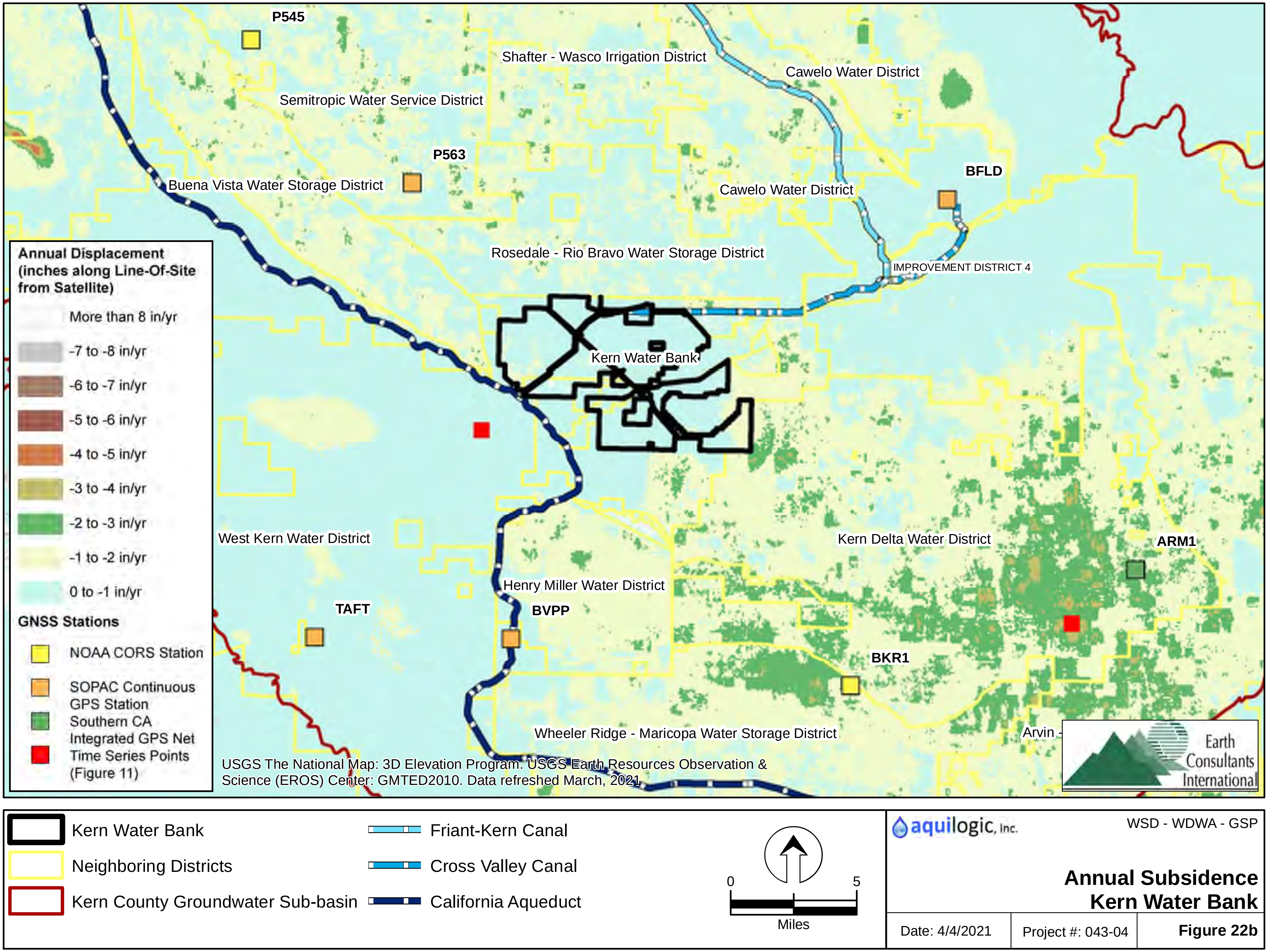
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Kern Water Bank

Date: 4/4/2021 | Project #: 043-04 | **Figure 22a**

DRAFT



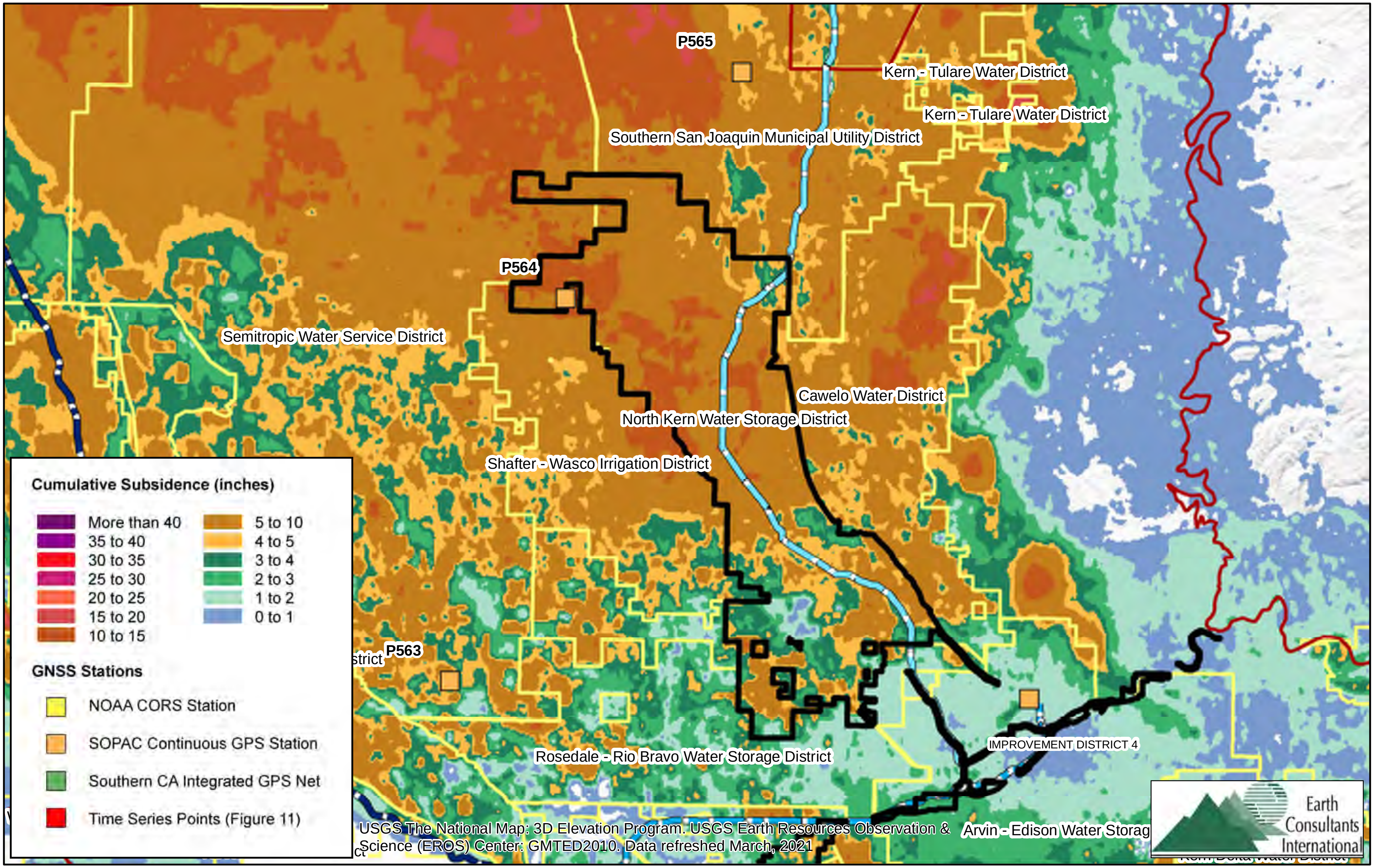
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Kern Water Bank

Date: 4/4/2021	Project #: 043-04	**Figure 22b**

DRAFT



North Kern WSD
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

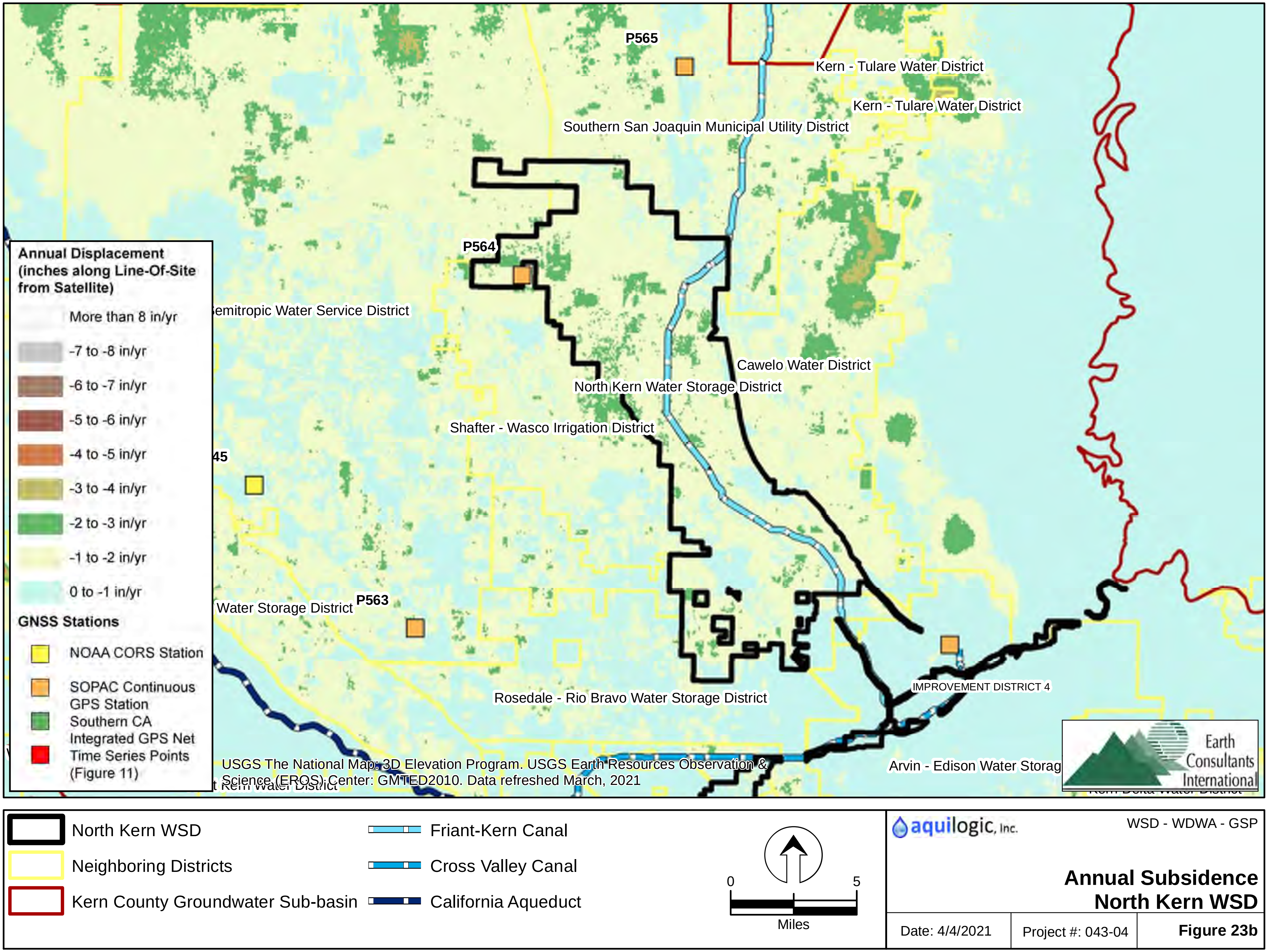
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
North Kern WSD

Date: 4/4/2021	Project #: 043-04	**Figure 23a**

DRAFT



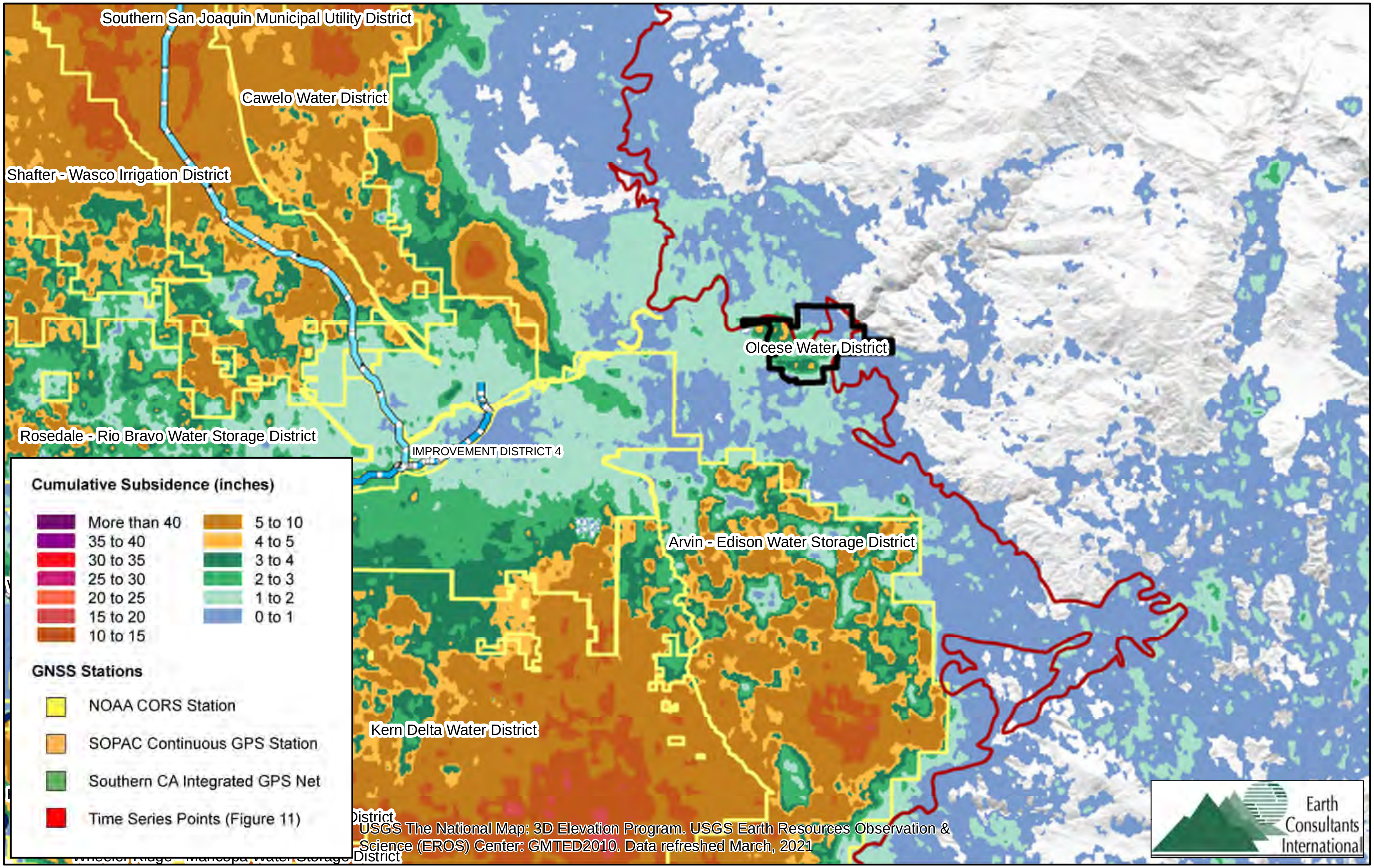
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence North Kern WSD

Date: 4/4/2021	Project #: 043-04	**Figure 23b**

DRAFT



Olcese Water District

Neighboring Districts

Kern County Groundwater Sub-basin

Friant-Kern Canal

Cross Valley Canal

California Aqueduct

0 5

Miles

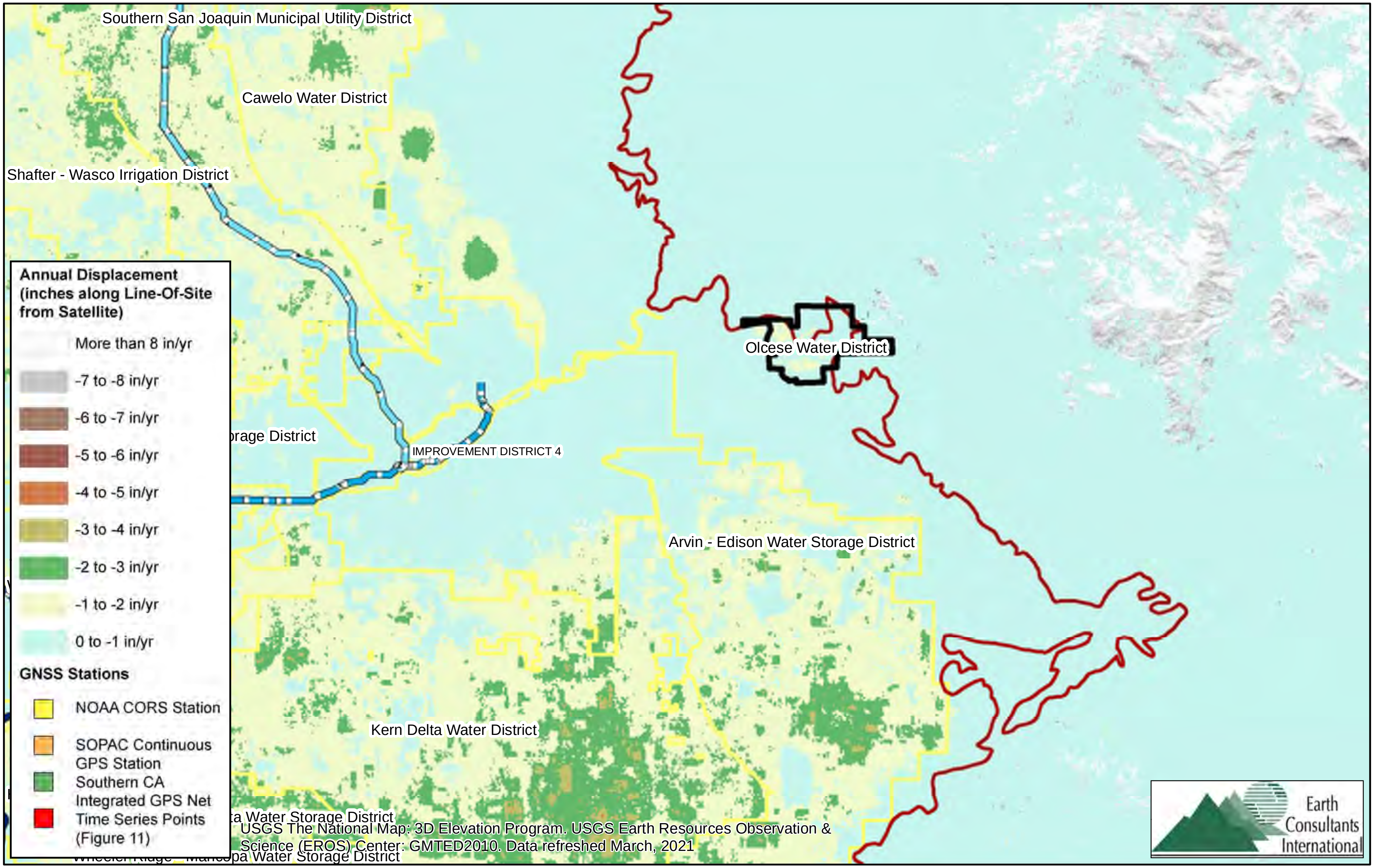
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Olcese Water District

Date: 4/4/2021	Project #: 043-04	**Figure 24a**

DRAFT



Olcese Water District
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

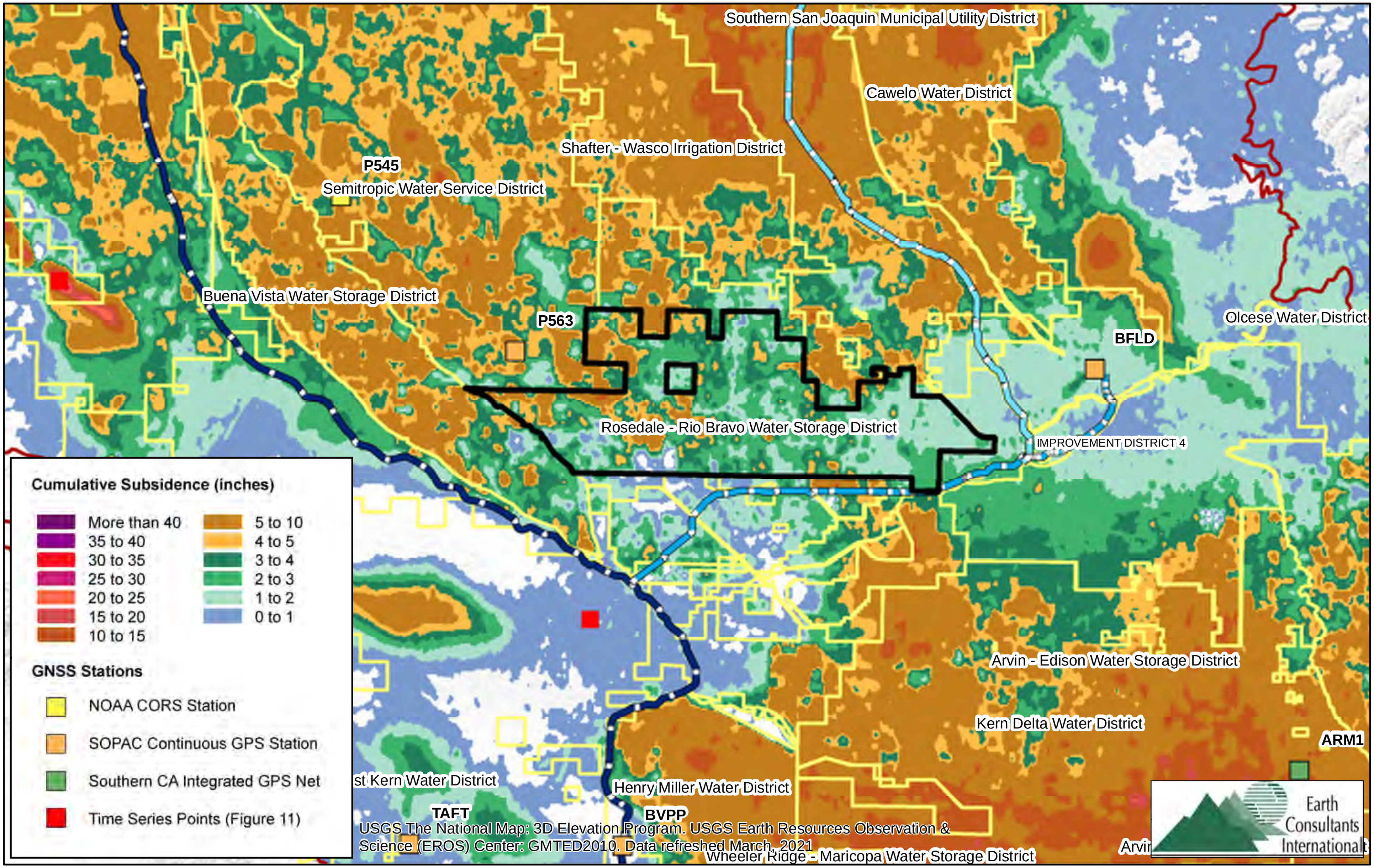
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Olcese Water District

Date: 4/4/2021	Project #: 043-04	**Figure 24b**

DRAFT



Rosedale-Rio Bravo WSD | Friant-Kern Canal
Neighboring Districts | Cross Valley Canal
Kern County Groundwater Sub-basin | California Aqueduct

0 5
Miles

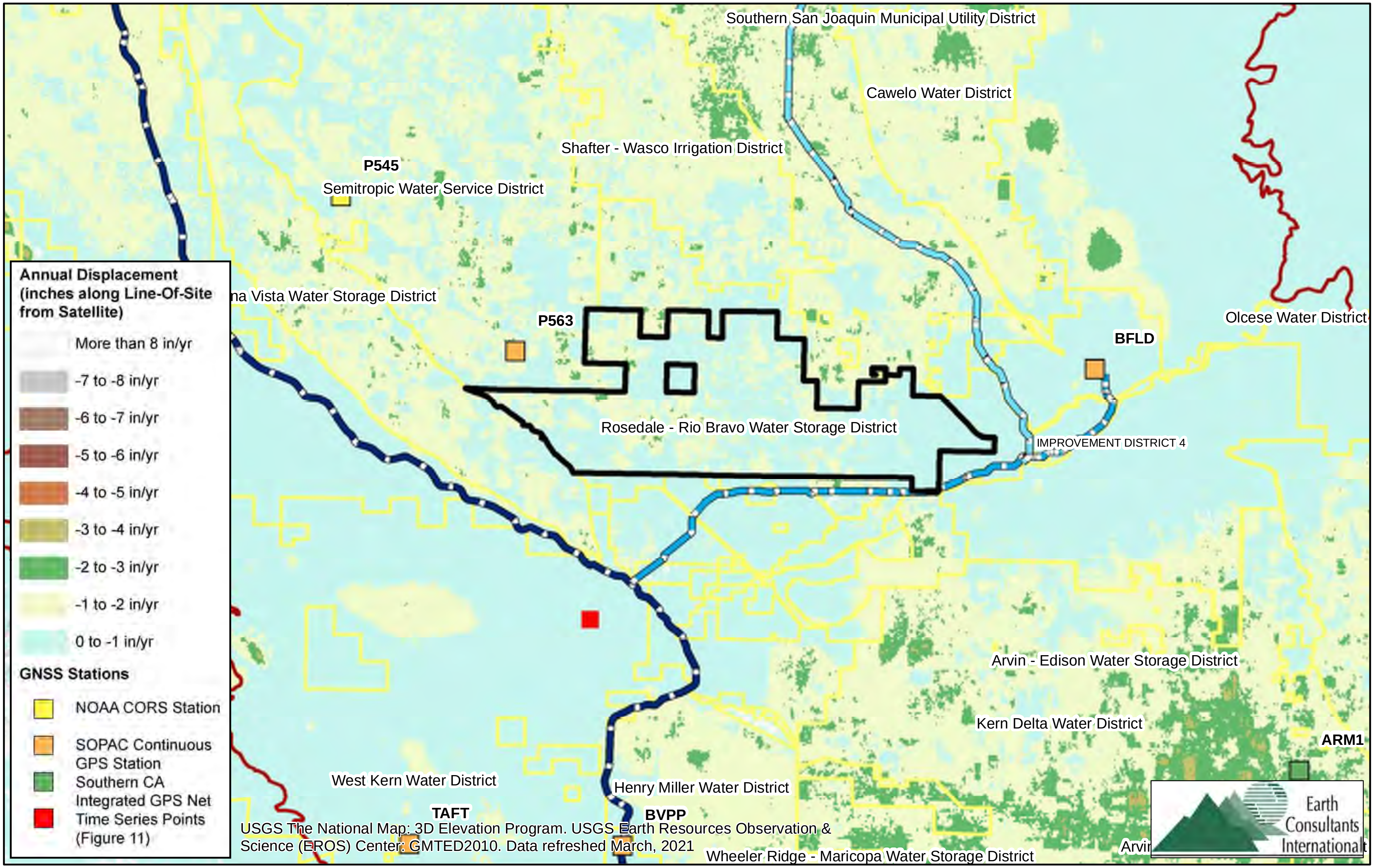
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Rosedale-Rio Bravo WSD

Date: 4/4/2021 | Project #: 043-04 | **Figure 25a**

DRAFT



Rosedale-Rio Bravo WSD
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

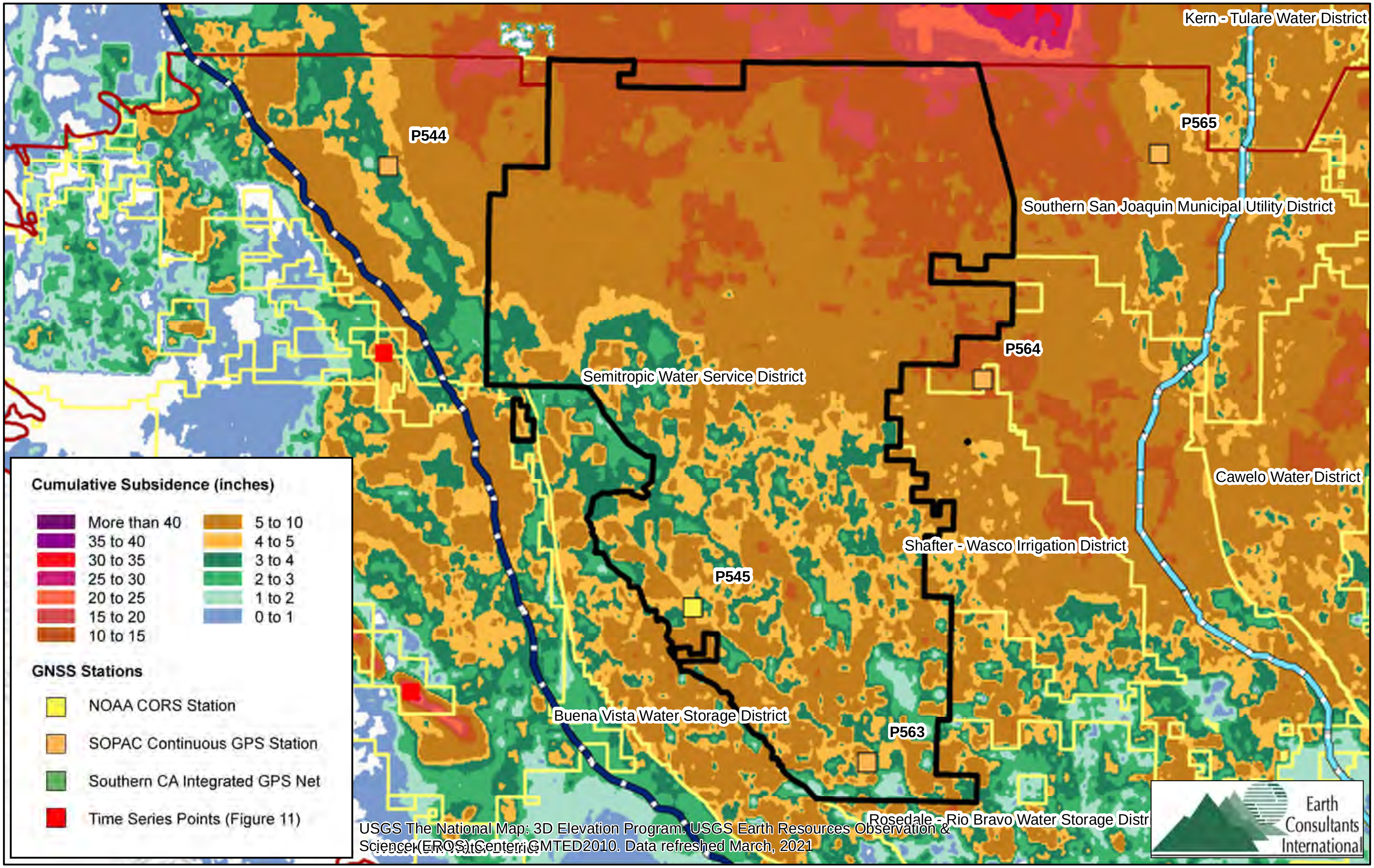
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Rosedale-Rio Bravo WSD

Date: 4/4/2021	Project #: 043-04	**Figure 25b**

DRAFT



Semi Tropic Water Service District
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

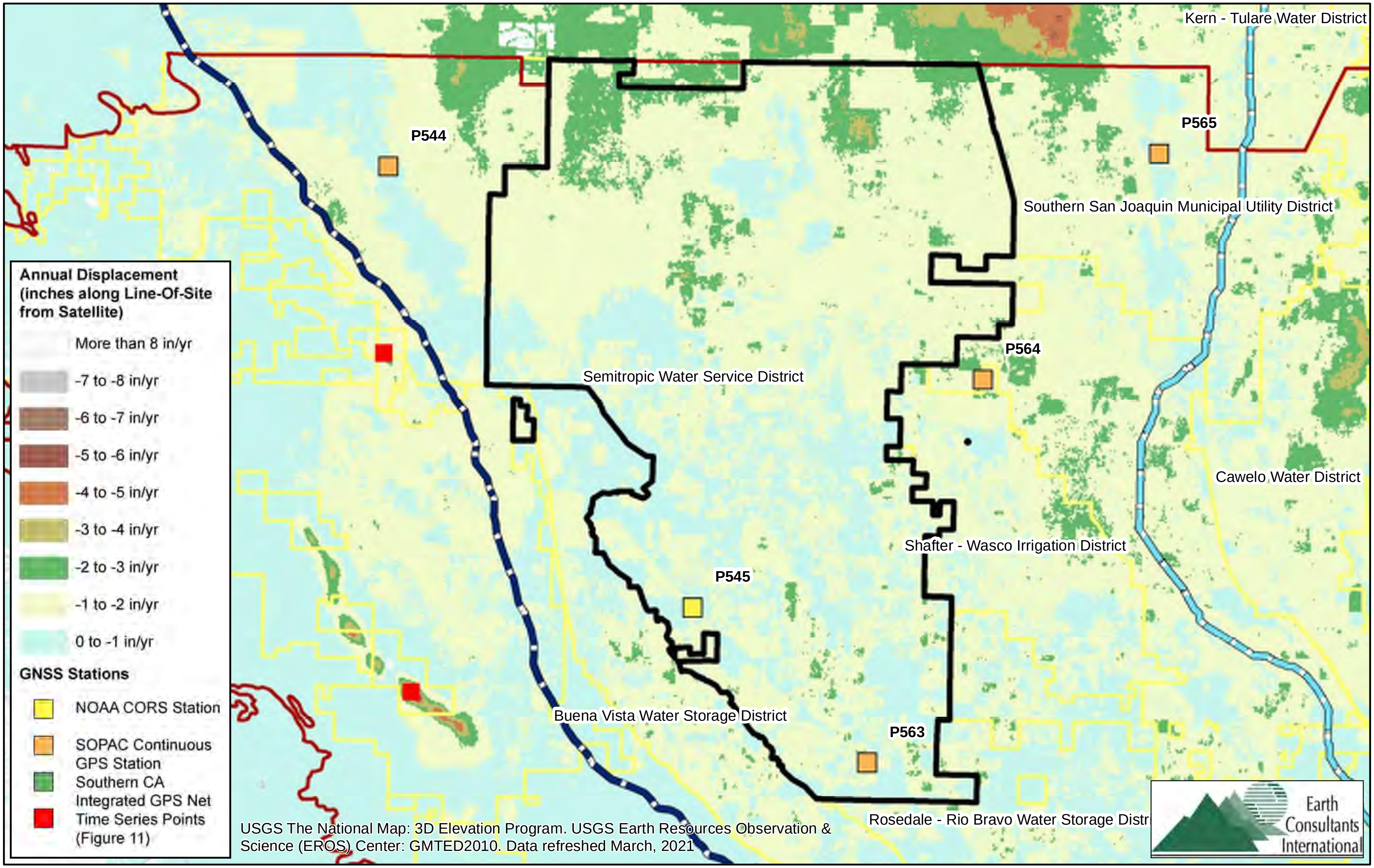
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Semi Tropic WSD

Date: 4/4/2021	Project #: 043-04	**Figure 26a**

DRAFT



Semi Tropic Water Service District

Neighboring Districts

Kern County Groundwater Sub-basin

Friant-Kern Canal

California Aqueduct

0 5

Miles

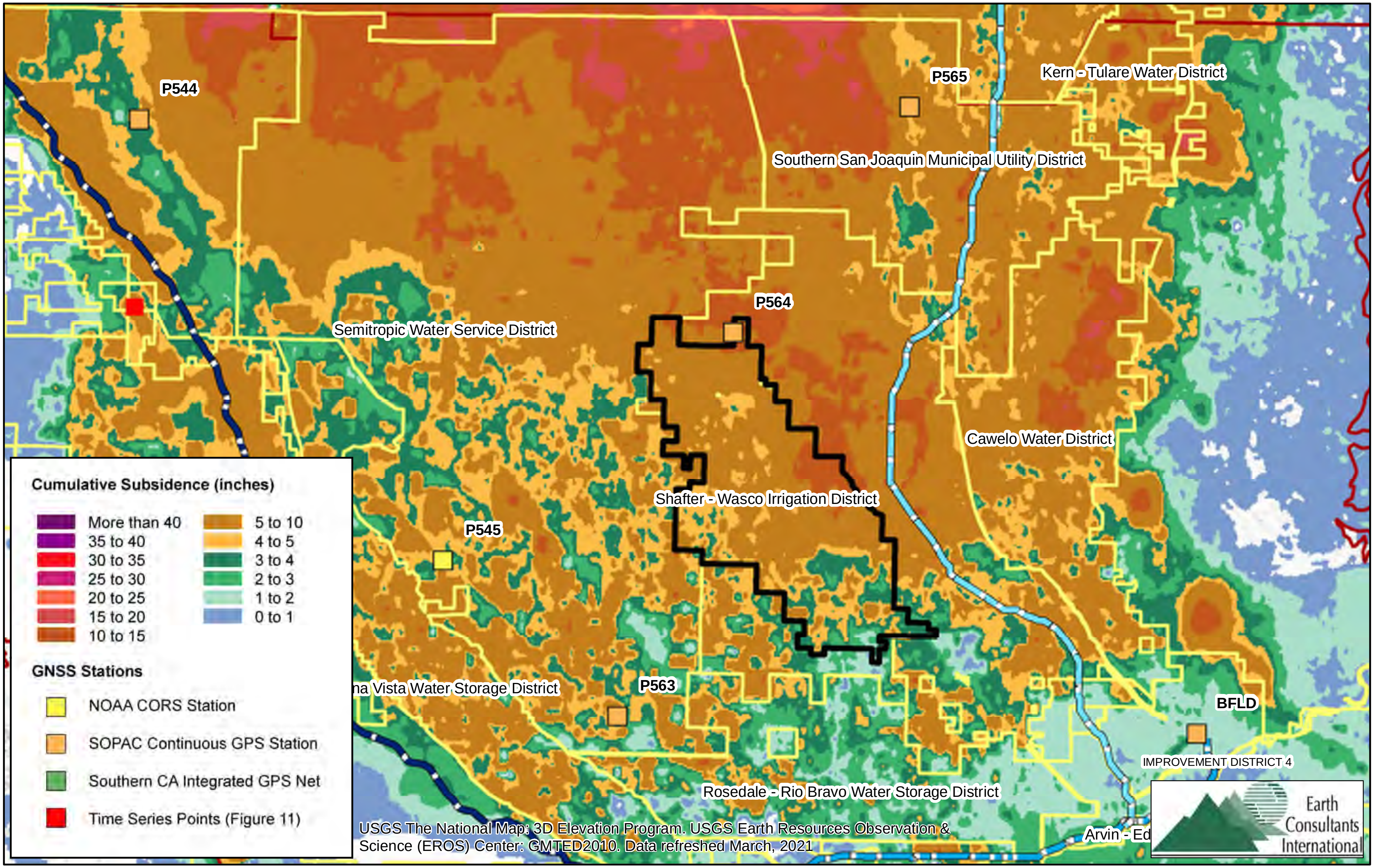
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence Semi Tropic WSD

Date: 4/4/2021	Project #: 043-04	**Figure 26b**

DRAFT



Shafter-Wasco Irrigation District
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

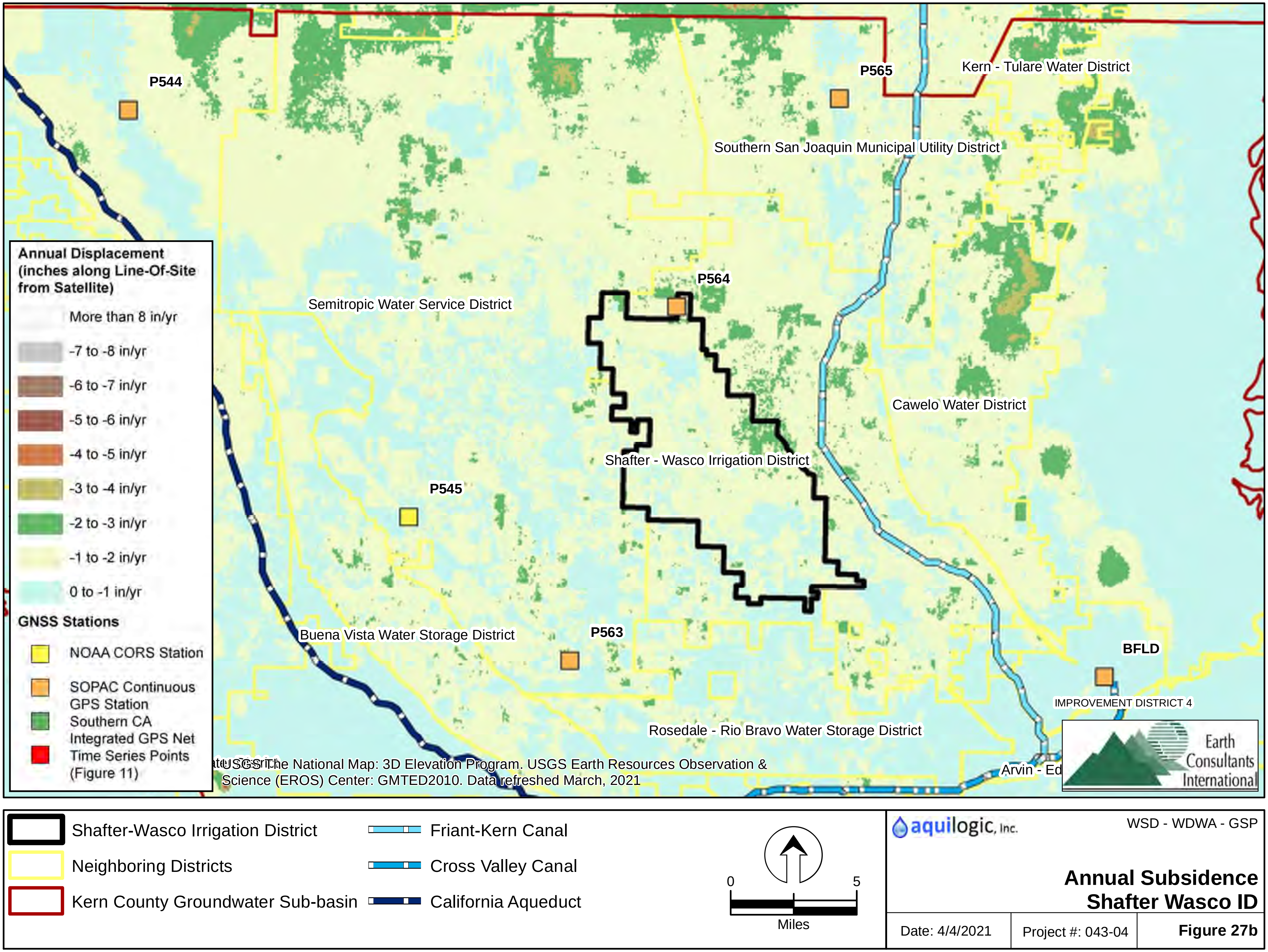
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Shafter Wasco ID

Date: 4/4/2021	Project #: 043-04	**Figure 27a**

DRAFT



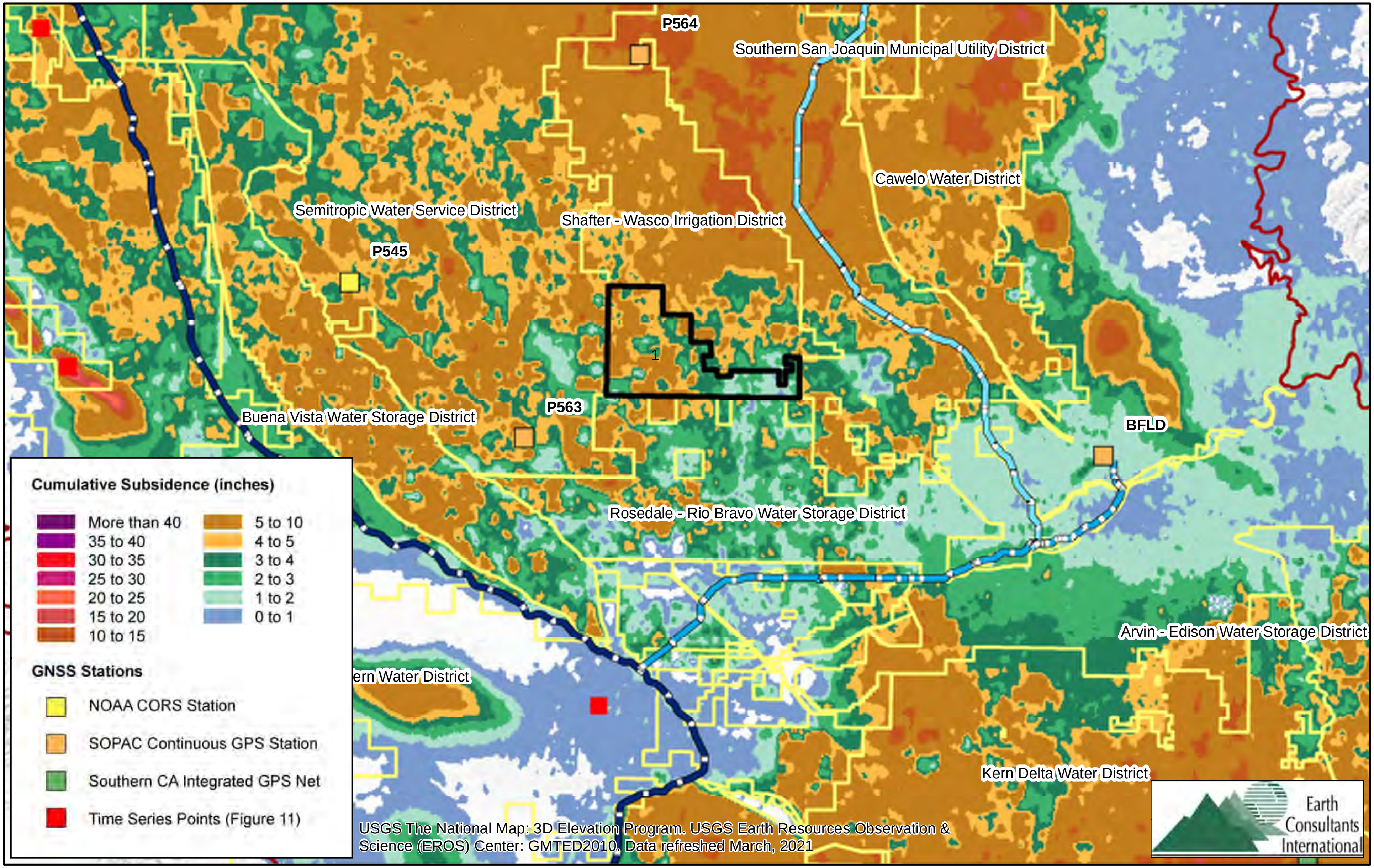
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Shafter Wasco ID

Date: 4/4/2021 | Project #: 043-04 | **Figure 27b**

DRAFT



Shafter-Wasco 7th Std. Annex Area (approx.)

Neighboring Districts

Kern County Groundwater Sub-basin

Friant-Kern Canal

Cross Valley Canal

California Aqueduct

0 5 Miles

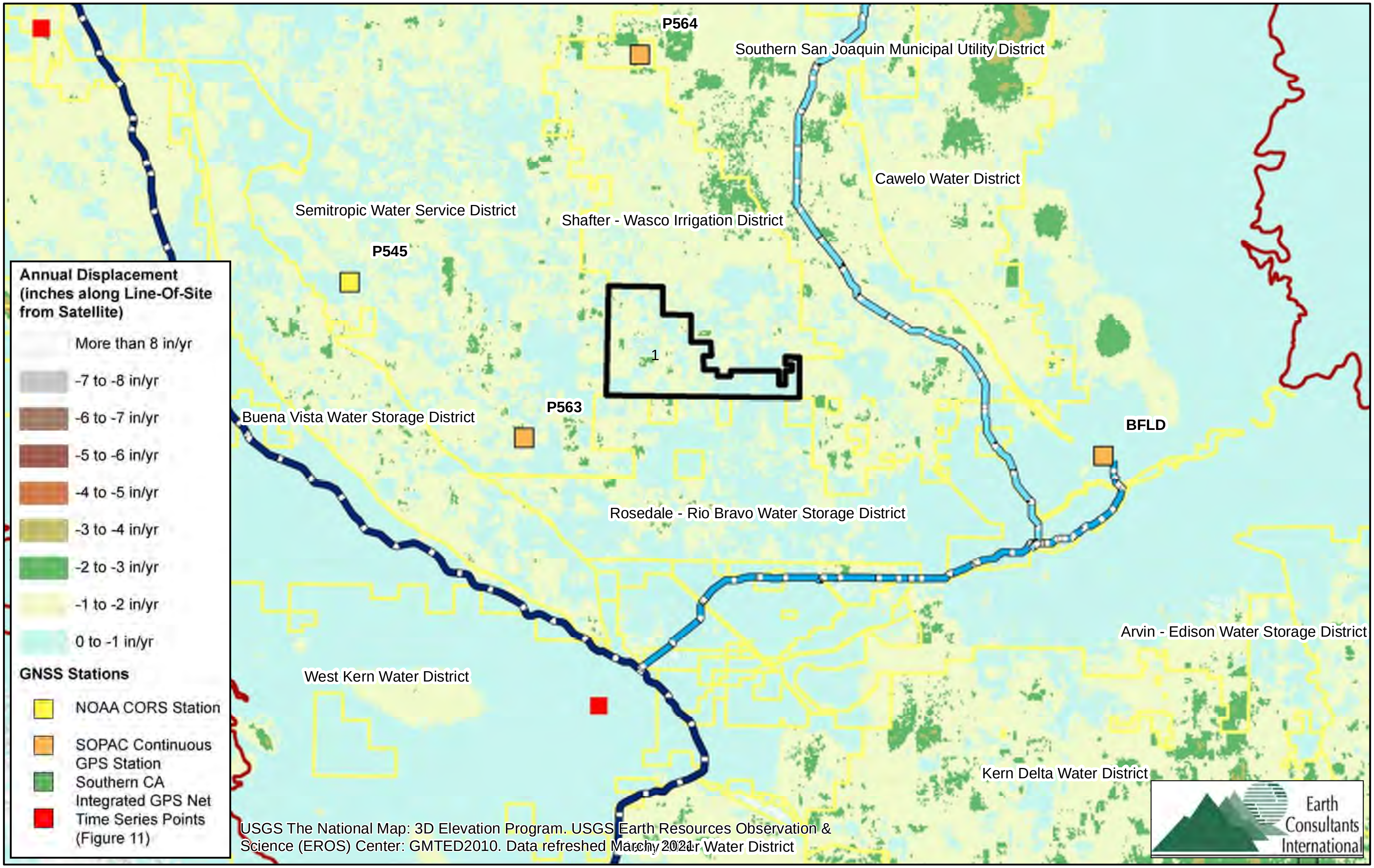
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Shafter-Wasco 7th Standard Annex

Date: 4/4/2021	Project #: 043-04	**Figure 28a**

DRAFT



Shafter-Wasco 7th Std. Annex Area (approx.)
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
Cross Valley Canal
California Aqueduct

0 5
Miles

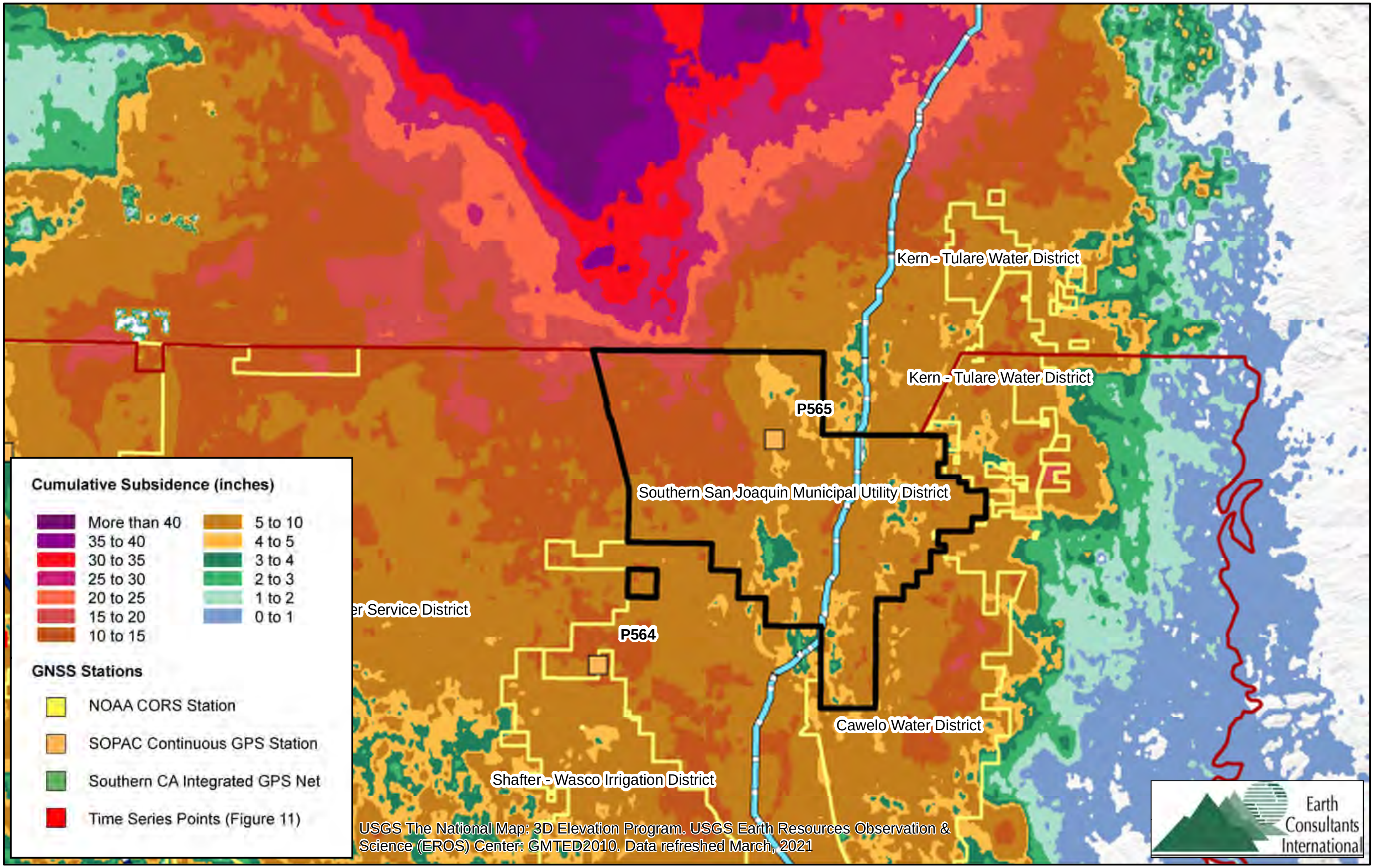
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Shafter-Wasco 7th Standard Annex

Date: 4/4/2021	Project #: 043-04	**Figure 28b**

DRAFT



Southern San Joaquin MUD
Neighboring Districts
Kern County Groundwater Sub-basin
Friant-Kern Canal
California Aqueduct

0 5
Miles

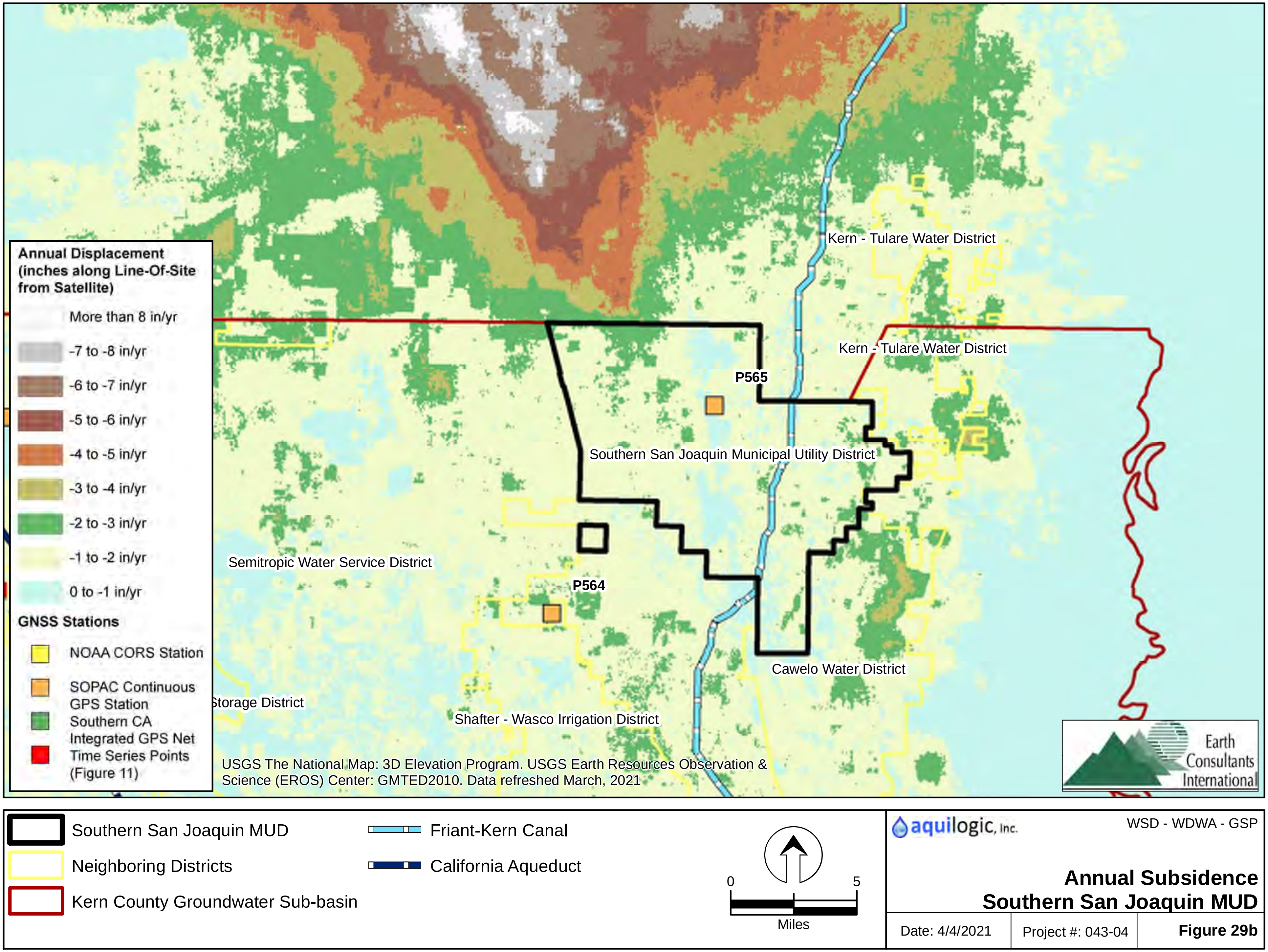
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Southern San Joaquin MUD

Date: 4/4/2021	Project #: 043-04	**Figure 29a**

DRAFT



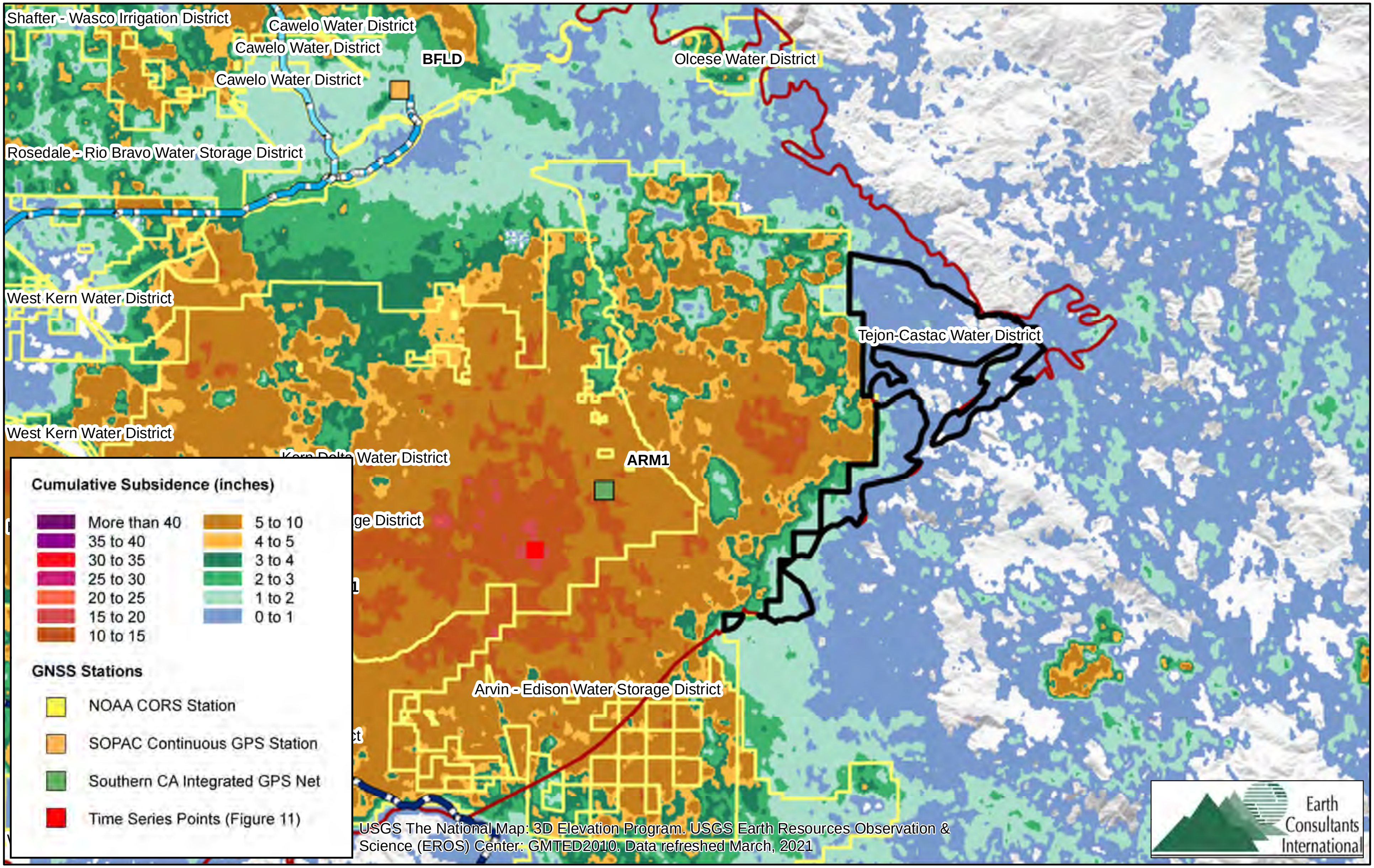
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Southern San Joaquin MUD

Date: 4/4/2021	Project #: 043-04	**Figure 29b**

DRAFT



Tejon-Castac Water District

Neighboring Districts

Kern County Groundwater Sub-basin

Friant-Kern Canal

Cross Valley Canal

California Aqueduct

0 5

Miles

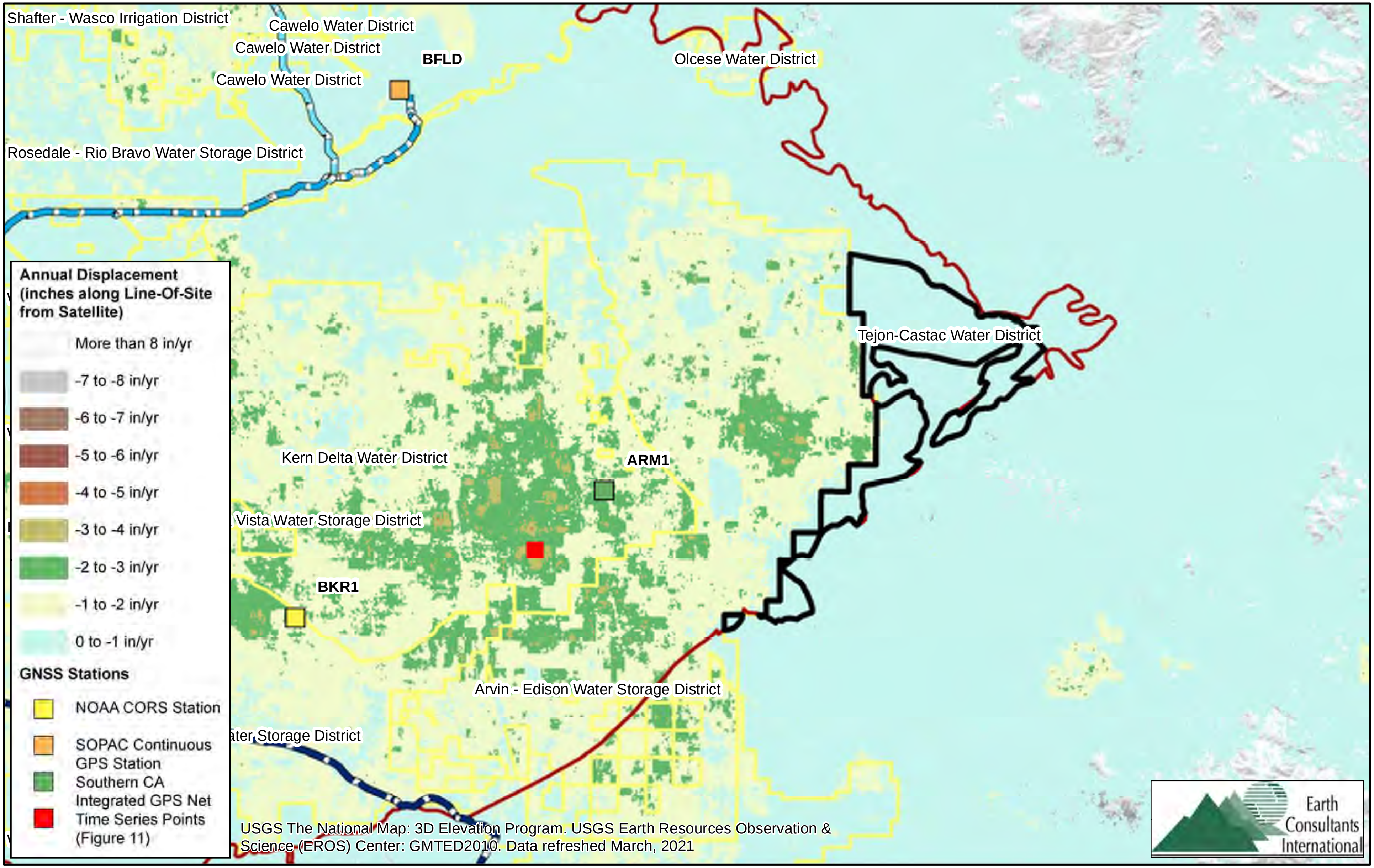
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Tejon-Castac Water District

Date: 4/4/2021	Project #: 043-04	**Figure 30a**

DRAFT



Tejon-Castac Water District

Neighboring Districts

Kern County Groundwater Sub-basin

Friant-Kern Canal

Cross Valley Canal

California Aqueduct

0 5

Miles

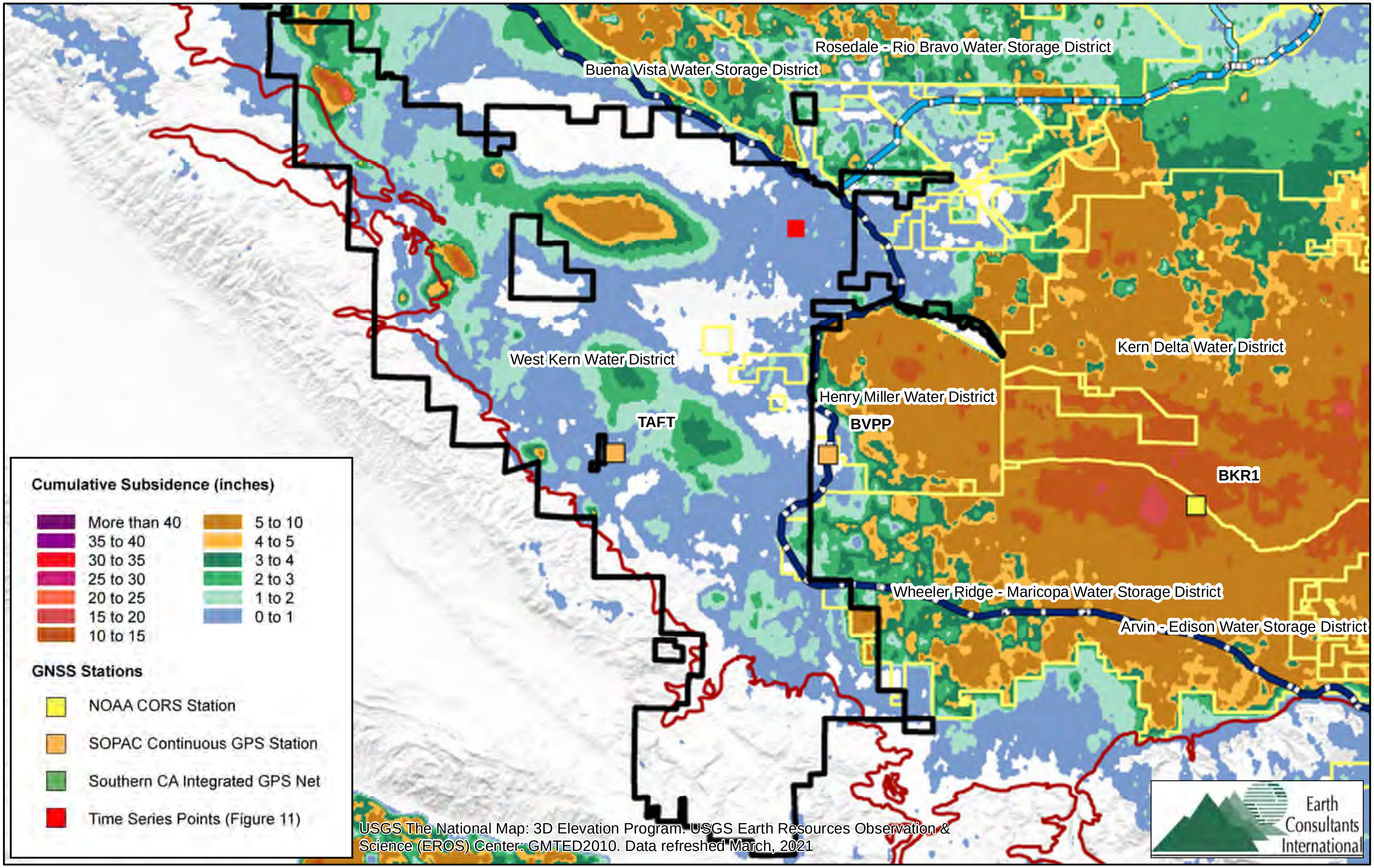
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Tejon-Castac Water District

Date: 4/4/2021	Project #: 043-04	**Figure 30b**

DRAFT



West Kern Water District
Neighboring Districts
Kern County Groundwater Sub-basin
California Aqueduct
Cross Valley Canal
Friant-Kern Canal

0 5
Miles

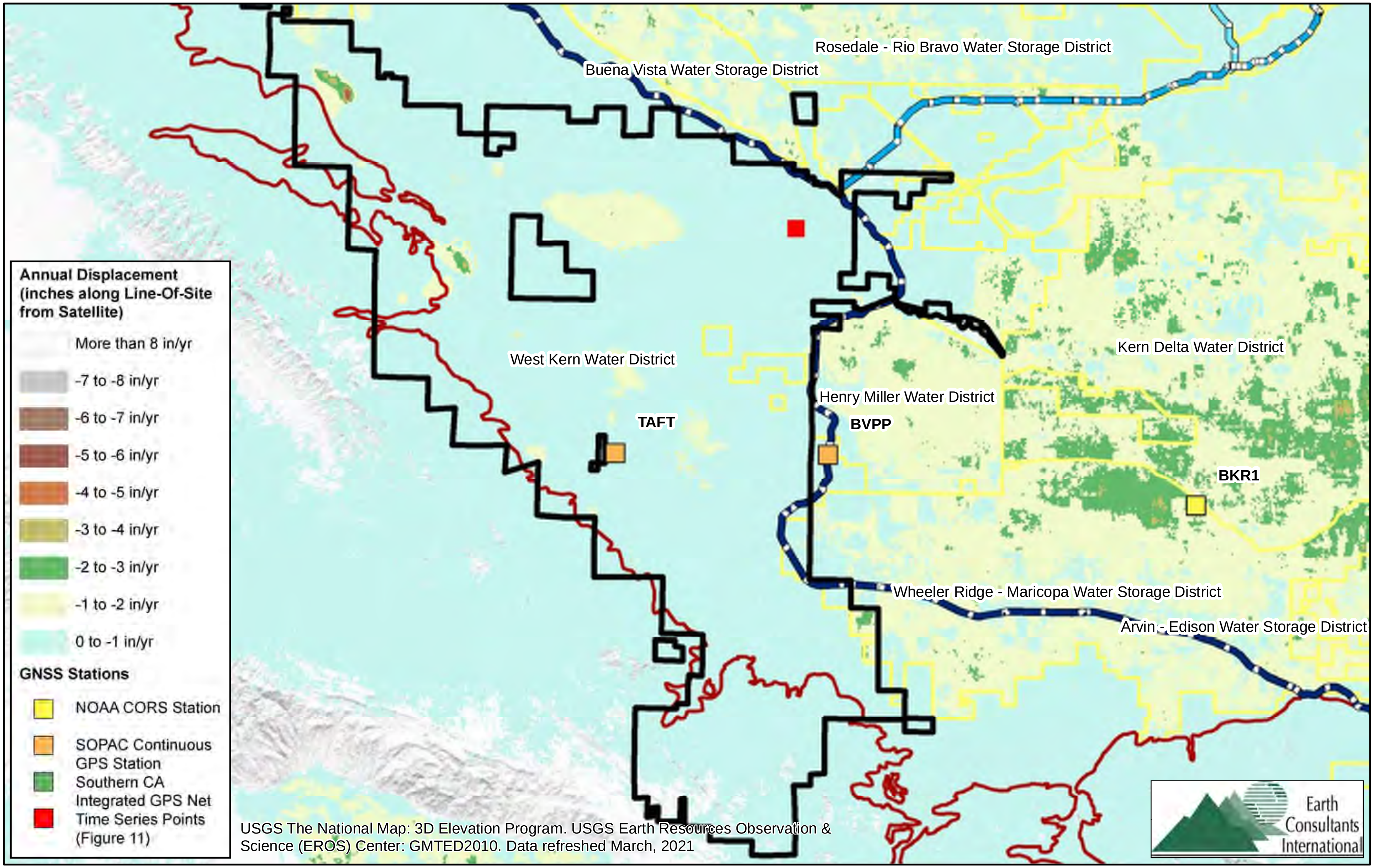
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
West Kern Water District

Date: 4/4/2021	Project #: 043-04	**Figure 31a**

DRAFT



West Kern Water District
Neighboring Districts
Kern County Groundwater Sub-basin
California Aqueduct
Cross Valley Canal
Friant-Kern Canal

0 5
Miles

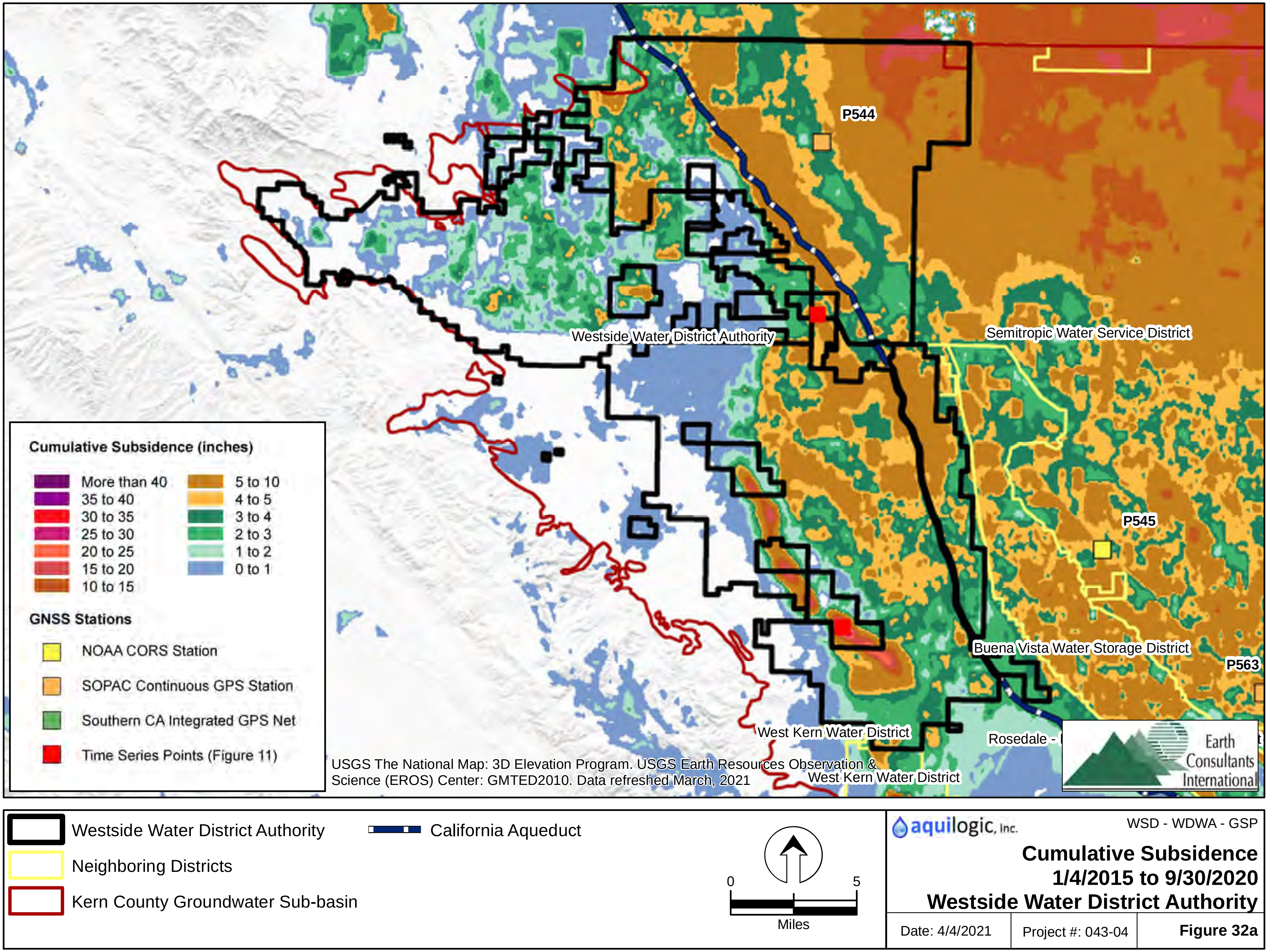
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
West Kern Water District

Date: 4/4/2021	Project #: 043-04	**Figure 31b**

DRAFT



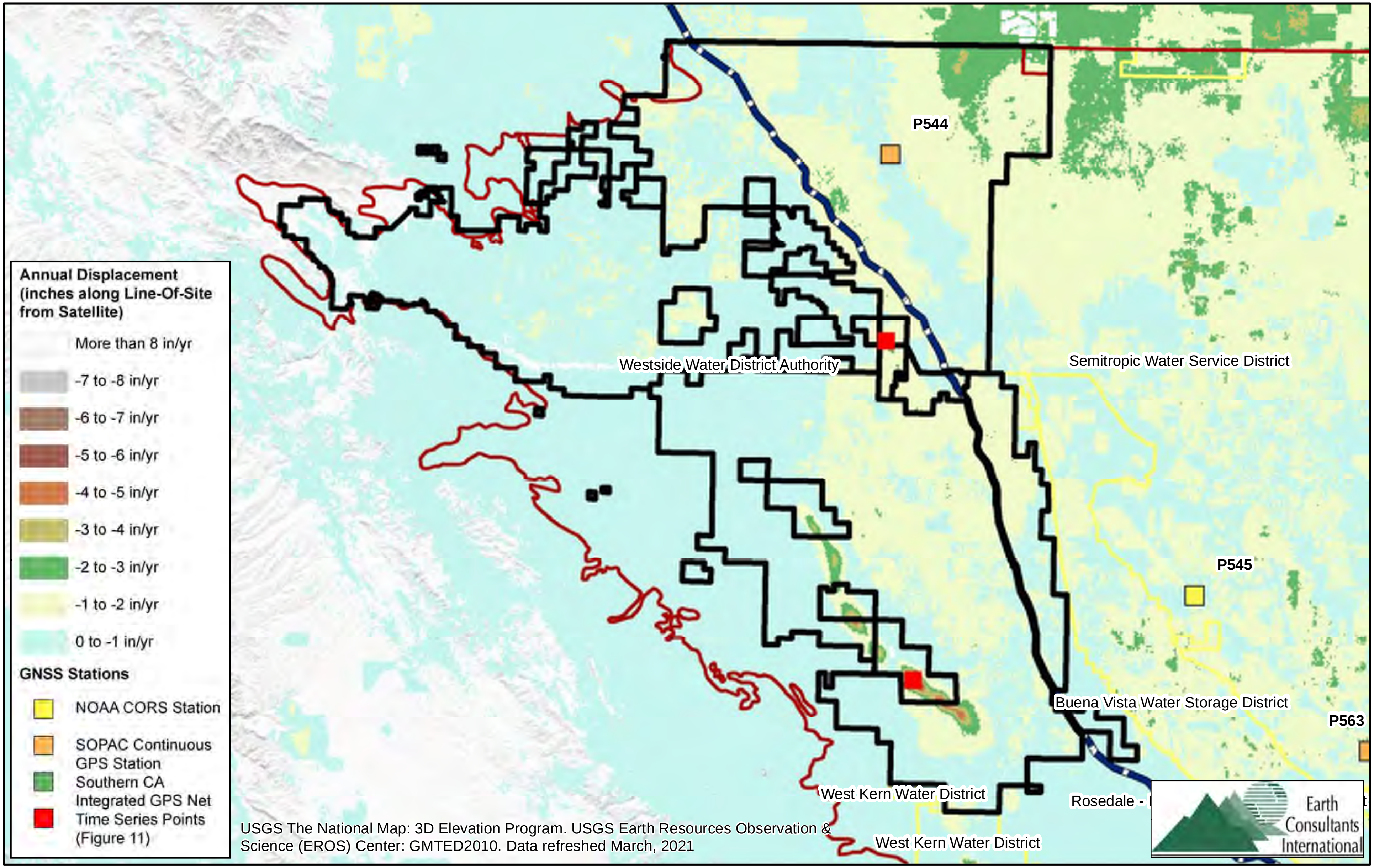
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Westside Water District Authority

Date: 4/4/2021	Project #: 043-04	**Figure 32a**

DRAFT



Westside Water District Authority

California Aqueduct

Neighboring Districts

Kern County Groundwater Sub-basin

0 5
Miles

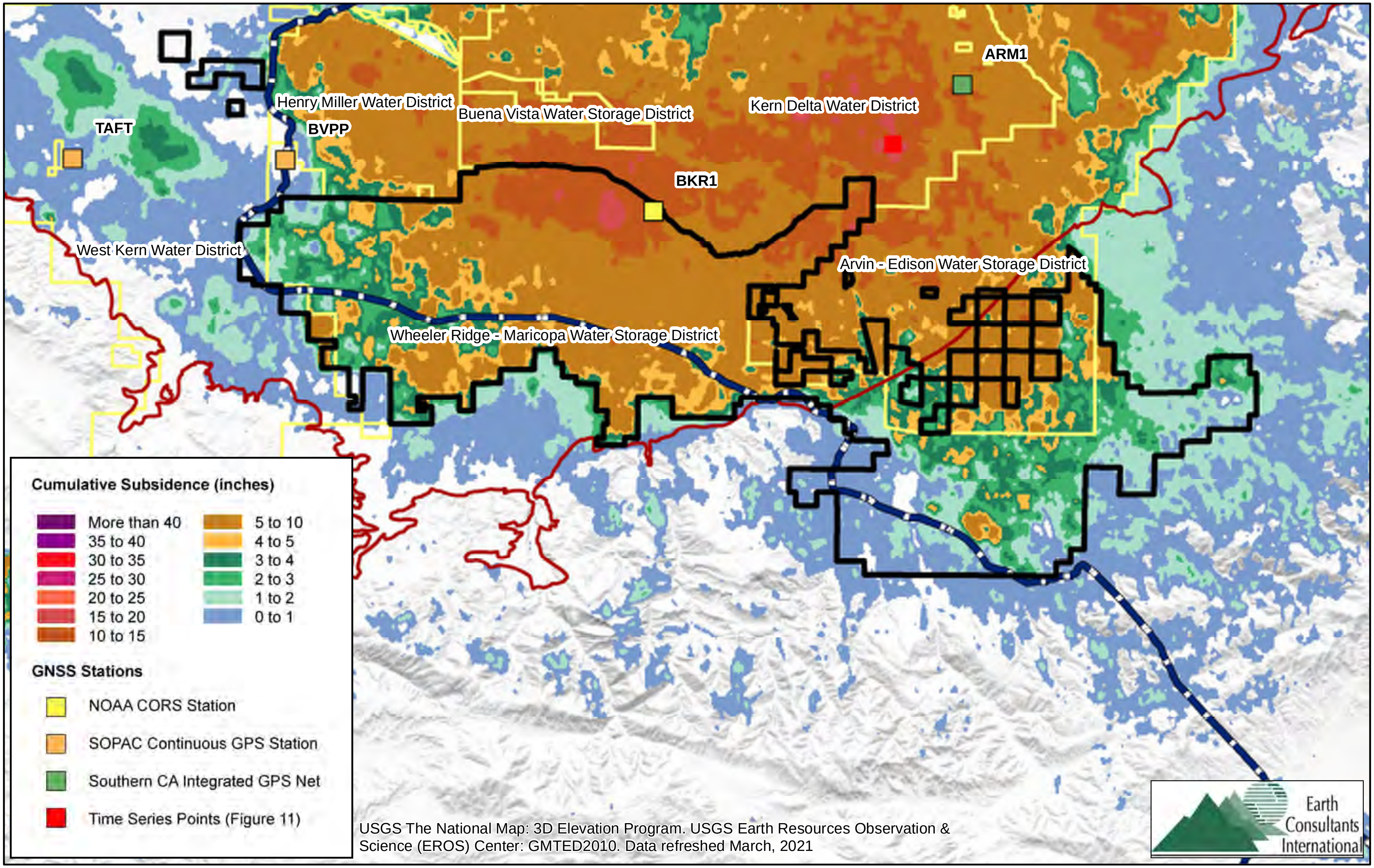
aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Westside Water District Authority

Date: 4/4/2021	Project #: 043-04	**Figure 32b**

DRAFT



Wheeler Ridge-Maricopa Water Storage District
California Aqueduct
Neighboring Districts
Kern County Groundwater Sub-basin

0 5
Miles

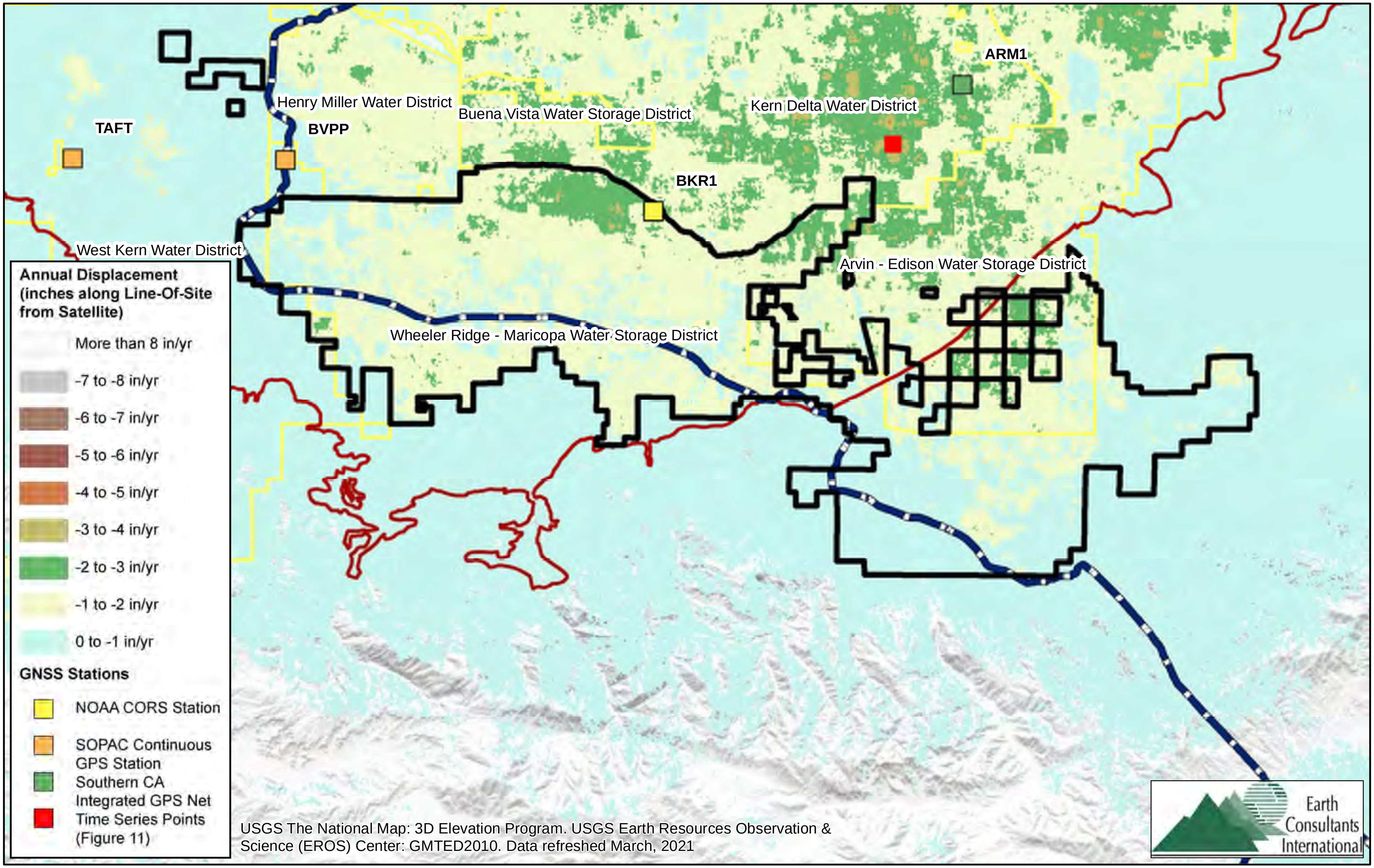
aquilogic, Inc.

WSD - WDWA - GSP

Cumulative Subsidence
1/4/2015 to 9/30/2020
Wheeler Ridge-Maricopa WSD

Date: 4/4/2021	Project #: 043-04	**Figure 33a**

DRAFT



Wheeler Ridge-Maricopa Water Storage District

California Aqueduct

Neighboring Districts

Kern County Groundwater Sub-basin

0 5
Miles

aquilogic, Inc.

WSD - WDWA - GSP

Annual Subsidence
Wheeler Ridge-Maricopa WSD

Date: 4/4/2021	Project #: 043-04	**Figure 33b**

DRAFT

APPENDIX A:
ADDITIONAL TECHNICAL INFORMATION REGARDING THE DINSAR AND STACKING METHODS.

APPENDIX A: ADDITIONAL TECHNICAL INFORMATION REGARDING THE DINSAR AND STACKING METHODS.

More In-Depth Description of the DInSAR Method as Used in This Study

DInSAR as utilized in this study is a satellite, airborne, radar-based system that generates high-resolution remote sensing imagery. The onboard signal processing system uses the magnitude and phase of the received signals over successive pulses from elements of a 'synthetic aperture' to create an image consisting of pixels containing both the phase and amplitude information. The distance the SAR device travels over a target in the time taken for the radar pulses to return to the antenna creates the large "synthetic" antenna aperture (the "size" of the antenna). Typically, the larger the aperture, the higher the image resolution will be, regardless of whether the aperture is physical (a large antenna) or 'synthetic' (a moving antenna). This allows SAR to create high-resolution images with the comparatively small antennas that fit onboard a satellite or aircraft.

The phase information of each image pixel represents the complex vector sum of the radar echoes from all scattering elements within a corresponding resolution cell on the ground, covering an area of approximately 20 x 5 meters for the ERS-1, -2 and Envisat satellites. Other satellites may have different resolution cell sizes, but the final pixel size is usually resampled to a square shape of 20 to 50 meters regardless of the size of the original cells.

The return phase of the signal from each scattering center has its phase determined by the two-way range to the satellite and this will typically vary by several hundred wavelengths (ERS-1, -2, Envisat, Sentinel-1A and 1B etc. 56.66 mm) across a typical resolution cell. The phase of an image pixel by itself is thus a random and not very meaningful parameter. There is, however, a correlation between the phase information in corresponding pixels in scenes covering the same area, and any movements that have occurred between the acquisitions of the scenes will be represented by a phase shift. For this assumption to be valid the satellite needs to be located very precisely over the target area and any difference in the repeat orbits will introduce phase shifts that need to be removed mathematically.

Depending on the intended use of the interferograms, detecting ground movements or generating Digital Elevation Models (DEMs), the maximum allowable offsets in the orbits differ. For DEM generation, a maximum value of the perpendicular offset (offset between orbits) is around 1100 m, whereas values of less than 250 m are needed to measure surface deformation. A high degree of control over the orbits of the satellites is also imperative if the SAR images are to be used for interferometric purposes. In addition to problems with phase shift introduced by offsets in the orbits, other problems will also occur. Examples are loss of coherence caused by differences in the viewing geometry, and ambiguities caused by the relief giving false signals in the interferogram. There are also other factors that may reduce or even totally compromise the quality of the DInSAR results. The most important one is related to temporal decorrelation phenomena caused by the variation of the electromagnetic properties of the radar targets. If the phase reflectivity value of a certain image pixel changes with time, the generation of an interferogram, i.e. the computation of the difference between the phase values of two SAR images; cannot highlight the displacement values. The impact of temporal decorrelation phenomena increases as the temporal baseline of the interferogram (i.e. the time lag between the two SAR acquisitions) increases. Apart from phase decorrelation, propagation effects in both the troposphere and the ionosphere can differ significantly during the first and the second acquisition, thus creating phase disturbances that at best will hinder the interpretation of SAR interferograms, or at worst, completely prevent the processing of the satellite data. Given all these potential issues, only a small number of the available archived scenes are suitable for the generation of interferograms. In general, it can also be said that the availability varies between the ages of the different satellite systems, with more modern systems having greater reliability. This is mostly the result of better control of the orbits of the satellites, but also because of developments that have given the onboard signal processing systems and computers better capabilities.

The interference pattern is a function of the geometries of the orbits as well as the topography of the target area. By analyzing the interference patterns, and knowing the precise orbits, the topography can be calculated and, if the topography also is known, any changes in the topography can be calculated from the interferogram by removing the topographic effects utilizing an existing DEM. The difference in phase between the SAR images is usually represented by color bands in such a way that a movement corresponding to half the wavelength of the radar is shown as a complete color cycle in a color band.

Apart from phase information, the quality of the correlation, (the 'coherence') between two SAR images can also be determined. Such coherence values are related to the nature of the ground surface. Any chaotic movements of the scatterers in the target area between the acquisitions will cause the coherence to be low. Open water and active agricultural areas are usually totally decorrelated, whereas urban areas and areas free of vegetation are more likely to have a high coherence over extended periods of time. Low coherence makes it impossible to calculate the phase shift, and thus a high degree of coherence is imperative in the areas of interest. Processing the raw SAR data to create interferograms is a multi-step operation involving Fourier transforms to extract the radar echoes, and other complex mathematics. The technical details of these procedures are beyond the scope of this report, but are described in detail in Lanari et al. (2004), and Hu et al., (2016).

Although several InSAR processing packages are available, we chose GMTSAR, which was developed by the Scripps Institution of Oceanography and the University of Hawaii. There are two reasons for choosing GMTSAR over other available software packages. First, the software is in the public domain and free to use by anyone without restrictions, as it is currently released as open source under the GNU General Public License. Second, when the European Space Agency opened their archives of ERS satellite data for general use in early April 2017, we found that they had changed the data format and virtually no other commercially available software was capable to read the new format. The open nature of GMTSAR allowed us to write a new pre-processor for the new file format, allowing us to process the data successfully.

The software can be divided into three parts:

a. A *pre-processor* responsible for importing and converting satellite data (ERS-1/2, ENVISAT, ALOS-1, TerraSAR-X, COSMOS-SkyMed, Radarsat-2, Sentinel-1A/B, and ALOS-2) to the internal native format used by GMTSAR.
b. *The InSAR processor*, which focuses and aligns stacks of images, maps topography into phase, and forms the complex interferograms.
c. The *post-processor*, which filters the interferograms and constructs interferometric products of phase, coherence, phase gradient, and line-of sight displacement in both radar and geographic coordinates.
d. The Short Baseline Subset (SBAS) processor which stacks the interferograms, removes atmospheric interference and calculates displacement rates (mm/year) using the least-squares method for linear regression.

As described above, the interferograms produced by subtracting phase data from separate radar images result in an image where every pixel describes the displacement that has occurred between the acquisitions of the images. However, the detected displacement will also contain an error of unknown magnitude due to atmospheric interference, which means that any deformation along line-of-sight only can be taken as an approximation for a single interferogram. The SBAS algorithm uses a number of interferograms (>3) and applies a least squares curve fitting on every corresponding pixel in the included interferograms to create an image where the pixels represent the velocity in millimeters per year that best fits any displacement that occurs over time. In addition, the software also outputs "synthetic" interferograms with the cumulative displacement that has occurred between the acquisitions of the radar images. It is also creating maps showing the residuals between the expected and measured displacements. A small residual means that there is a good fit between the model for the displacement and the interferometrically detected displacement of the same pixel.

References

Hu, J., Ding, X.L., Lia, Z.W., Zhang, L., Zhu, J.J., Sun, Q., and Gao, G.J., 2016, Vertical and horizontal displacements of Los Angeles from InSAR and GPS time series analysis: Resolving tectonic and anthropogenic motions: *Journal of Geodynamics*, Vol. 99, Sept 2016, pp. 27-38.

Lanari R., Lundgren P., Mariarosaria M., and Casu, F., 2004, Satellite radar interferometry time-series analysis of surface deformation for Los Angeles, California: *Geophysical Research Letters,* Vol. 31, No. 23, 16 Dec., 2004, 5p.

APPENDIX B:
Listing of Analyzed Radar Images.

Full listing of the downloaded Sentinel-1 SAR data files
The following 172 data files were downloaded from the Alaska Satellite Facility (ASF) for processing. Due to the target being located on the border between two satellite images, two neighboring images located along track had to be downloaded and merged for every acquisition date, resulting in 86 images that were processed with GMTSAR.

S1B_IW_SLC__1SDV_20190504T015752_20190504T015820_016088_01E434_6042.zip
S1B_IW_SLC__1SDV_20190504T015818_20190504T015845_016088_01E434_ADD1.zip
S1A_IW_SLC__1SDV_20190510T015829_20190510T015856_027159_030FBB_8DD7.zip
S1A_IW_SLC__1SDV_20190510T015854_20190510T015921_027159_030FBB_6B86.zip
S1B_IW_SLC__1SDV_20190516T015753_20190516T015821_016263_01E9BA_05BF.zip
S1B_IW_SLC__1SDV_20190516T015819_20190516T015846_016263_01E9BA_D0E5.zip
S1A_IW_SLC__1SDV_20190522T015829_20190522T015857_027334_031536_8DDC.zip
S1A_IW_SLC__1SDV_20190522T015855_20190522T015922_027334_031536_6D0B.zip
S1B_IW_SLC__1SDV_20190528T015754_20190528T015821_016438_01EF17_2F06.zip
S1B_IW_SLC__1SDV_20190528T015819_20190528T015846_016438_01EF17_38B0.zip
S1A_IW_SLC__1SDV_20190603T015830_20190603T015858_027509_031AA4_EE58.zip
S1A_IW_SLC__1SDV_20190603T015856_20190603T015923_027509_031AA4_869C.zip
S1B_IW_SLC__1SDV_20190609T015754_20190609T015822_016613_01F44E_9A7C.zip
S1B_IW_SLC__1SDV_20190609T015820_20190609T015847_016613_01F44E_33A9.zip
S1A_IW_SLC__1SDV_20190615T015830_20190615T015858_027684_031FEF_A71B.zip
S1A_IW_SLC__1SDV_20190615T015856_20190615T015923_027684_031FEF_3470.zip
S1B_IW_SLC__1SDV_20190621T015755_20190621T015823_016788_01F984_B9D1.zip
S1B_IW_SLC__1SDV_20190621T015821_20190621T015848_016788_01F984_0FCE.zip
S1A_IW_SLC__1SDV_20190627T015831_20190627T015859_027859_032528_FFEC.zip
S1A_IW_SLC__1SDV_20190627T015857_20190627T015924_027859_032528_D24D.zip
S1B_IW_SLC__1SDV_20190703T015756_20190703T015824_016963_01FEAF_7691.zip
S1B_IW_SLC__1SDV_20190703T015821_20190703T015848_016963_01FEAF_0A5E.zip
S1A_IW_SLC__1SDV_20190709T015832_20190709T015900_028034_032A7D_B0BE.zip
S1A_IW_SLC__1SDV_20190709T015858_20190709T015925_028034_032A7D_C8D6.zip
S1B_IW_SLC__1SDV_20190715T015756_20190715T015824_017138_0203D9_B96D.zip
S1B_IW_SLC__1SDV_20190715T015822_20190715T015849_017138_0203D9_5273.zip
S1A_IW_SLC__1SDV_20190721T015833_20190721T015901_028209_032FC2_1C5D.zip
S1A_IW_SLC__1SDV_20190721T015859_20190721T015926_028209_032FC2_2A34.zip
S1B_IW_SLC__1SDV_20190727T015757_20190727T015825_017313_0208EF_2BA1.zip
S1B_IW_SLC__1SDV_20190727T015823_20190727T015850_017313_0208EF_234F.zip
S1A_IW_SLC__1SDV_20190802T015834_20190802T015901_028384_033517_4B19.zip
S1A_IW_SLC__1SDV_20190802T015859_20190802T015926_028384_033517_BBDA.zip
S1B_IW_SLC__1SDV_20190808T015758_20190808T015826_017488_020E36_EF0C.zip
S1B_IW_SLC__1SDV_20190808T015824_20190808T015851_017488_020E36_5F8C.zip
S1B_IW_SLC__1SDV_20190820T015759_20190820T015826_017663_0213AD_41B2.zip
S1B_IW_SLC__1SDV_20190820T015824_20190820T015851_017663_0213AD_8E10.zip
S1A_IW_SLC__1SDV_20190826T015835_20190826T015903_028734_0340DA_57FB.zip

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Attachment E2

Lawrence Berkely National Laboratory Subsidence Study

To:

Ms. Particia Poire

Executive Director

Kern Ground Water Authority

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Bakersfield, CA 93301

From:

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Below is my report on the rate of subsidence in the Kern County Subbasin and in four sub-domains within the subbasin. Estimates of the subsidence rates were made for both an extended time period from 2015 to 2021, and for the particular year 2020. Efforts were made to highlight the temporal and spatial variations in the rates and to distinguish rate variations between the various sub-domains.

Introduction

Background and Purpose

This study was undertaken in order to determine the baseline rate of subsidence in the Kern County Subbasin for the study period and the year 2020. Study data was also compared to The March 2021 Differential Interferometric Synthetic Aperture Radar (DInSAR) Study conducted by Earth Consultants International (ECI) on behalf of the Kern Groundwater Authority (KGA) and other Groundwater Sustainability Agencies (GSAs) in the Kern County Subbasin (KCS).

For comparison, and to understand yearly variations, the cumulative line-of-sight displacement and the yearly displacement rates were determined for a roughly seven-year interval extending from early 2015 until late 2021. These values will be used in a follow-on study to better assess the vulnerability of critical infrastructure within the subbasin. These include, but are not limited to, gravity-driven surface water delivery systems, of which the primary regional conveyance structures are the California Aqueduct (Aqueduct) and the Friant-Kernel Canal (FKC). In order to better understand the long-term viability of these important structures, we will estimate the

Figure 1. Outline of the Kern County Subbasin and the four sub-areas used in the analysis. The color variations indicate subsidence within the subbasin.

maximum, minimum, and mean rate of subsidence for the KCS. Due to varying processes within the sub-basin, which include groundwater pumping for agricultural, industrial, and oil and gas extraction, the basin will be further sub-divided into eastern, western, southern, and central regions and the maximum, minimum, and mean subsidence will be computed for each area (Figure 1).

The west region of the KCS is distinguished by extensive areas of open range land and oil field operations interspersed with cultivated lands. Much of the Westside has no significant current or planned groundwater use because of naturally poor water quality due to the presence of marine sediments and saline connate water. As such, surface water delieveries from the State Water Project via the Aqueduct are a primary source of water for agriculture. Signficant volumes of oil field produced water are genrated in the west region. Produced water is a by-product of oil production common to almost all oil fields in the KCS. Produced water is exempt from the Sustainable Groundwater Managment Act (SGMA), and therefore outside of the control of the KGA or other GSAs in the KCS.

The southern region is charcterized by a mixture land uses including agriculture, urban development and oil field operations. SGMA related groundwater extractions include industrial, municipal and agriculture. The southern region also recieves surface water delivered by the Aqueduct.

The eastern region is bounded by the FKC on the west and the foothills of the Sierra-Nevada Range on the east. It encompasses both agiculture use and oil field activities. Groundwater quality is generally good in this area, and is utilized for various SGMA related purposes (e.g., municipal, agriculture, industry). Deleveries of surface water via the FKC is a primary source of water for agriculture, although not all growers have access to FKC water.

The central region of the KCS is charterized by widespread agricultural activety, interspersed with municipal and industrial uses. Scattered oilfield operations are also present. The central region is particularly susceptable to land subsidence caused by groundwater extraction. This is due to the presence of extensive and layers of clay (e.g. Corcoran Clay) and other fine grained sediments in the subsurface. The sources of water include groundwater, and surface water deliveries from the Aqueduct and FKC.

The estimates are derived from line-of-sight displacements calculated using satellite-based synthetic aperture radar (SAR) phase changes, as outlined in the following section. The raw SAR data are publicly available and provided free of charge by the European Space Agency (ESA), but, as noted below, sophisticated processing algorithms are required in order to convert the phase changes within the raw data into displacements in the look direction of the satellite (Ferretti 2014). These estimates are useful in monitoring water usage and have been applied in the Central Valley (Vasco et al. 2019).

Interferometric Synthetic Aperture Radar

Interferometric Synthetic Aperture Radar (InSAR) has become the geodetic method of choice for monitoring deformation associated with fluid extraction. In fact, some of the earliest applications of InSAR were

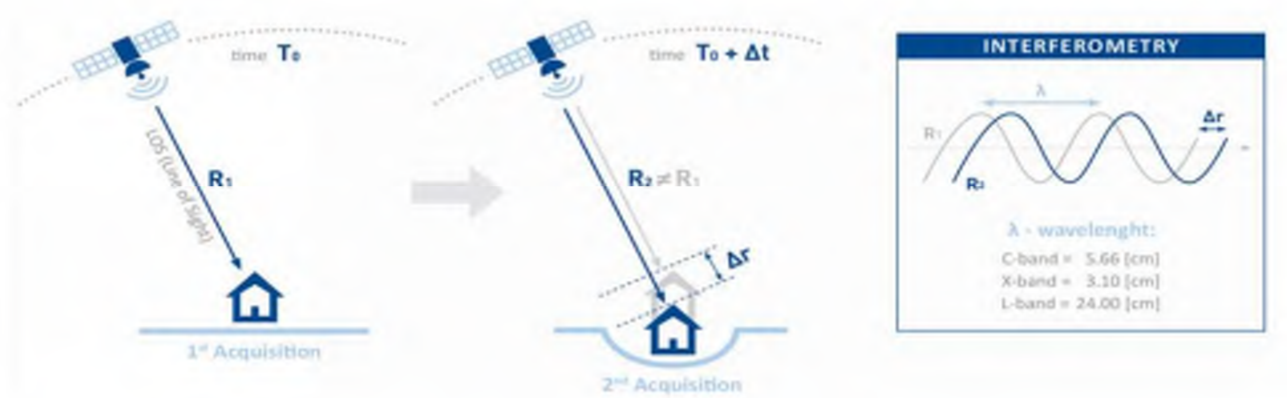

Figure 2. Principles underlying Interferometric Synthetic Aperture Radar (InSAR). Acquisitions at different times provide time series of microwave reflections from points on the Earth. If the surface characteristics do not change substantially, the phase shifts between the time series can be related to the change in line length, the range.

observations related to subsidence due to geothermal production (Massonnet et al. 1997, Carnec and Fabriol 1999). The characteristics that contribute to its appeal for long-term monitoring over large areas are the fact that it is a remote sensing technique, usually satellite-based, it samples areas with high spatial resolution, and satellite revisit times are months to weeks and even days. While the technology and processing associated with estimates of surface deformation are sophisticated (Gabriel et al. 1989, Massonnet and Feigl 1998, Bürgmann and Thatcher 2013, Ferretti 2014), the underlying principle is similar to that of echo location (Figure 2).

A microwave chirp from an orbiting satellite propagates to the Earth's surface where it is reflected from various scattering points and the return is stored for later use. Several stages of processing result in very accurate estimates of changes in the effective signal phase for points on the surface of the Earth (Ferretti 2014). These interferograms that are then mapped into range change, the movement of the object in the line-of-sight direction (Figure 6). Thus, the three-dimensional displacements are projected onto the direction in which the satellite is 'looking'. Typically, the satellite looks down from a nearly vertical position and the displacement is assumed to be mostly due to vertical displacement. As might be imagined, changes in the characteristics of the Earth's surface between satellite passes can have a pronounced effect on the estimates of range change. Extensive vegetation, snow cover, and wind-blown sand are some of the more common issues, particularly for the shorter wavelength C-band InSAR data. However, processing technology has advanced and improved satellite hardware and orbital configurations, including shortened return time of 6 days, have helped to overcome or mitigate many of these problems (Lanari et al. 2004, Hooper 2008, Ferretti et al. 2011, Samsonov and d'Oreye 2012).

European Space Agency Sentinel Satellite Observations

The data used in this study were gathered by the European Space Agency's Sentinel 1-2 satellite C-band system, using data from 216 orbits, spanning a time interval from early 2015 until late in 2021. The time interval between

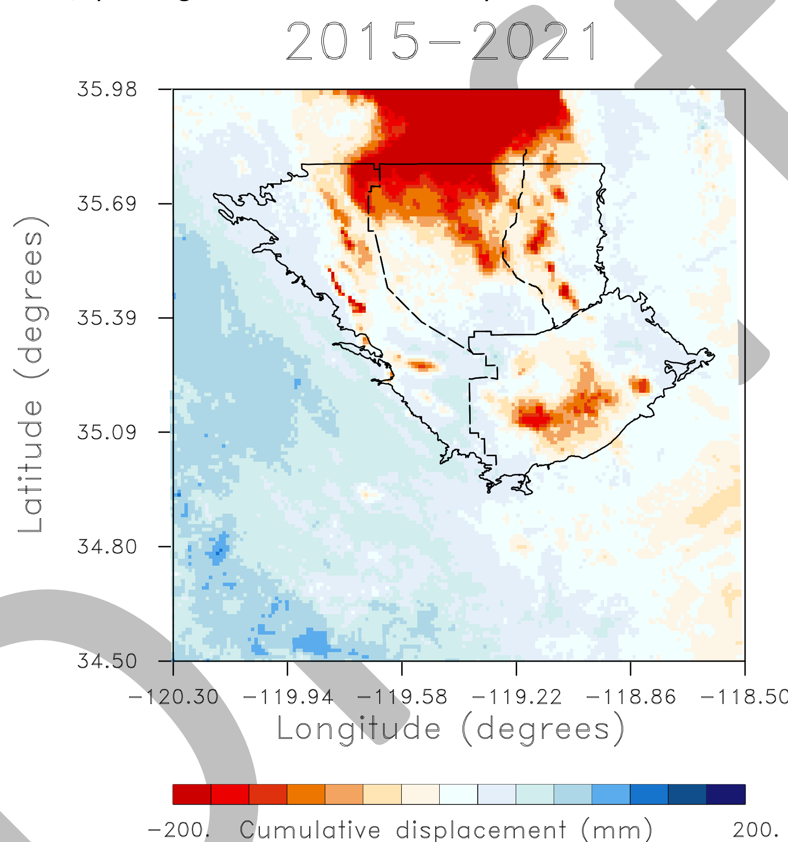

Figure 3. Cumulative displacements between 2015 and 2021 in milli-meters. The displacements were obtained from the ESA's Sentinel 1 and 2 SAR satellites. The red colour denotes downward line-of-sight displacement, typically due to subsidence, while the blues indicate upward movement. The four areas denoted in Figure 1 are superimposed on the map of displacements (dashed lines) as is the outline of the Kern County subbasin (solid line).

satellite passes varied during this time period, starting at 12-day orbits during the first few years and transitioning to shorter 6 day returns after a reconfiguration in 2018. The shorter orbital intervals improved the accuracy of the estimates and mitigated the effects of vegetation changes due to agriculture, improving spatial coherence. An example of the cumulative displacement from 2015 until 2021, the entire time interval under consideration is plotted in Figure 3, with the four area boundaries superimposed upon the line-of-sight displacement field. The displacements indicate mostly subsidence for the entire interval. The large and widespread subsidence to the north of the KCS and mainly in the central area is due to agricultural water withdrawal. Smaller scale subsidence in the western and eastern areas is primarily due to oil and gas extraction and is of a different character from the agricultural-related subsidence both spatially and temporally. This difference is the reason that we chose to sub-divide the subbasin into four distinct area in order to distinguish the differing subsidence rates.

Displacement Rates

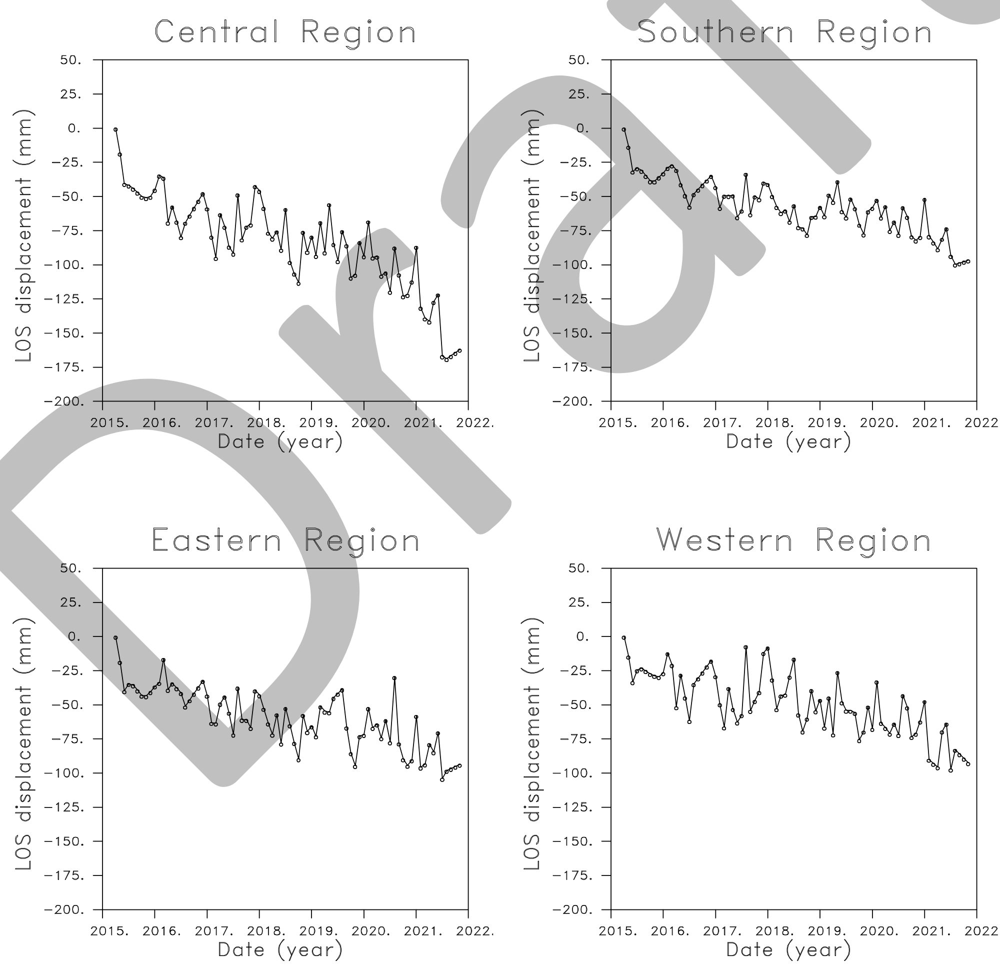

Figure 4. Cumulative monthly displacements for the four regions denoted in Figure 1. The cumulative displacement for each month was obtained by interpolating the full set of InSAR time series.

The displacement rates were computed from the Sentinel observations of cumulative displacements. For the purposes of interpretation, the displacements were interpolated onto monthly changes, as shown in Figure 4. Clearly, the central region has the most significant cumulative displacement, in agreement with the plot of spatially-varying displacement (Figure 3). The long-term trends in the different regions vary as functions of time, leveling off between 2016 and 2020 for most regions, due to the end of the drought. Interesting the exact date at which the average slope changes differs in each region. In order to smooth out the fluctuations and to compute uncertainties, the cumulative displacements were averaged over a moving window with a half-width of 5 months (Figure 5).

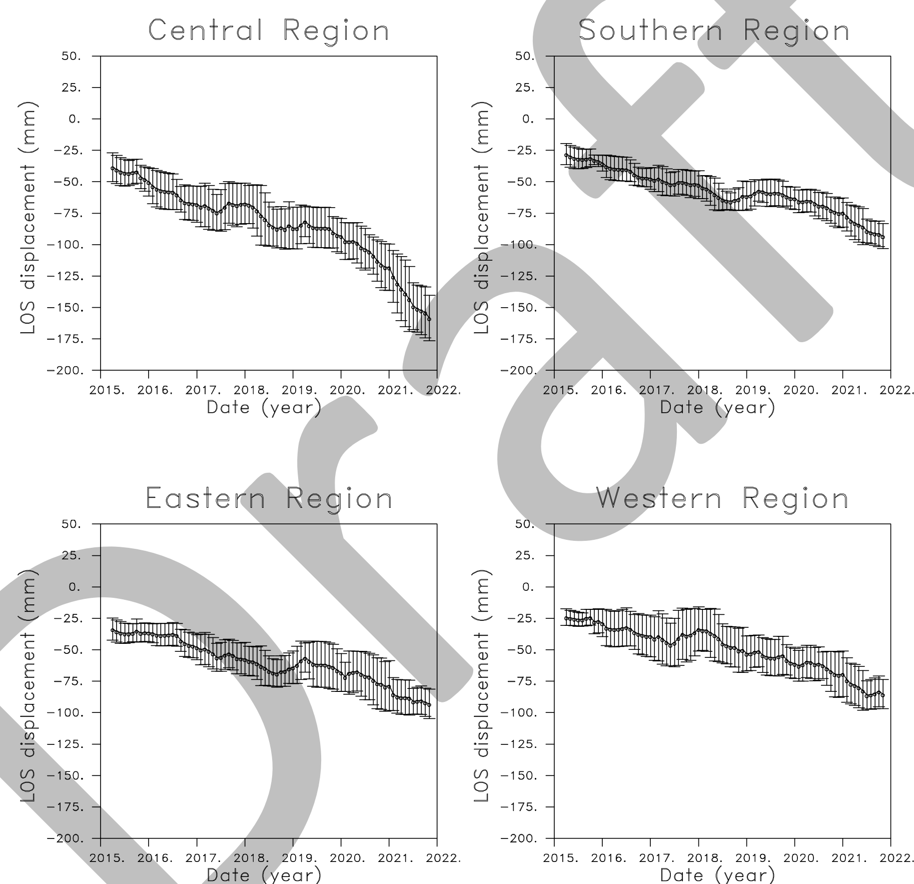

Figure 5. Mean displacements obtained by averaging over a moving window with a half-length of 5 months. The error bars denote one standard error.

The general features of the east, west, and southern region seem to exhibit subsidence at a constant rate (slope) until the wet years where the relative displacement is upward (i.e., component of elastic rebound), followed by continued subsidence at almost the same slope. Contributing factors to this trend could be proximity to areas of natural recharge (i.e., mountain fronts), availability of surface water, and land use variety. For the central region, which is predominately agriculture use and distal to areas of natural recharge, we see an initial constant rate of subsidence, with a 'bump' in 2017 and a flattening in 2018, followed by a steepening dip indicating an increasing rate of subsidence. Interestingly, the change in slope in the southern, eastern, and western regions occurs at different times for each of the regions. In the south and east it occurs in 2018, while in the western region, which is bounded by mountain front recharge, and has a low rate of groundwater extraction for SGMA related uses, it occurs in 2017. From Figure 3 it is clear that the central region and a localized area in the northeast of the western region are impacted by a higher rate of annual subsidence due to agricultural usage of groundwater,

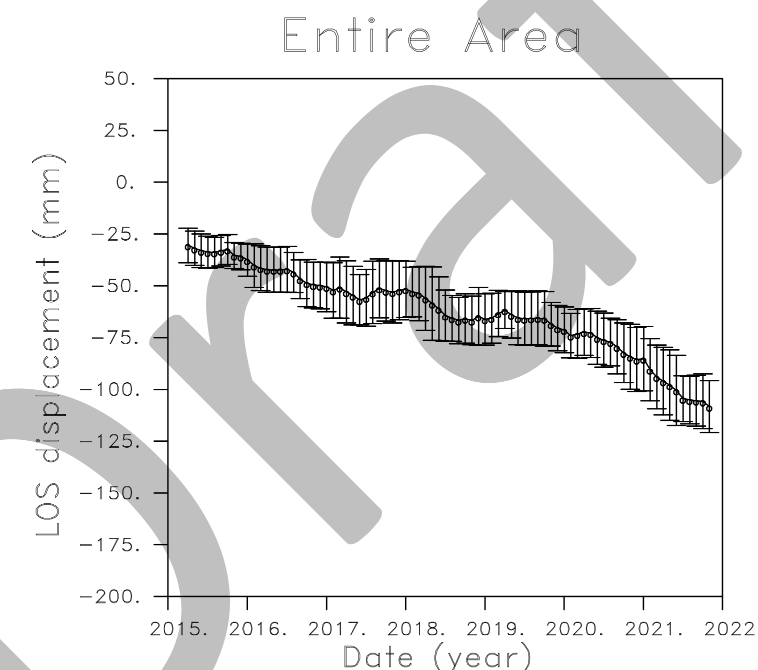

Figure 6. Mean line-of-sight displacements for the entire subbasin. The error bars indicate one standard error.

visible in the northern edge of the figure. The locus of this subsidence is north of the KCS. The rebound in 2017 may be due to the curtailment of groundwater pumping in the groundwater basin to the north of the KCS as the irrigation may have switched to available surface sources. The eastern and southern areas do not extend significantly into the subsidence bowl and hence might not see any major effects from the cessation of pumping from the concentrations of wells to the north, within the subsidence bowl.

The mean line-of-sight displacement for the entire subbasin is plotted in Figure 6. The time variation appears to contain features of all of the curves in Figure 5. That is, it has a rebound in early 2017, flattening in 2018, and a steepening dip from 2020 onward concomitant with drought and the decrease in state surface water deliveries throughout the KCS.

The yearly rates are obtained by calculating the yearly displacement from the cumulative displacements shown in Figures 5 and 6. In Figure 7 we plot the yearly rates as a function of time for the four regions that comprise the Kern County subbasin.

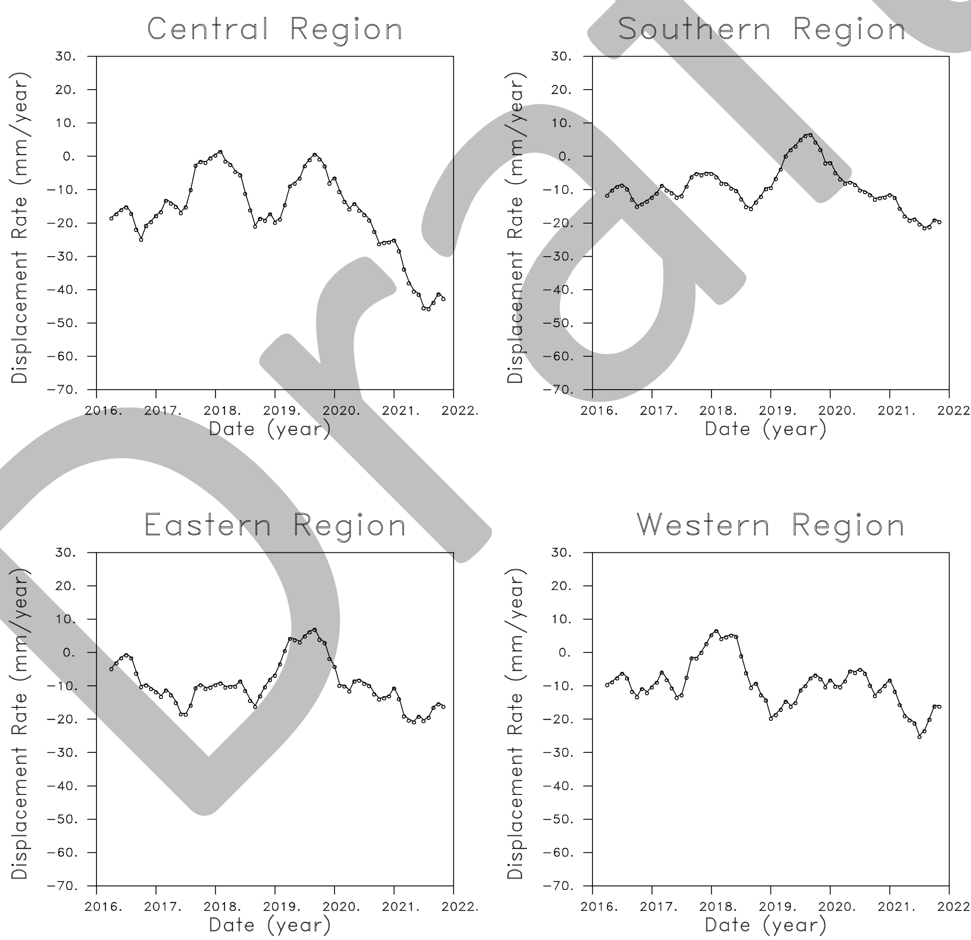

Figure 7. Yearly rates in milli-meters/year for the four sub-domains of the Kern County subbasin. Negative values indicate subsidence, positive values correspond to uplift.

For the central region there appears to be a baseline subsidence rate of -2.0 cm/year (-0.78 inch/year) up to 2019, with a decrease in rate to around 0.0 at the end of 2017 and into 2018, the ‘bump’ that was previously

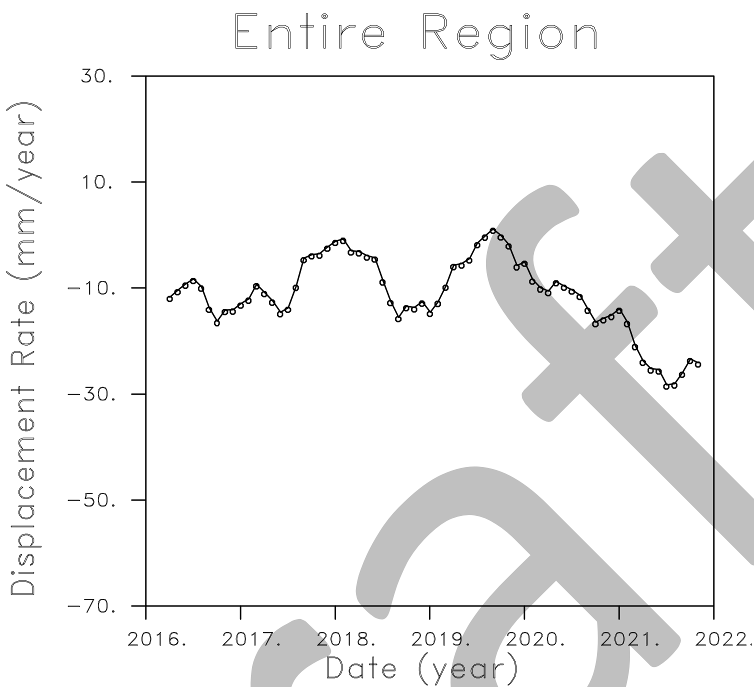

Figure 8. Variation in rate from 2016 until the end of 2021. Negative values indicate subsidence, positive values correspond to uplift.

noted in the discussion surrounding Figure 5. This ‘bump’ is also notable in the rates in the western region. In the western region the background subsidence rate is lower than the rate for the central region, around -0.39 inch/year (-1.0 cm/year). This lower background rate of about -0.39 inch/year is also observed in the southern and eastern regions. The subsidence rates all seem to increase after 2020, though the increase in subsidence is much larger in the central region, likely due to its greater exposure to the large subsidence bowl to the north of the KCS, a result of groundwater pumping for agricultural uses. The overall rates for the entire region are plotted in Figure 8. The rate is around -0.59 inch/year (-1.5 cm/year) until 2019. As in the sub-regions, the subsidence decreases and even changes to slight uplift in late 2017 and early 2018. After the second peak in late 2019, the subsidence rate decreases to around -1.18 inches/year (-3.0 cm/year) in mid-2021. The subsidence rate in 2020 is changing in a roughly linear fashion. The minimum, maximum, and mean subsidence rates for the entire region, and for the sub-domains are given in Table 1. The region as a whole is subsiding at a mean rate of -0.44 inches/year and a maximum yearly rate of around -1 inch/year, but this subsidence can reverse to uplift during a wet year. The central region is undergoing the most significant subsidence with a mean rate of -0.65 inches/year and maximum rate that is slightly less than -2 inches/year. Again, this is due to the fact that the central region encompasses the southern edge of the major subsidence bowl north of the KCS. However, even for this area the subsidence is arrested during rainy years and the sub-region is uplifted overall by 0.05 inches/year. The three other regions are subject to subsidence rates that are roughly half of the central area's rate, slightly less than -0.5 inches/year. The maximum yearly rate for the eastern, western, and southern regions are slightly less than 1 inch/year. All of the regions rebound during rainy years at a rate of around 0.25 inches/year.

Table 1: Kern County Subbasin

Region	Description	Subsidence Rate (inches/year)
Entire Region	Mean yearly rate	-0.440
	Minimum yearly rate	+0.046
	Maximum yearly rate	-1.111
Central Region	Mean yearly rate	-0.654
	Minimum yearly rate	+0.064
	Maximum yearly rate	-1.791
Southern Region	Mean yearly rate	-0.361
	Minimum yearly rate	+0.265
	Maximum yearly rate	-0.838
Eastern Region	Mean yearly rate	-0.356
	Minimum yearly rate	+0.281
	Maximum yearly rate	-0.811
Western Region	Mean yearly rate	-0.365
	Minimum yearly	+0.265
	Maximum yearly rate	-0.984

Table 1. Subsidence (negative values) and uplift (positive values) rates in the Kern County subbasin and the various sub-areas in the basin.

A recent (2021) InSAR study conducted by ECI on behalf of the KCS processed 172 Sentinal-1 radar images to produce 86 paired synthetic aperture radar images which were combined to produce 526 interferograms spanning the period 2015 to 2020. The data were processed multiple times to reduce atmospheric effects and improve accuracy. As a final check the data were ground-truthed against 13 continuous geospatial position data. The ECI study data has a vertical resolution of approximately 0.094 inch/year (2.4mm) and a horizontal pixel resolution of around 82ft. (25 meters), with no space between pixels. The ECI provided updated subsidence information on five identified areas of interest (AOIS) in the KCS. These are:

1. AOI 1: Friant-Kern canal MP 120-130 (eastern region)
2. AOI 2: LHOF Aqueduct MP 195-215 (western region)
3. AOI 3: Friant Kern Canal MP130-137 (eastern region)
4. AOI 4: Aqueduct MP 267-271 (southern region)
5. AOI 5: (central region)

With regard to the individual AOIs the KCS/KGA study found:

AOI 1: The annual subsidence rate averaged between 2 and 3 inches/year versus about 5 inches/year in a previous NASA/JPL study.

AOI 2: Identified the LHOF as the contributing factor of subsidence with rates of around 3 inches/year.

AOI 3: The annual subsidence rate averaged between 1 and 2 inches/year versus 2 to 3 inches/year in a NASA/JPL study.

AOI 4: The annual subsidence rate averaged between 1 and 2 inches/year versus 2 to 4 inches/year in a NASA/JPL study.

AOI 5: The annual subsidence rate averaged between 2 and 4 inches/year within the KCS versus 5 to 8 inches/year in a NASA/JPL study.

A key finding of the ECI report was that Previous JPL/NASA studies may have overestimated subsidence rates associated with seasonal groundwater pumping (i.e., agricultural use). ECI suggests this phenomenon may be the result of the short time intervals (i.e., often less than five years) related to the InSAR acquisition in those studies. The annual subsidence rates identified in the ECI study through the beginning of 2020 are in reasonable agreement with this subject study, though comparisons between displacement rates on a curve and rates for a region containing the curve are difficult to make, so that the comparison for AOI 5 with the current central region rate is the most meaningful.

Rates for the Year 2020

We also examined the rates of subsidence in 2020, as an example of a yearly change. The large spatial variations in subsidence are evident in Figure 9 and suggest caution in interpreting large scale averages in either time or in space.

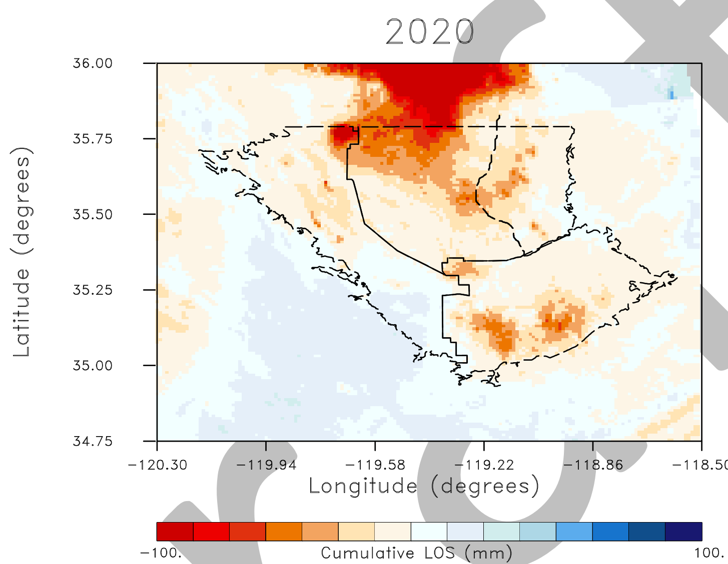

Figure 9. Cumulative line-of-sight displacement during 2020.

In order to capture the spatial variability, we scanned the pixels in each region in order to determine the greatest subsidence in a given area. Similarly, we found the pixel with the smallest subsidence rate. Finally, we computed the average subsidence rate in the region. The greatest variation was found in the western region where the mean annual subsidence rate is -0.43 inches/year and a maximum subsidence rate of -7.7 inches/year was found. The maximum rate corresponds to the localized dark red feature in the northeast corner of the western region (Figure 9). The largest uplift of 0.7 inches/year was also found in the western region. This is likely attributable to low volumes of groundwater extraction for SGMA related use, and availability of surface water. The central region also has notable subsidence at its northern edge, with a maximum rate of -3.2 inches/year. There is also a small amount of rebound or uplift in the central region, about 0.02 inches/year. The mean subsidence rate in the central region is -1.1 inches/year, which is more than twice that of the western area. It is clear from examining Figure 9, that subsidence is more widespread in the central region. There is also widespread subsidence in the southern region (Figure 9), and the mean subsidence is -0.7 inches/year. The maximum subsidence rate is -2.6 inches/year and the maximum uplift in the area is 0.5 inches/year. As stated previously, there is a variety of SGMA related uses in the southern region, as well as oilfield activities as contributing factors. Finally, the mean and maximum subsidence rates for the eastern region are -0.7 and -2.4 inches/year. There is some uplift in the eastern region, around 0.1 inches/year. Oil field activities are a contributing factor in this region. The rates for 2020 are summarized in Table 2.

Table 2: Subsidence and Uplift Rates for the year 2020

Region	Description	Rate (inches/year)
Central Region	Mean yearly subsidence rate	-1.130
	Maximum uplift rate	0.022
	Maximum subsidence rate	-3.254
Southern Region	Mean yearly subsidence rate	-0.738
	Maximum uplift rate	0.461
	Maximum subsidence rate	-2.599
Eastern Region	Mean yearly subsidence rate	-0.688
	Maximum uplift rate	0.114
	Maximum subsidence rate	-2.362
Western Region	Mean yearly subsidence rate	-0.431
	Maximum uplift rate	0.712
	Maximum subsidence rate	-7.688

Table 2. Subsidence and uplift rates for the four sub-domains of the Kern County Subbasin. Subsidence values are negative and uplift values are positive for these rates and the displacements in Table 1.

Conclusions

Surface deformation in the KCS is a complicated dynamic process that is the result of groundwater extraction, soil moisture, oil and gas extraction, soil types and natural consolidation, tectonic activity, Earth tides, and other effects. These processes operate on differing time scales whereby some processes are elastic and produce near instantaneous responses while other processes might be visco-elastic, poro-elastic, or simply inelastic. Thus, the deformation over even short time intervals may be influenced by events that are much earlier. Still, the main drivers for much of the deformation are agricultural groundwater pumping and water banking and oil and gas extraction and injection. The seasonal cycles associated with groundwater usage are evident in Figure 4, as are longer term changes that are likely due to aquifer compaction, both natural and due to changes in effective pressure within the subsurface aquifer.

Because of the variability of subsidence in time, we have examined the temporal variation in rates for the entire region, as well as for the four sub-domains (central, east, west, and south, as shown in Figure 1). These are area-wide averages and, as noted below, do not capture the spatial variability in rates. Still, the averages provide an indication of the temporal variability in rates. The large-scale (spatially) rates indicate a background 'floor" of subsidence values of around -0.4 inches/year for the eastern, western, and southern regions, interrupted by decreases in subsidence in wetter years leading to net uplift. The central region, with its greater exposure to the large-scale subsidence bowl to the north, has a larger background rate that is higher, around -0.6 inches/year. Again, during wet years the subsidence is arrested and can even reverse to uplift. This indicates the potential for water-banking or some other mitigation technique to reduce subsidence if applied on a large scale. There are indications that the subsidence rate has increased since 2020, most dramatically in the central region. Perhaps the easiest way to visualize the temporal changes in the four regions is to examine Figure 5. The time series of displacements for the three regions (east, west, south) is roughly linear, then interrupted by a rather abrupt shift upward, likely due to the effects of the wet years, availability of surface water, existing water banking programs and a pause or end of the drought around 2017. As noted above, this shift occurs at different times for the central and western regions. Factors contributing to this temporal difference may include proximity to areas of natural recharge, such as in the west (the central region is more distal), groundwater dependence (the central region has higher dependence), and availability of surface water. In the two other regions s (southern and eastern), the shift might represent natural recharge of deeper aquifers. The shift is then followed by a linear behavior in time, at roughly the same slope as before, suggesting a return to the previous subsidence rate. The behavior for the central region is different in that the curve does not return to a linear trend, but rather seems to indicate an increase in the rate of subsidence after 2020 or so. One take-away from these results is that when calculating rates, it can be important to consider the temporal changes in rates. A rate calculation incorporating the rapid shift during the wet time interval, can significantly skew the rate estimates, as evident in Figure 7.

As indicated in Figures 3 and 9, the spatial distribution of surface displacement, and hence subsidence, is highly variable and typically concentrated within the various sub-regions. This concentration is most notable for oil and gas fields. These regions can have dramatic changes, both subsidence and uplift, over short periods (Vasco et al. 2017), and probably cannot be characterized accurately by a single rate. Still, it is possible to examine yearly averages that measure accumulated surface deformation. In this study, we considered the deformation rate for the year 2020, and the spatial variability in rates that can occur within the four sub-domains (Figure 9 and Table 2). The yearly rates of change in 2020 were calculated for all points of the four regions. In order to capture the spatial variability within each region, we scanned the rates and determined the locations with the maximum subsidence and the minimum rate of subsidence (typically uplift), as well as computing the mean of all of the rates for the given sub-domain. The resulting maximum rates of subsidence were around 2-3 inches/year with an anomalously large value of -7.7 inches/year in the western sub-area. This area of extreme subsidence is visible in Figure 9, at the northeastern corner of the western sub-region. The activities in this area should probably be examined in more detail, as the subsidence rate is significant and fairly concentrated. Outside of this anomalous area, the western sub-domain has relatively moderate subsidence in 2020, though there are concentrations in selected oil and gas fields. We should note that the yearly rates of -3.2, -2.6, and -2.4 inches/year for the central, southern, and eastern areas are in line with estimates in the March 2021 report by Earth Consultants International, who found subsidence rates of 2-3 inches/year in the northern edge of the Kern County Subbasin and 3-4 inches/year south of Bakersfield.

Again, peak rates for specific areas are subject to dramatic temporal changes as local activities vary. When focusing on specific infrastructure we can derive more detailed and specific estimates along the given paths of the canals, pipelines, and transmission lines. Given current rates of subsidence buried infrastructure, like pipelines, would not experience significant adverse effects provided “hinge line” factors (stream crossings, faults, changes in elevation and grade etc.) were minimal. However, further study is needed to quantify and confirm the types of stresses that may be present. In addition, the line-of-sight displacements are dominated by subsidence but there will also be notable horizontal displacement, particularly from the subsidence bowl at the northern edge of the subbasin. Such north-south displacement can be estimated from an inversion for volume change, as in Vasco et al. (2019), followed by a forward geomechanical calculation of three-dimensional displacements, as in Vasco et al. (2017).

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Attachment E3

California Aqueduct White Paper

WHITE PAPER – JULY 2022
BASIN-WIDE COORDINATED GSP SUBSIDENCE PLAN
DEFINITIONS AND SUSTAINABLE MANAGEMENT CRITERIA
CA AQUEDUCT

1. Introduction

The Kern Subbasin has developed the following white paper to document the process and methods for establishing interim Sustainable Management Criteria (SMCs) for Land Subsidence. The California Aqueduct (Aqueduct) and the Friant-Kern Canal have been identified as Regional Critical Infrastructure within the Kern Subbasin. This white paper describes the methods and data used to determine a coordinated approach for establishing interim subsidence SMCs that are consistent with the unique conditions that exist across the breadth and width of the Subbasin. Therefore, while the overall methodology to arrive at interim SMCs at the Aqueduct and Friant-Kern Canal are fundamentally similar there are variations to account for local conditions along each infrastructure, such as local beneficial users, geologic and hydrogeologic conditions, and operational consideration of the facilities.

The Kern Subbasin has adopted two classifications for critical infrastructure: Regional Critical Infrastructure and Management Area Critical Infrastructure.

> *Regional Critical Infrastructure* is defined as infrastructure located within the Subbasin that serves multiple areas of the Subbasin and whose loss of significant functionality due to inelastic subsidence, if caused by SGMA related Subbasin groundwater extractions, would have significant impacts to beneficial users. The Subbasin has collectively determined that the only infrastructure that meets the definition for Regional Critical Infrastructure are the California Aqueduct and the Friant-Kern Canal.
>
> *Management Area Critical Infrastructure* is defined as infrastructure located within a particular Subbasin Management Area whose loss of significant functionality due to inelastic subsidence if caused by SGMA related Subbasin groundwater extractions would have significant impacts to beneficial users within that Subbasin Management Area. Each Subbasin Management Area has identified their respective Management Area Critical Infrastructure in their Management Area Plan or individual GSP.

The Subbasin’s coordinated definition for a basin-wide undesirable result for land subsidence is:

> *The point at which significant and unreasonable impacts, as determined by a subsidence rate and extent in the basin, that affects the surface land uses or critical infrastructure.*
>
> *This is determined when subsidence results in significant and unreasonable impacts to critical infrastructure as indicated by monitoring points established by a basin wide coordinated GSP subsidence monitoring plan.*

An undesirable result for land subsidence is further identified as the occurrence of a single minimum threshold exceedance along either the Aqueduct or the Friant-Kern Canal. The minimum thresholds for the Aqueduct are detailed in this white paper. See the Friant-Kern white paper for a detail discussion the minimum thresholds for that facility.

At the June 17, 2022, meeting with DWR, the Kern Subbasin presented the findings of two important subsidence studies conducted subsequent to the January 2020 submission of the Subbasin groundwater sustainability plans (GSP). Both subsidence studies indicate that groundwater extractions under the purview of SGMA are not the sole cause of historical subsidence. The studies also identified that significant additional data is required to fully understand the dynamics of subsidence, its impacts on critical infrastructure including the California Aqueduct and the Friant-Kern Canal, and whether such impacts can be influenced by groundwater management as altered by future projects and management actions.

Based on the presentation of data, the Kern Subbasin Groundwater Sustainability Agencies (GSAs) expressed concern with setting SMCs where significant data gaps exist. The Kern Subbasin GSAs understand that DWR has addressed the issue of data gaps in the Monitoring Networks and Identification of Data Gaps Best Management Practice warning that "Data must be of sufficient quality to enable scientifically defensible decision." (Monitoring Networks and Identification of Data Gaps Best Management Practice, page 27.)

DWR SGMA staff understood the data provided by the Kern subbasin and appreciated the challenge of setting sustainable management criteria in the face of data gaps. However, DWR stated substantial compliance with the requirements of the Sustainable Groundwater Management Act (SGMA) requires the development of interim SMCs for subsidence and DWR SGMA staff stated that the setting of the SMC can include caveats. Therefore, the Kern subbasin will proceed with the development of sustainable management criteria for subsidence with the following caveats which may not be inclusive.

- The sustainable management criteria can be interim, will only be valid until 2025, and will be updated in the 2025 GSP update;
- Due to the complexity of the Kern Subbasin, setting of an interim SMC for subsidence, does not require GSAs take responsibility, manage, regulate or otherwise be liable for impacts resulting from actions outside the authority of the GSA or outside the GSA's ability to manage sustainability under SGMA; and
- That the Kern Subbasin GSAs are not responsible for addressing subsidence caused by activities outside of the jurisdiction of SGMA i.e., extractions from exempt aquifers, or caused by activities other than extraction of water on behalf of the beneficial users under the purview of SGMA.

The SMCs for subsidence described in the remainder of this white paper were developed with consideration of these caveats.

2. Undesirable Results – Land Subsidence, CA Aqueduct

The California Aqueduct (Aqueduct) has been identified as regional critical infrastructure on the west side of the Subbasin. The Subbasin definition of an undesirable result for land subsidence is the point at which the amount of inelastic subsidence, if caused by SGMA-related Subbasin groundwater extractions, creates a significant and unreasonable impact (requiring either retrofitting or replacement to a point that is economically unfeasible to the beneficial users) to surface land uses or critical infrastructure. A significant loss in functionality that could be mitigated through retrofitting and is considered economically feasible to the beneficial users would not be considered undesirable.

Each Aqueduct Pool has a unique existing freeboard condition according to the 2019 DWR Subsidence Report, therefore the amount of subsidence (e.g. vertical displacement or settlement) that may occur without causing an undesirable result at the MO and MT can be unique comparing all pools.

Based on the findings of the 2019 DWR California Aqueduct Subsidence Program Report (CASP), subsidence has reduced original design freeboard and has potentially impacted conveyance capacity in select Aqueduct pools in the Subbasin. Maintaining reasonable operating freeboard and conveyance capacity is critical to long-term sustainability of the Aqueduct.

A variety of subsurface conditions and mechanisms, not all completely understood, can cause subsidence. A relatively minor amount of subsidence over a wide area can be insignificant and/or imperceptible, whereas a significant amount of localized subsidence can create an unreasonable impact to overlying infrastructure. Although groundwater extractions for agricultural or other uses have potential under limited conditions to cause subsidence, recent studies conducted by Management Areas on the west side and the KGA have identified soluble soils, natural differential compaction and oil and gas production activities as potential contributors to subsidence along the Aqueduct. None of the subsidence modes besides groundwater extraction for agricultural and other Management Area beneficial uses are within the control or jurisdiction of Subbasin GSAs. Identifying the subsurface conditions and mechanisms causing subsidence in the Subbasin will be a critical first step to managing current and future impacts and identifying appropriate management actions.

3. Monitoring Plan – Land Subsidence, CA Aqueduct

Subsidence will be assessed in a five-mile-wide monitoring corridor (i.e., 2.5 miles on either side of the Aqueduct). Since physical access to surveying benchmarks along the Aqueduct for independent parties is limited, the Aqueduct subsidence monitoring reports produced by DWR will be one of the sources to identify the rate and magnitude of subsidence (i.e., change in freeboard) on the Aqueduct. The DWR reports provide complete coverage of each Pool within the Subbasin and represent one method to monitor subsidence for the Aqueduct. Below, Table 1b provides the latest range of available freeboard by pool using the latest DWR survey data through 2022. The amount of remaining concrete liner was calculated relative to the original as-built liner elevations or subsequent liner raises where applicable.

As a supplement to the DWR subsidence monitoring reports, InSAR data will, at a minimum, be reviewed on an annual basis to inform Management Areas of whether subsidence rates could lead to an undesirable result. InSAR data will be ground-truthed by comparison to NOAA CORS station P545, SOPAC CGPS location P544, and available local existing extensometers in or adjacent to the subsidence monitoring corridor for the Aqueduct, in addition to any future CORS, CGPS, extensometer, or other pertinent facilities that may be constructed in the future in or adjacent to the monitoring corridor discussed below in coordination with DWR-CASP staff.

Monitoring Corridor

The subsidence monitoring corridor for the Aqueduct will include lands within 2.5 miles on either side of the Aqueduct (i.e., total of five miles wide centered on the Aqueduct). The width of the monitoring corridor was based on a review of Subbasin hydrogeology, historical InSAR datasets, the 2019 DWR-CASP report, and current land use along the Aqueduct.

Areas of Interest (AOIs)

Pools that have experienced subsidence which has significantly reduced freeboard and, in some cases, impacted flow capacity will be identified as “Areas of Interest” and be subject to focused monitoring by the collection and ground-truthing of InSAR data on a annual basis and the preparation of focused studies or investigations to assess the cause of subsidence in consultation with the adjacent Management Areas and DWR. If it is determined that the sole or principal cause of subsidence in a particular AOI is groundwater extraction for SGMA-related beneficial use, these sites will be identified for additional Subbasin monitoring stations in the future and/or management actions based on the data. Current AOIs for the Subbasin include the Kern bowl (a portion of Pool 23, all of Pools 24, 25 and a portion of Pool 26), Maricopa bowl (a portion of Pool 30, all of Pools 31 and 32), and Pleito bowl (a portion of Pool 34 and all of Pool 35). Studies conducted by the Management Areas on the west side have concluded that subsidence between Aqueduct Mile Post 195 to approximately 214 (i.e., Pools 23 through 25) is attributable to oil and gas activities. As such, the subsidence attributable to oil and gas activities at the Kern Bowl is beyond the ability of the Subbasin to control or mitigate. Further, additional study of the Maricopa and Pleito bowls is required to more fully understand potential causes of identified subsidence.

Watch Areas (WAs)

The 2019 DWR-CASP Report and 2022 CASP survey data show that subsidence in several pools has been minimal with top of concrete liner elevations in 2017 being comparable to those measured when the Aqueduct was constructed over 50 years ago, accordingly, neither freeboard nor capacity has been significantly impacted (i.e., undesirable results have not been experienced). Any significant loss of conveyance capacity from design specifications was found to be caused from aging concrete liner with increased hydraulic roughness and other factors. Pools that have experienced minimal subsidence historically will be identified as “Watch Areas”. Watch Areas will be monitored utilizing annual ground-truthed InSAR data and the most current DWR-CASP Aqueduct report. In the event that future monitoring determines that conditions have changed, the subject Watch Area may be redesignated as an AOI. Pool specific Monitoring Classification, and Management Areas associated with each Pool are summarized in the below table.

Table 1a: CA Aqueduct Pools in Kern Subbasin and Associated Management Areas

CA Aqueduct Pool	Management Area Within 5-Mile Corridor	Pool Monitoring Classification
Pool 23	KGA (WDWA)	AOI/WA
Pool 24	KGA (WDWA, SWSD), BVGSA	AOI

Pool 25	KGA (WDWA), BVGSA	AOI
Pool 26	KGA (WDWA), BVGSA	AOI/WA
Pool 27	KGA (WKWD), BVGSA	WA
Pool 28	KGA (WKWD, KWB), BVGSA	WA
Pool 29	KGA (WKWD, KWB), HMGSA	WA
Pool 30	KGA (WKWD), HMGSA	AOI/WA
Pool 31	KGA (WKWD), HMGSA, SOKR	AOI
Pool 32	KGA (WKWD), SOKR	AOI
Pool 33	SOKR, KGA	WA
Pool 34	SOKR, KGA	AOI/WA
Pool 35	SOKR, KGA	AOI

Table 1b: CA Aqueduct Pools in Kern Subbasin and Monitoring Classification Extent

CA Aqueduct Pool	2022 Range of Available Freeboard by Pool (Ft)[4]	Watch Area Mile Post (MP) Extent	Area of Interest Mile Post (MP) Extent
Pool 23	1.48 to 3.74	MP-184.5 to MP-194	[1]MP 194 to MP 197
Pool 24	0 to 2.19	N/A	[1]MP-197 to MP 208
Pool 25	0 to 3.43	MP-216 to MP-218	[1]MP-208 to MP-216
Pool 26	1.67 to 4.01	MP-216 to MP-222.5	[2]MP-222.5 to MP-223.5
Pool 27	3.62 to 4.32	MP-223.5 to MP- 231.5	N/A
Pool 28	1.51 to 4.35	MP-231.5 to MP-238	N/A
Pool 29	2.18 to 2.92	MP-238 to MP-244.5	N/A
Pool 30	2.65 to 8.11	MP-249.5 to MP-251	[2]MP-244.5 to 249.5
Pool 31	0.97 to 4.61	N/A	[3]MP-249.5 to MP-256.5
Pool 32	3.20 to 4.86	N/A	[3]MP-256.5 to MP 261.5
Pool 33	5.72 to 6.53	MP-261.5 to 267.5	[3]N/A
Pool 34	5.07 to 6.01	MP- 267.5 to 269.5	[3]MP-269.5 to MP- 271.5
Pool 35	3.59 to 6.64	N/A	[3]MP- 271.5 to MP- 278.5

[1]Vicinity of Lost Hills Oil Field; [2]Potential geotechnical effects; [3]Potential oil and other effects;
[4] California Aqueduct Adjusted NGVD29 Kettleman-Edmonston+Lat Long (CASP) Report, June 2022

4. Methodology for Establishing Interim Measurable Objectives and Interim Minimum Thresholds

At the June 17, 2022, meeting with DWR, the Kern subbasin presented the findings of two important subsidence studies that were conducted subsequent to the January 2020 submission of the GSPs. DWR staff indicated their understanding of the studies/data and appreciated the challenge of setting sustainable management criteria in the face of data gaps thus stated that an interim SMC with caveats would be better than setting no SMC. The caveats for subsidence include but are not limited to:

- The sustainable management criteria can be interim, will only be valid until 2025, and will be updated in the 2025 GSP update;
- Due to the complexity of the Kern Subbasin, setting of an interim SMC for subsidence, does not require GSAs take responsibility, manage, regulate or otherwise be liable for impacts resulting from actions outside the authority of the GSA or outside the GSA's ability to manage sustainability under SGMA; and
- That the Kern Subbasin GSAs are not responsible for addressing subsidence caused by activities outside of the jurisdiction of SGMA i.e., extractions from exempt aquifers, or caused by activities other than extraction of water on behalf of the beneficial users under the purview of SGMA.

The Interim Measurable Objective for land subsidence for the California Aqueduct is defined as the avoidance of a permanent loss (associated with inelastic subsidence) of conveyance capacity as attributable to subsidence as limited by remaining concrete liner freeboard for a specific Aqueduct Pool that exceeds the average observed rate from 2016-2022. Using the 2022 CASP survey data, the average observed rate was calculated to be -0.05 ft/yr for all Pools of the Aqueduct within the Kern Subbasin. The MO rate of subsidence is calculated and assessed as an average annual rate over a rolling 6-year monitoring period.

The Minimum Threshold for land subsidence for the California Aqueduct is defined as the avoidance of a permanent loss (associated with inelastic subsidence) of conveyance capacity as attributable to subsidence as limited by remaining concrete liner freeboard for a specific Aqueduct Pool that exceeds twice the average observed rate from 2016-2022. Using the 2022 CASP survey data, twice the average observed rate was calculated to be -0.10 ft/yr for all Pools of the Aqueduct within the Kern Subbasin. The MT rate of subsidence is calculated and assessed as an average annual rate over a rolling 6-year monitoring period.

The above methodology for developing MOs and MTs, recognizing the baseline subsidence rate as calculated from the latest CASP survey data, is supported by the findings of the KGA Subsidence Study and Lawrence Livermore Study. The Subsidence Rate for the MO and MT as described below are interim, pending the collection and analysis of additional data, and will be updated in the 2025 GSP. The following table presents an interim MO and MT by Pool:

CA Aqueduct Pool	[1]Measurable Objective Rate (INTERIM) from 2022-2025 (Ft/Yr)	[2]*Measurable Objective Total Extent (INTERIM) from 2022-2040 (Ft)*	[1]Minimum Threshold Rate (INTERIM) from 2022-2025 (Ft/Yr)	[2]*Minimum Threshold Total Extent (INTERIM) from 2022-2040(Ft)*
Pool 23	-0.05	*-0.9*	-0.1	*-1.8*
Pool 24	-0.05	*-0.9*	-0.1	*-1.8*
Pool 25	-0.05	*-0.9*	-0.1	*-1.8*
Pool 26	-0.05	*-0.9*	-0.1	*-1.8*
Pool 27	-0.05	*-0.9*	-0.1	*-1.8*
Pool 28	-0.05	*-0.9*	-0.1	*-1.8*
Pool 29	-0.05	*-0.9*	-0.1	*-1.8*
Pool 30	-0.05	*-0.9*	-0.1	*-1.8*
Pool 31	-0.05	*-0.9*	-0.1	*-1.8*
Pool 32	-0.05	*-0.9*	-0.1	*-1.8*
Pool 33[3]	-0.07	*-1.35*	-0.15	*-2.7*
Pool 34[3]	-0.07	*-1.35*	-0.15	*-2.7*
Pool 35[3]	-0.07	*-1.35*	-0.15	*-2.7*

[1]The MO & MT rate are calculated over a rolling 6-yr period, averaging Pools 23-32 and Pools 33-35; the interim rate identified for the MO and MT is for subsidence due to activities under the purview of SGMA. The interim rate is established based upon findings from the 2022 CASP survey data, and the InSAR Study and LBL preliminary study (KGA 2021). **The Interim Rate will be updated in the 2025 GSP Update.**

[2]**The extent of subsidence (INTERIM) for the term 2022 – 2040 utilizes the Interim MO and MT Rate and will be updated as the MO and MT rates for subsidence are updated in the 2025 GSP Update.**

[3]Information regarding the SMC for Pools 33, 34, and 35 can be found in the South of Kern River GSP.

The Interim Measurable Objectives and Minimum Thresholds are only valid until 2025 and they will be updated in the 2025 GSP Update, and only apply when the permanent loss of freeboard is a result of subsidence due to SGMA-related groundwater extractions from the following beneficial uses/users: agricultural, domestic, municipal, or urban. Permanent loss of freeboard from land subsidence due to other causes including but not limited to: due to oil or gas production, natural compaction of shallow underlying soils beneath or near the Aqueduct, or any other cause that is not within the jurisdiction of a GSA, shall not be considered as a loss of freeboard that contributes to the amount specified for any MO or MT. When considering Measurable Objective and Minimum Threshold rates beyond 2025 it will be critical to fully understand design considerations of the identified critical infrastructure. It is typical that major infrastructure designs incorporate assumptions for natural settling, subsidence of any type, service life, repair and replacement cycles, etc. It is expected that when selecting Minimum Threshold rates of subsidence beyond the interim 2025 period that MO and MT rates may require reduction based on these and other critical elements as the basin approaches its 2040 sustainability goal.

For example, if the MT for subsidence for a particular pool of the Aqueduct within a Management Area was determined to be 0.10 ft/yr over a 6-year period, and SGMA-related beneficial uses within the jurisdiction of a GSA were deemed to cause 0.07 ft /yr of subsidence within that pool while non-jurisdictional uses were deemed to cause 0.15 ft/yr, the Management Area would only consider the 0.07 ft/yr subsidence rate (and related loss of pool freeboard) when evaluating MT compliance, and in that case would not determine that an MT exceedance has occurred.

As the Kern subbasin moves forward, we believe significant data gaps pertaining to the various causes and rates of subsidence in the KCS still exist and, that if addressed, will lead to better defined management objectives for the Aqueduct and help focus planned and future monitoring resources where they will be most effective. We also believe that working jointly and in close consultation with the DWR-California Aqueduct Subsidence Project (CASP) team would multiply the respective expertise and resources of both parties to the benefit of all those dependent on the Aqueduct. The Kern subbasin has been meeting with the CASP team since 2019 to move forward this concept of joint cooperation to develop data-based management objectives and future sustainable management criteria. As such, the Kern Subbasin and DWR CASP have agreed, as proponents for the sustainable management of the Aqueduct, to continue to work collaboratively to assess the causes and potential solutions to subsidence on the Aqueduct.

Attachment E4

Friant-Kern Canal White Paper

WHITE PAPER – JULY 2022
BASIN-WIDE COORDINATED GSP SUBSIDENCE PLAN
DEFINITIONS AND SUSTAINABLE MANAGEMENT CRITERIA
FRIANT-KERN CANAL

1. Introduction

The Kern Subbasin has developed the following white paper to document the process and methods for establishing interim Sustainable Management Criteria (SMCs) for Land Subsidence. The California Aqueduct (Aqueduct) and the Friant-Kern Canal have been identified as Regional Critical Infrastructure within the Kern Subbasin. This white paper describes the methods and data used to determine a coordinated approach for establishing interim subsidence SMCs that are consistent with the unique conditions that exist across the breadth and width of the Subbasin. Therefore, while the overall methodology to arrive at interim SMCs at the Aqueduct and Friant-Kern Canal are fundamentally similar there are variations to account for local conditions along each infrastructure, such as local beneficial users, geologic and hydrogeologic conditions, and operational consideration of the facilities.

The Kern Subbasin has adopted two classifications for critical infrastructure: Regional Critical Infrastructure and Management Area Critical Infrastructure.

> *Regional Critical Infrastructure* is defined as infrastructure located within the Subbasin that serves multiple areas of the Subbasin and whose loss of significant functionality due to inelastic subsidence, if caused by SGMA related Subbasin groundwater extractions, would have significant impacts to beneficial users. The Subbasin has collectively determined that the only infrastructure that meets the definition for Regional Critical Infrastructure are the California Aqueduct and the Friant-Kern Canal.
>
> *Management Area Critical Infrastructure* is defined as infrastructure located within a particular Subbasin Management Area whose loss of significant functionality due to inelastic subsidence if caused by SGMA related Subbasin groundwater extractions would have significant impacts to beneficial users within that Subbasin Management Area. Each Subbasin Management Area has identified their respective Management Area Critical Infrastructure in their Management Area Plan or individual GSP.

The Subbasin's coordinated definition for a basin-wide undesirable result for land subsidence is:

> *The point at which significant and unreasonable impacts, as determined by a subsidence rate and extent in the basin, that affects the surface land uses or critical infrastructure.*
>
> *This is determined when subsidence results in significant and unreasonable impacts to critical infrastructure as indicated by monitoring points established by a basin wide coordinated GSP subsidence monitoring plan.*

An undesirable result for land subsidence is further identified as the occurrence of a single minimum threshold exceedance along either the Aqueduct or the Friant-Kern Canal. The minimum thresholds for the Friant-Kern Canal are detailed in this white paper. See the Aqueduct white paper for a detail discussion the minimum thresholds for that facility.

At the June 17, 2022, meeting with DWR, the Kern Subbasin presented the findings of two important subsidence studies conducted subsequent to the January 2020 submission of the Subbasin groundwater sustainability plans (GSP). Both subsidence studies indicate that groundwater extractions under the purview of SGMA are not the sole cause of historical subsidence. The studies also identified that significant additional data is required to fully understand the dynamics of subsidence, its impacts on critical infrastructure including the Aqueduct and the Friant-Kern Canal, and whether such impacts can be influenced by groundwater management as altered by future projects and management actions.

Based on the presentation of data, the Kern Subbasin Groundwater Sustainability Agencies (GSAs) expressed concern with setting SMCs where significant data gaps exist. The Kern Subbasin GSAs understand that DWR has addressed the issue of data gaps in the Monitoring Networks and Identification of Data Gaps Best Management Practice warning that "Data must be of sufficient quality to enable scientifically defensible decision." (Monitoring Networks and Identification of Data Gaps Best Management Practice, page 27.)

DWR SGMA staff understood the data provided by the Subbasin and appreciated the challenge of setting sustainable management criteria in the face of data gaps. However, DWR stated substantial compliance with the requirements of the Sustainable Groundwater Management Act (SGMA) requires the development of interim SMCs for subsidence and DWR SGMA staff stated that the setting of the SMC can include caveats. Therefore, the Kern subbasin will proceed with the development of SMCs for subsidence with the following caveats which may not be inclusive.

- The sustainable management criteria can be interim, will only be valid until 2025, and will be updated in the 2025 GSP update;
- Due to the complexity of the Kern Subbasin, setting of an interim SMC for subsidence, does not require GSAs take responsibility, manage, regulate or otherwise be liable for impacts resulting from actions outside the authority of the GSA or outside the GSA's ability to manage sustainability under SGMA; and
- That the Kern Subbasin GSAs are not responsible for addressing subsidence caused by activities outside of the jurisdiction of SGMA i.e., extractions from exempt aquifers, or caused by activities other than extraction of water on behalf of the beneficial users under the purview of SGMA.

The SMCs for subsidence described in the remainder of this white paper were developed with consideration of these caveats.

2. Sustainable Management Criteria – Land Subsidence, Friant-Kern Canal

Defined as one of the two Regional Critical Infrastructures, the Lower Reach of the Friant-Kern Canal (FKC) almost entirely lies within the Subbasin between the northern boundary and the terminus at the Kern River.

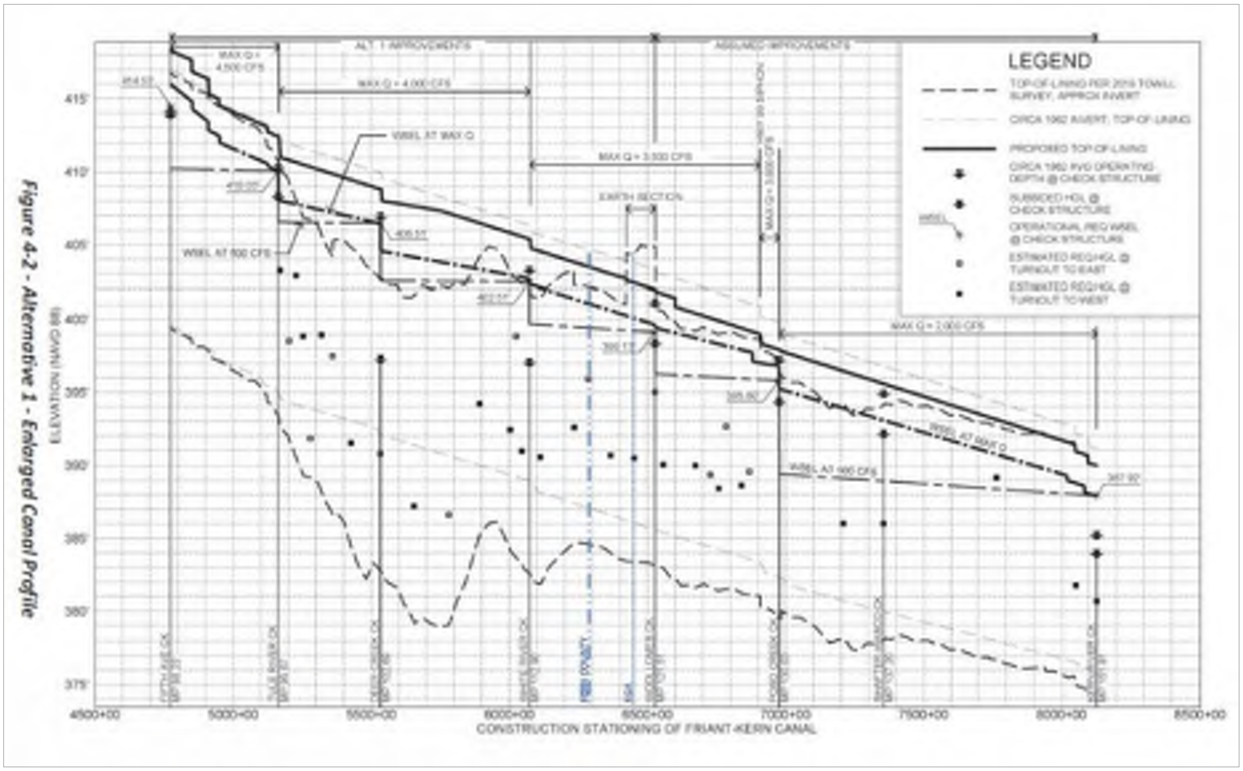
Appendix A of the Friant-Kern Canal Middle Reach Capacity Correction Project, Feasibility Report, November 2019 indicates subsidence has occurred in the Lower Reach that ranges from an estimated 1 to 4 feet below initial operating elevations in 1951. A recent report provided by

Lawrence Berkley National Laboratory, July 12, 2022, indicated worst-case subsidence along the Friant corridor to be 4.5 inches from 2015 to 2021. Additionally, information from DWR's California Groundwater Live website indicates an additional estimated range of 0.3 to 0.6 feet of subsidence since 2019. Currently, design freeboard in the Lower Reach is impacted due to subsidence. The top of liner between Woollomes Check (Mile Post 122) and approximately 1 mile downstream of the Shafter Check (Mile Post 138) is below design freeboard operating levels.

The original design capacity of the Lower Reach is 2,500 cfs and Friant Water Authority currently estimates operating capacity of approximately 1,900 cfs. The reduced Lower Reach capacity can be contributed to design flaws (assumed roughness coefficient) as well as subsidence and primarily the impacted canal pool between Poso and Shafter-Wasco Checks.

Figure 1. Friant-Kern Canal Check Locations

Figure 2. Friant-Kern Canal Profile, HEC-RAS Modeling TM, March 15, 2019



Undesirable Result

An undesirable result for land subsidence is defined as the point at which the amount of inelastic subsidence, if caused by Subbasin groundwater extractions, creates a significant and unreasonable impact to surface land uses or critical infrastructure. A significant and unreasonable impact to the FKC is determined when the flow capacity through the Lower Reach is reduced to capacities below historical operational flow capacities over the previous 10 years, impacting surface land uses of available water supplies, as a result of groundwater extractions from agricultural, domestic, municipal, or urban beneficial users within the Kern County Subbasin.

The cause of subsidence is attributable to the compaction of underground materials as a result of the lowering of groundwater levels or oil and gas production activities. Other contributing factors can be natural events such as seismic activity, other soil compaction, and residual subsidence. As seen throughout the San Joaquin Valley, subsidence can occur over large regional areas or in smaller localized zones. It can be challenging to determine the cause of subsidence and requires a thorough understanding of all the beneficial uses and user activities occurring in the region and local areas along with the physical geologic structure and character of the aquifer layers. Identifying all of the potential factors (local, regional, out of region) contributing to subsidence will be a critical first step to managing current and future impacts and identifying appropriate management actions.

At this time, the Subbasin GSAs believe it is inappropriate to set SMCs and MTs for Regional Critical Infrastructure due to limited data and a lack of a subsidence model. However, the Subbasin is required to establish SMCs and MTs in order to satisfy DWR requirements for a plan that substantially complies with GSP regulations. Therefore, the Subbasin GSAs have established an interim SMC and interim MT for the FKC that will only be valid until 2025, at which time a new SMC and MT will be established based on the additional data acquired from the basin study and subsidence modeling.

Minimum Threshold

The methodology to determine and set minimum thresholds is defined as the avoidance of permanent loss of historical operational flow capacities for the Lower Reach as a result of groundwater extractions from agricultural, domestic, municipal, or urban beneficial users within the Kern County Subbasin. In order to set an appropriate MT, additional studies and subsidence modeling is necessary to understand the cause of subsidence, identify appropriate management actions, and develop a mitigation plan. However, as previously noted, the Subbasin GSAs will establish an interim MT.

Since the submittal of initial GSPs in January 2020, the Subbasin was proactive in developing a basin study proposal that will provide, among many other objectives, much needed data and modeling to determine activities that are contributing to subsidence impacts. Additionally, the KGA engaged Lawrence Berkeley National Laboratory to provide additional data for Subbasin baseline subsidence and infrastructure assessment. The Subbasin was recently awarded a $7.6 million DWR grant that includes funding for basin-wide proposals to 1) conduct the basin study 2) support subsidence monitoring in 2 areas of interest along the FKC and 1 area of interest on the Aqueduct and 3) develop coordinated monthly field by field evapotranspiration data based on robust and repeated ground station data. Additional subsidence focused studies and modeling will be conducted, as necessary.

Kern Subbasin is in contact with the FWA and will continue to work with FWA on filling data gaps as well as coordinate on a monitoring network. The Friant Water Authority (in conjunction with the Bureau of Reclamation) is developing a proposed a system-wide Friant-Kern Canal Capacity Correction Program (Program). Both entities have already begun the correction phase of the Middle Reach, which experienced significant capacity loss (over 60%) as a result of regional subsidence. The proposed Program includes identifying impacts to water supplies from the loss of flow capacity in the Lower Reach. Several Kern Subbasin representatives are involved in the Program and will continue to monitor the Program with respect to SGMA compliance and implementation.

The interim MT for the entire Lower Reach within the Kern Subbasin is defined as the average annual rate of subsidence over the last 6 years and the corresponding total interim extent from 2022 until 2040. Based on information provided by the DWR's California Groundwater Live website, the annual rate of subsidence is presented as a range and MT is set at the average of lower elevation of the subsidence ranges. The MT rate of allowable subsidence is -0.2 feet per year and MT extent is -3.6 ft until the 2040. A new MT rate and extent will be established in the 2025 GSP updates based on data from the previously discussed basin study and subsidence modeling. For evaluation and reporting, the annual rate of subsidence will be calculated and assessed as an average annual rate over a rolling 6-year period. Table 1 provides additional information in the determination of the annual average rate and corresponding MT

Table 1: Annual Subsidence Ranges

Year	InSAR - Maximum Reported Subsidence Range for FKC Lower Reach (Ft) (1)	Lower of Reported Subsidence Elevation Range (Ft)	Upper of Reported Subsidence Elevation Range (Ft)
2016	-0.2 to -0.1	-0.2	-0.1
2017	-0.1 to 0.0	-0.1	0.0
2018	-0.2 to -0.1	-0.2	-0.1
2019	-0.1 to 0.0	-0.1	0.0
2020	-0.4 to -0.2	-0.4	-0.2
2021	-0.2 to -0.1	-0.2	-0.1
Average	**-0.2 to -0.1**	**-0.2**	**-0.1**

(1) Source: DWR California Groundwater Live website

MT	Interim Minimum Threshold, Annual Rate (Ft/yr)	**-0.2**	
MO	Interim Measurable Objective, Annual Rate (Ft/yr)		**-0.1**

Data from DWR's California Groundwater Live website will be the primary source to determine the average annual rate over a rolling 6-year period for evaluation and reporting.

Measurable Objectives

Based on information provided by the DWR's California Groundwater Live website, the annual rate of subsidence is presented as a range and the interim MO is set at the average of upper elevation of subsidence ranges. The MO rate of allowable subsidence is -0.1 feet per year and interim MO extent is -1.8 ft until 2040. A new MO rate will be established in the 2025 GSP updates based on data from the previously discussed basin study and subsidence modeling. The rate of subsidence is calculated and assessed as an average annual rate over a rolling 6-year period. Table 1 provides additional information in the determination of the annual average rate and corresponding MO. Table 2 provides a summary of the Interim MO, MT and corresponding extents.

Table 2: FKC Lower Reach Interim Measurable Objectives, Minimum Thresholds and Extent

Measurable Objectives Rate from 2022 to 2025 (Ft/Yr)	Measurable Objective Total Extent from 2022 to 2040 (Ft)	Minimum Threshold Rate from 2022 to 2025 (Ft/Yr)	Minimum Threshold Total Extent from 2022 to 2040 (Ft)
-0.1	**-1.8**	**-0.2**	**-3.6**

3. Monitoring Network

Annual InSAR data will be used to evaluate subsidence, at a minimum, within the Lower Reach monitoring corridor which is 2.5 miles on either side of the FKC. Additional surrounding areas potentially contributing to subsidence impacts will be monitored as appropriate pending additional data obtained from future studies and modeling. Furthermore, land-based monitoring of focused areas of interest will be established utilizing survey control points and NOAA CORS. Recently awarded DWR grant also provides for installation of 2 extensometers in the Lower Reach area that will be incorporated into the monitoring network. Kern Subbasin is committed to coordinate with the FWA on establishing this network.

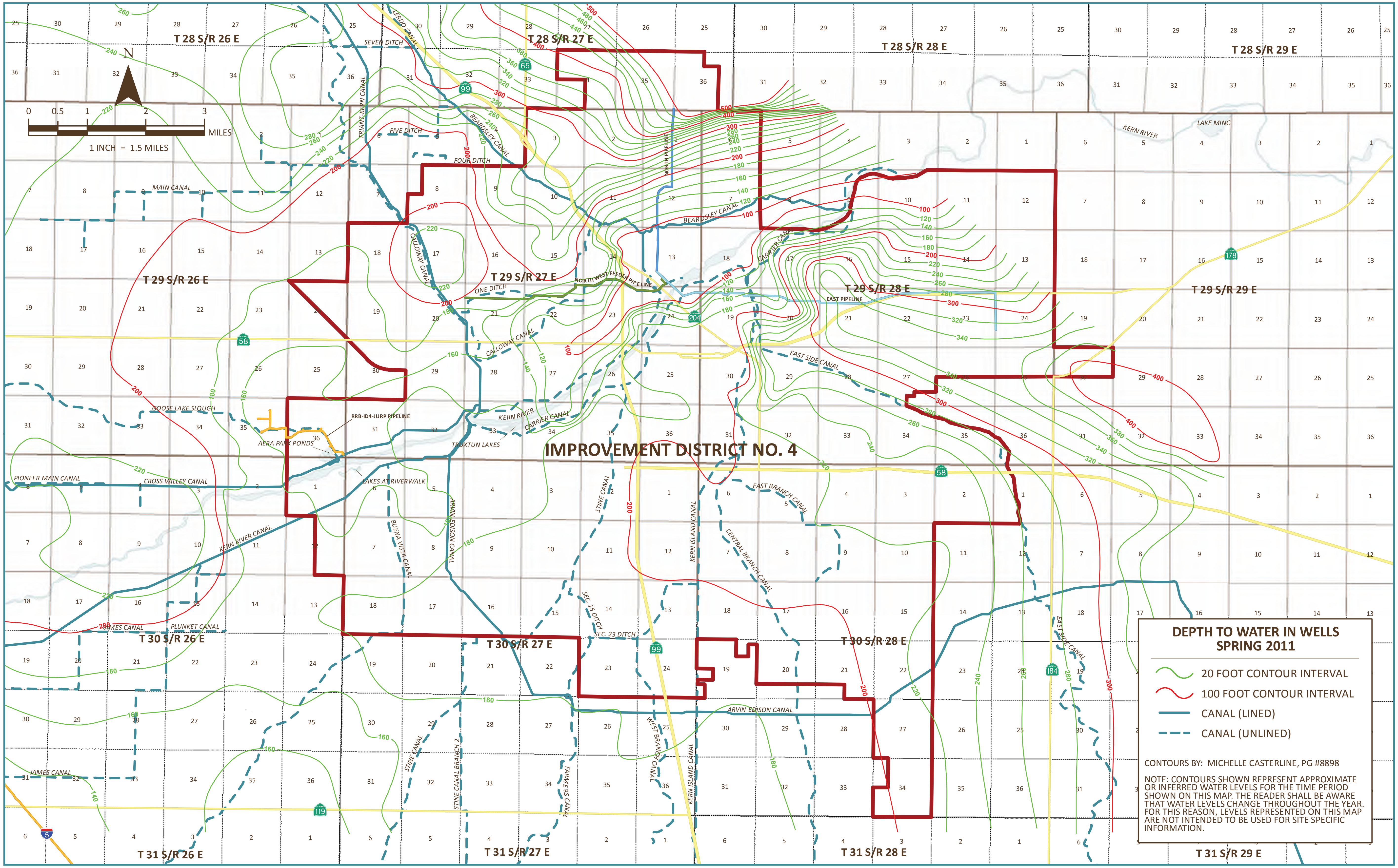
4. Mitigation Plan

Additional studies and subsidence modeling is necessary to understand the cause of subsidence, identify appropriate management actions, and to develop an appropriate mitigation plan that considers beneficial users and all contributors to significant and unreasonable impacts to surface land uses or the FKC.

In order to develop an appropriate mitigation plan, additional studies and subsidence modeling is necessary to understand the cause of subsidence and determine which activities are contributing to subsidence impacts. Once the subsidence modeling is complete, the Kern County Subbasin will develop and implement any necessary mitigation plan.

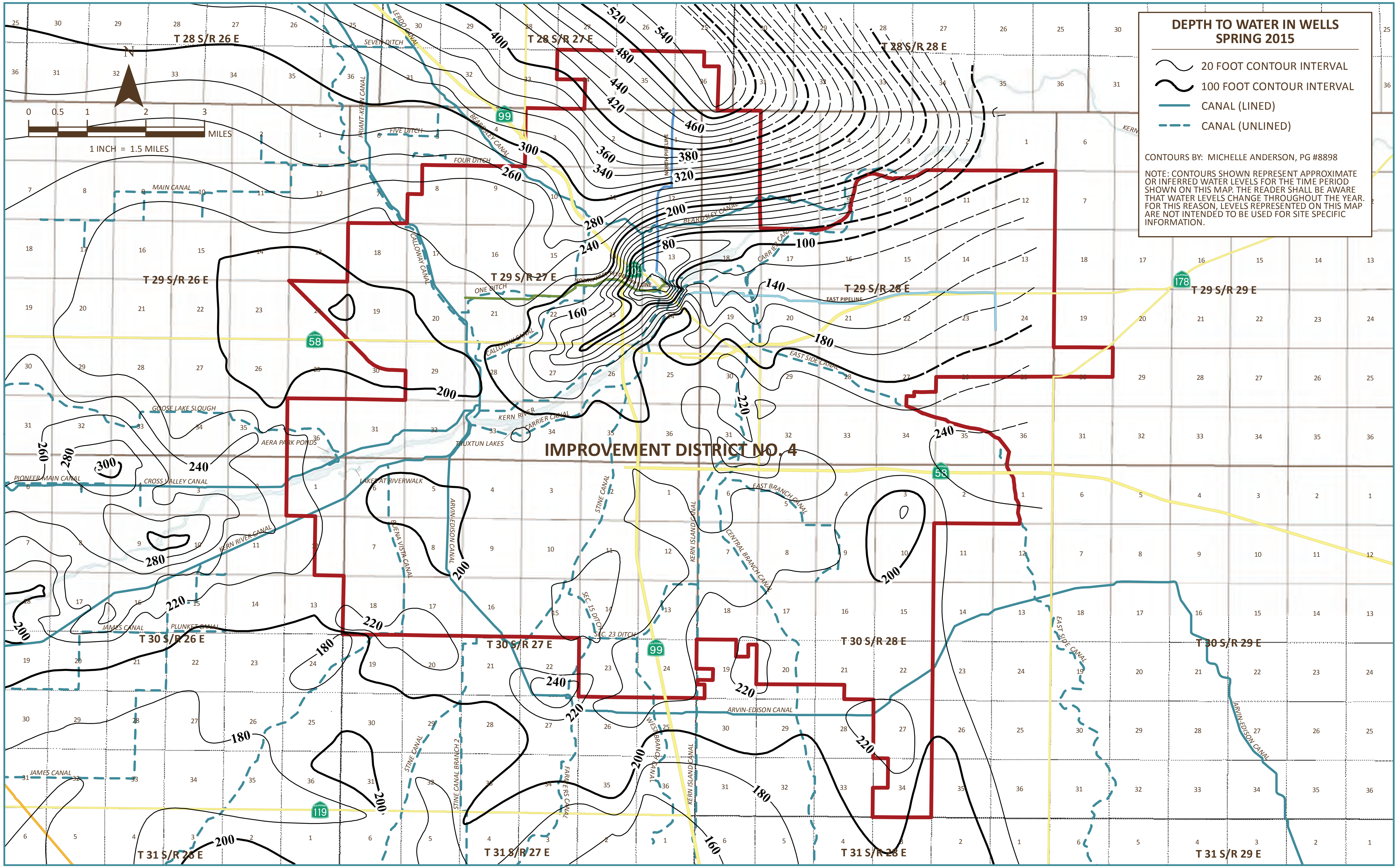
Attachment G

Groundwater Dependent Ecosystems



BY: S. CHAMBLESS
DATE: DECEMBER 5, 2011
REVIEWED BY: M. VARGA
FILENAME: Plate 7 - Depth to Water in Wells (2011).mxd

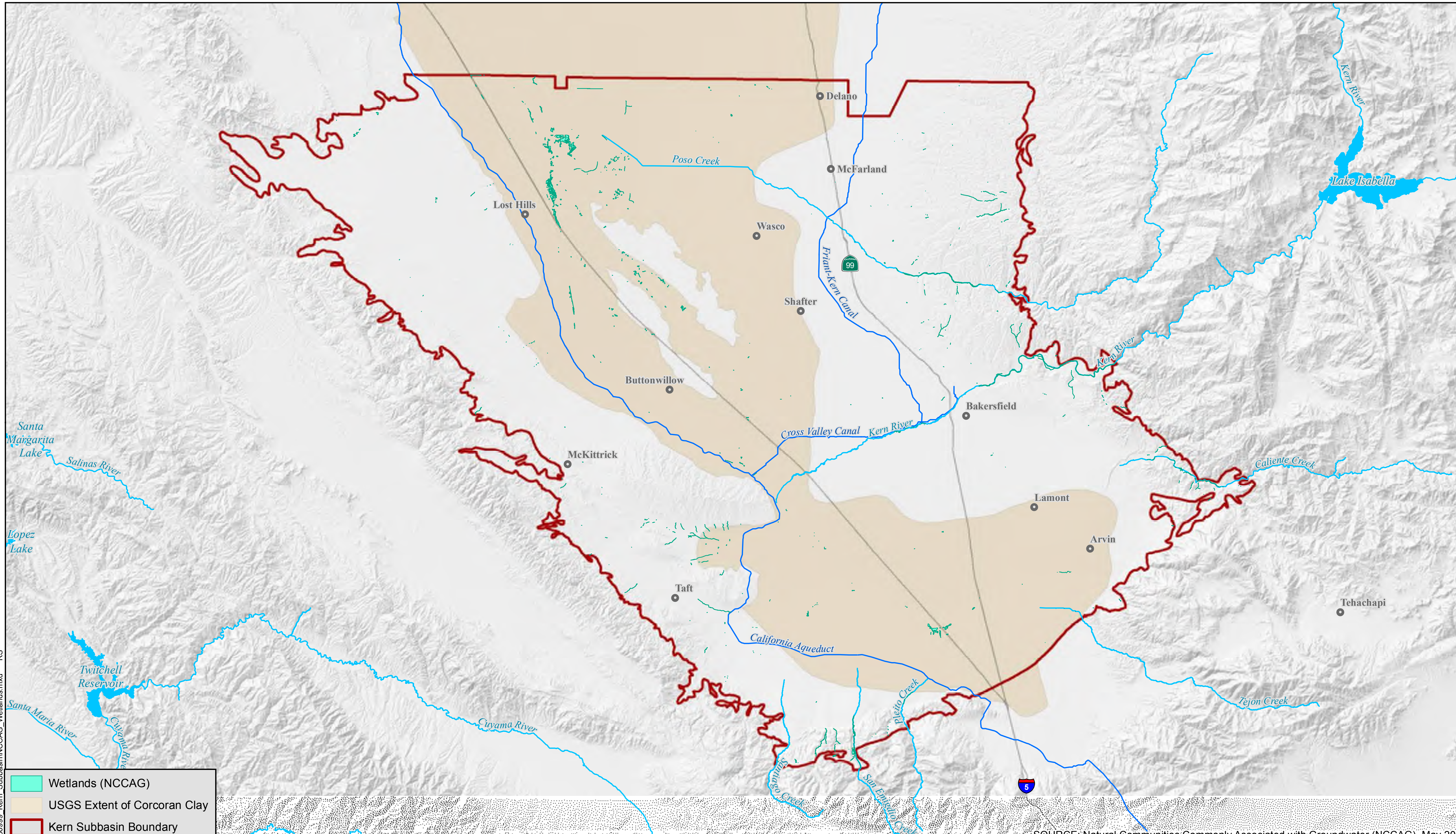
Depth to Water in Wells



BY: M. ALLEN
DATE: NOVEMBER 4, 2015
REVIEWED BY: M. VARGA
FILENAME: Plate 7 - Depth to Water in Wells (2015).mxd

Attachment G

Groundwater Dependent Ecosystems



8 4 0 8

Miles

N W E S

Kern Groundwater Authority
Basin Setting

Kern County, California

GEI Consultants

NCCAG WETLANDS

JANUARY 2019

DRAFT

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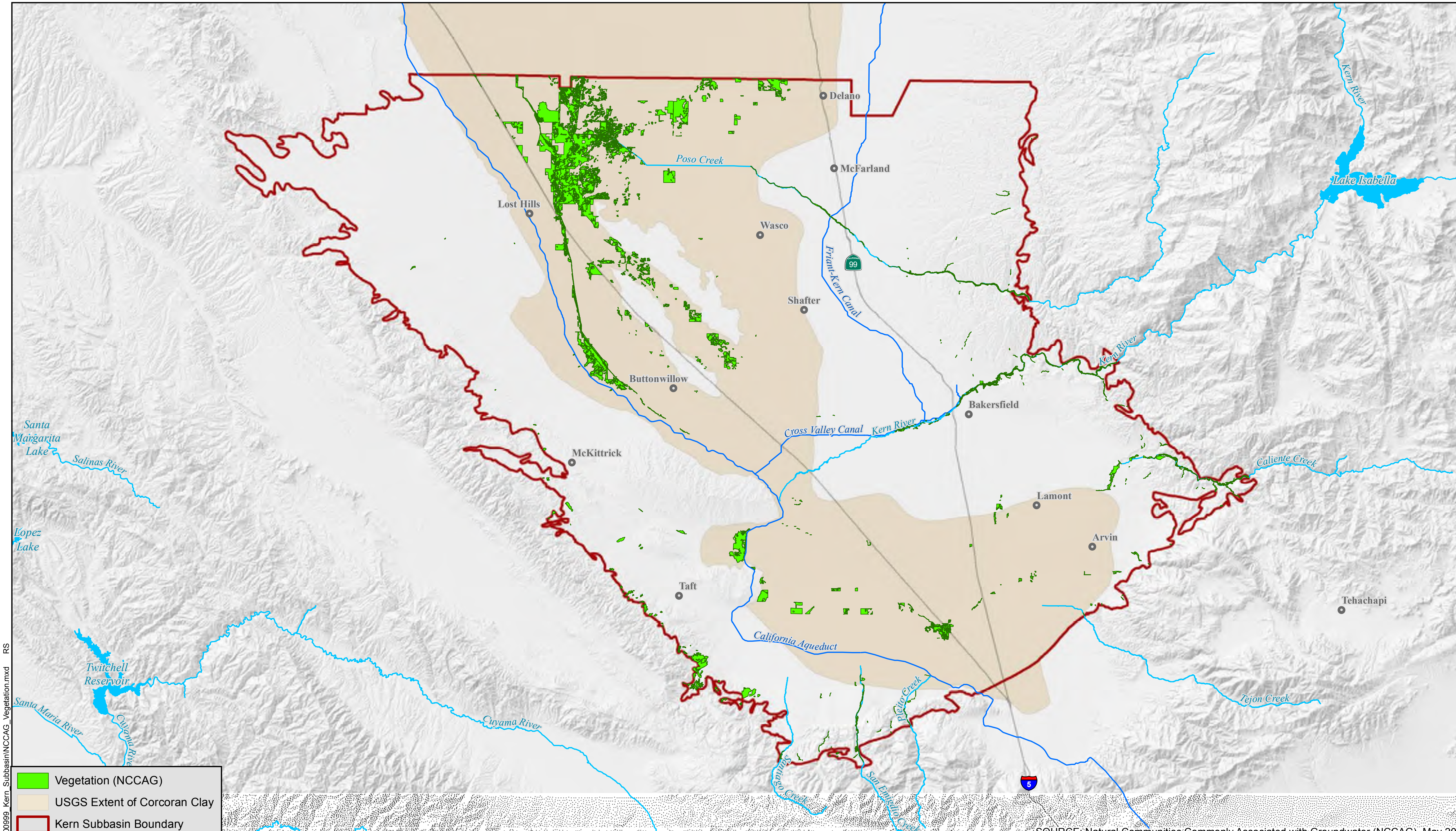

SOURCE: Natural Communities Commonly Associated with Groundwater (NCCAG), May 2018

8 4 0 8

Miles

N W E S

Kern Groundwater Authority
Basin Setting

Kern County, California

GEI Consultants

NCCAG VEGETATION

JANUARY 2019

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Attachment H

Historical and Projected Future Water Budget Development with C2VSim FG-Kern Model

TODD GROUNDWATER

January 7, 2020

MEMORANDUM

To: Mark Mulkay, Kern River GSA
Patty Poire, Kern Groundwater Authority GSA

From: Michael Maley, Todd Groundwater
Charles Brush, Hydrolytics LLC

Re: **SGMA Water Budget Development using C2VSimFG-Kern in support of the Kern County Subbasin Groundwater Sustainability Plans (GSPs)**

1. INTRODUCTION

In compliance with the Sustainable Groundwater Management Act (SGMA), the multiple Groundwater Sustainability Agencies (GSAs) of the Kern County Subbasin (**Figure 1**) have successfully coordinated on the development of Groundwater Sustainability Plans (GSPs). The Kern County Subbasin, the largest in the State, was designated as critically-overdrafted by the California Department of Water Resources (DWR). Water management in the Kern County Subbasin is complex. It involves more than 30 water districts/systems, contains large groundwater banking projects of State-wide importance, and provides large quantities of groundwater to support both large urban centers and one of the top agricultural-producing areas in the country. In addition, most agencies are involved in conjunctive management of local surface water, imported state and federal water, and groundwater.

Within this complex water management setting, GSAs recognized that a numerical modeling tool would be needed to meet GSP regulations for assessment of historical, current, and future projected water budgets that are developed on a Subbasin-wide basis (§357.4(b)(3)). The California Central Valley Groundwater-Surface Water Simulation Model (C2VSim) is anticipated to be DWR's primary tool for evaluating water management in the Central Valley and is specifically referenced in the GSP regulations for application to GSP water budgets (§354.18(f)); therefore, C2VSim was selected by the GSAs for GSP compliance.

This technical memorandum describes the process and approach for selection, revisions, and application of the C2VSim to the Kern County Subbasin. The memorandum documents the development of Subbasin water budgets and presents the results. This document is being prepared as an attachment to Subbasin GSPs and as an attachment to the Kern County Subbasin GSAs' coordination agreement.

1.1 Background

During late 2016 and 2017, Subbasin GSAs held a series of meetings and workshops to evaluate potential modeling tools for GSP application. Although numerous existing models had been developed by various entities in the Subbasin over time, none of those models covered the entire Subbasin or incorporated all of the local water budget components necessary to meet GSP requirements.

During the time that the Subbasin was evaluating various modeling alternatives, DWR was in the process of updating the regional C2VSim model through water year (WY) 2015. In particular, the GSP regulations stated that DWR would provide the C2VSim model "for use by Agencies in developing the water budget." Todd Groundwater developed an approach for review, revisions, and application of the C2VSim model to the Kern County Subbasin. In March 2017, the Kern River GSA (KRGSA), on behalf of the Subbasin GSAs, entered into a contract with Todd Groundwater to conduct the proposed scope of work. The Kern Groundwater Authority (KGA), on behalf of the Subbasin GSAs, also retained Woodard & Curran to conduct a peer review of the Todd Groundwater C2VSim model revisions and application for the Kern County Subbasin.

DWR released the C2VSim Fine Grid Public Beta model (C2VSimFG-Beta) on May 18, 2018 (CNRA, 2018). An initial model review indicated that the C2VSimFG-Beta generally had good historical precipitation, streamflow, land use and crop acreage for the entire Central Valley. Historical water supply and demand data were also generally good in the Sacramento Valley and San Joaquin River hydrologic regions; however, data were considered less reliable in the Tulare Lake hydrologic region including Kern County. To address this concern, Todd Groundwater – working with all Subbasin GSAs –revised the Kern County portion of C2VSimFG-Beta for WY1985 to WY2015. This revised version of C2VSim for the Kern County Subbasin, referred to herein as the C2VSimFG-Kern model, was used to develop historical, current and projected-future water budgets in accordance with the requirements in the GSP regulations.

The Central Valley portion of Kern County contains two groundwater subbasins, the Kern County Subbasin (5-022.14) and the White Wolf Subbasin (5-22.18) based on DWR Bulletin 118 (DWR, 2016A). All of the agencies that deliver water in White Wolf Subbasin also deliver water in the Kern County Subbasin and participated in the C2VSim revision. The White Wolf Subbasin portion of C2VSimFG-Beta model was included in this update to ensure coordination of groundwater conditions between the two subbasins. These are considered separate groundwater basins under SGMA with the Kern County Subbasin listed by DWR as critically-overdrafted with a GSP deadline of January 30, 2020, whereas the White Wolf Subbasin is listed as medium priority with a GSP deadline of January 30, 2022. Therefore, only the model results for the Kern County Subbasin are evaluated and reported here.

1.2 General Approach

The current C2VSim model has a detailed finite element mesh that closely follows local hydrologic features. As a regional model, the C2VSimFG-Beta may over-generalize local conditions within the Kern County Subbasin so as to be inconsistent with local site-specific data and knowledge. To address this concern, the managed water supply and demand inputs were updated to better represent the local water balance. To do this, the more general assumptions in C2VSimFG-Beta were replaced with local data and knowledge that are regionally or locally significant over the WY1995 to WY2015 Hydrology Period. Local managed water supply input data (e.g., surface water deliveries, land use, irrigation demand, return flows, and groundwater banking) were collected and applied to C2VSim. Improvement of Kern County data focused on incorporating:

- Surface water delivery volumes, application areas and use by water district,
- Groundwater banking recharge, recovery and application of recovered water,
- Irrigation demand from recent analyses of remote sensing data of evapotranspiration in the Kern County Subbasin based (ITRC, 2017),
- Urban demand for the Subbasin focusing on Metropolitan Bakersfield, and
- Data on other water sources and demands of local significance to individual districts/GSAs.

Compiling the data needed for the model revision required a coordinated effort from the Subbasin GSAs (**Figure 1**) to provide locally derived data on managed water supply and demand that was used to revise the C2VSimFG-Beta for the Kern County Subbasin. The Subbasin GSAs also coordinated on selection of consistent study periods for the C2VSimFG-Kern water budget analyses. Based on technical considerations and a review of regional data, the following study periods were selected:

- Historical Water Budget - WY1995 through WY2014 (Section 3.2), and
- Current Water Budget - WY2015 (Section 3.2),
- Projected Water Budget - WY2021 through WY2070 using 50 years of hydrologic data based on historical data (Section 6.1).

Todd Groundwater also coordinated data collection and model revision efforts with a Technical Peer Review Team and local agencies to ensure input data were accurately represented in the model. Tabulated input data, model files and model-derived water budgets were provided to the Technical Peer Review Team for review of accuracy and appropriateness. Model input data and results were also provided to Kern County Subbasin water districts and local water purveyors for their review. Comments and data issues were reconciled and incorporated into the revised C2VSimFG-Kern model.

1.3 Acknowledgements

These regional model revisions were enhanced by the participation of the many agencies that provided local water budget input data. Todd Groundwater worked with the member agencies, and their consultants, including the Kern River GSA, Kern Groundwater Authority GSA, Henry Miller Water District GSA, Olcese Water District GSA, and Buena Vista GSA to coordinate acquisition of input data from other agencies in formats that could be easily incorporated into the C2VSim model. On-going review of interim model results by these agencies, including local zonal water budgets, groundwater hydrographs and other model results, helped ensure that the revised model reproduced local mass balance estimates across the Subbasin.

Woodard & Curran conducted an on-going peer review of model input files at the request of the GSAs in the Kern County Subbasin. Todd Groundwater worked with Woodard & Curran throughout the historical model revision process. The C2VSimFG-Kern input files for the Kern County Subbasin revised historical simulation were provided to DWR for incorporation into future C2VSim public releases.

Dr. Charles Brush of Hydrolytics LLC was added to the Todd Groundwater modeling team. As an early developer of C2VSim for DWR, he provided his experience and expertise with the C2VSim. This collaborative effort provided further assurance that the significant model revisions could be managed in an efficient manner to meet the expedited schedule for water budget development.

2. C2VSIM

C2VSim uses DWR's modeling code *Integrated Water Flow Model* (IWFM) and covers the entire California Central Valley. Kern County is located at the far southern end of the Central Valley (**Figure 2**). C2VSim simulates the full hydrologic cycle, calculating water demands and tracking water movement through surface water and groundwater systems, and is therefore well suited to support GSP development.

2.1 C2VSim Background

DWR developed C2VSim to simulate water demands and supplies in the Central Valley. C2VSim is an application of DWR's IWFM software. IWFM is an integrated hydrologic model that simulates water flows on the linked land surface, unsaturated zone, groundwater, and surface water flow systems. A key feature of IWFM is DWR's agricultural and urban water supply and demand management module that dynamically simulates the delivery of both surface water and groundwater supplies based on both water availability and calculated water demands, as affected by usage and climatic conditions.

The C2VSim is derived from a series of Central Valley hydrologic models developed by DWR and other agencies beginning in the early 1990s. Each model in this series has incorporated significant improvements over the previous version (Brush, Dogrul and Kadir, 2013). The groundwater flow system is modeled in IWFM using the finite element method and uses a highly efficient solver developed at UC Davis. The IWFM Demand Calculator (IDC) and land surface simulation process were developed with input from California irrigation management professionals. Given DWR's emphasis on water management, detailed water budgets produced by C2VSim provide strong representations of the surface water and groundwater flow systems and make it a preferred platform for developing water budgets.

2.2 C2VSImFG-Beta Model

DWR's 2018 release of C2VSimFG-Beta includes historical input data for WY1922 to WY2015. C2VSimFG-Beta includes historical precipitation, stream inflow, land use and crop acreage for the entire Central Valley. These data include monthly precipitation and annual land use for each model element and estimated monthly evapotranspiration for each modeled land use type and agricultural crop. Historical surface water data include monthly surface water inflow for each river entering the model boundary and monthly surface water diversions and deliveries.

The C2VSimFG-Beta finite element grid divides the Central Valley into 32,537 model elements (**Figure 2**). Element areas are small near streams and in developed areas and expand to larger sizes in undeveloped areas. Element sizes average 407 acres and range from 4 to 1,770 acres. Central Valley rivers and streams are represented with a network of 110 stream reaches. Surface water and groundwater inflows from uplands along the model boundary are simulated with 1,033 small watersheds. Within the Kern County Subbasin, the land surface elevation varies from 208 feet above mean sea level (msl) in the north to 3,922 feet above msl in the foothills.

The groundwater aquifer system is represented with four aquifer layers and one regional confining layer. The aquifer thickness in the Kern County Subbasin varies from 857 to 9,054 feet and the deepest aquifer location is 8,752 feet below msl. The Central Valley aquifer is simulated with the following hydrostratigraphic layers, listed from top to bottom:

- Shallow, unconfined aquifer,
- Regional confining layer,
- Active confined aquifer (contains high level of pumping),
- Inactive confined aquifer (contains limited pumping), and
- Saline confined aquifer.

C2VSimFG-Beta includes annual land use and crop acreages and monthly precipitation, evapotranspiration, stream inflows, surface water deliveries and specified groundwater pumping rates for WY1922 to WY2015. C2VSimFG-Beta uses IDC to dynamically calculate distributed monthly water demands, allocate available water supplies to meet these demands, and calculate unmetered groundwater pumping necessary to satisfy unmet demands. C2VSimFG-Beta produces detailed monthly water budgets for arbitrary sets of elements grouped into zones.

Water demands are calculated dynamically for each model element using the IWFM Demand Calculator (IDC) for agricultural, urban, native and riparian land use types. Agricultural demand is calculated based on annual crop type distribution mapping and user-specified evapotranspiration rates for 20 irrigated crop types and managed seasonal wetlands at the Kern National Wildlife Refuge. Agricultural water demand is determined based on a soil moisture balance that uses local soil properties to assess the amount of applied water (precipitation and specified surface water applications) available to meet the crop demand. If water demands in an element are not satisfied from these sources, the C2VSim model calculates the groundwater pumping needed to eliminate any deficit.

Urban demands are calculated based on population and per-capita water demands. Water demands for native, undeveloped, fallow or riparian settings are calculated from monthly evapotranspiration rates and the amount of precipitation. If water demands in an element are not satisfied, no applied water is provided to these areas, and the vegetation is assumed to be in a stressed state. Runoff of precipitation in developed and undeveloped areas within the Subbasin and surrounding small watersheds is calculated using methodology included in IWFM that is based on the Soil Conservation Service Curve Method (NRCS, 2004).

C2VSimFG-Beta was released after a preliminary model calibration. The distribution of aquifer parameters was based on a texture analysis of lithologic well logs compiled by the US Geological Survey (USGS, 2009) from Well Completion Reports submitted to DWR by well drillers. The texture analysis interpolated the percentage of coarse-grained material at each well location and depth of the C2VSimFG-Beta mesh. Aquifer parameters were then calculated for the model mesh based on the percentage of coarse-grained material and estimated properties for pure coarse- and fine-grained materials. Transmissivities were estimated using specific capacity tests, where available. Soil properties for each model element were derived from digitized soil maps published by the US Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS, 2018).

3. KERN COUNTY REVISIONS

C2VSimFG-Beta input files were revised to incorporate locally-derived managed water supply and demand data to better represent the local water budgets for the Kern County Subbasin. Additional revisions were made to C2VSimFG-Beta model to address issues that were identified with the physical representation of the Kern County Subbasin. The result of these Kern County specific modifications is a local version of C2VSimFG-Beta that is referred to here as C2VSimFG-Kern. The following provides a summary of the model modifications.

3.1 C2VSimFG-Kern Model

C2VSimFG-Kern input files incorporate locally-derived historical data for the Kern County and White Wolf subbasins to better represent local water conditions. These are two separate groundwater subbasins in the Kern County portion of the San Joaquin Groundwater Basin. The Kern County Subbasin is listed as critically-overdrafted by DWR with a GSP deadline of January 30, 2020, whereas the White Wolf Subbasin is listed as medium priority by DWR with a GSP deadline of January 30, 2022. C2VSimFG-Kern was not changed for areas outside of the Kern County Subbasin.

Historical surface water diversion, water bank recharge and water bank withdrawal information were collected from local GSAs, management areas, water agencies and purveyors. Urban land use was restricted to developed areas, and urban populations and per-capita water demands were updated. Model structure (elements, streams, stratigraphy, etc.) was not modified. Model parameters were not calibrated, although some model parameters were adjusted to improve model performance in specific geographic areas.

3.2 Simulation Time Period

GSP requirements indicate a need to identify an average hydrologic study period for purposes of the groundwater analyses in the basin-wide water budgets. In order to select a consistent study period, the Kern County Subbasin GSAs agreed upon an historical hydrologic study period covering WY1995 through WY2014 (October 1, 1994 through September 30, 2014). The selection of the historical hydrologic study period was based on a variety of technical criteria including:

- Covers at least 10 years consistent with GSP regulations (§354.18(c)(2)(B)),
- Contains 10 years characterized as above normal or wet years based on precipitation; also contains 10 years of below normal or dry years, including four critically dry years,
- 100 percent of the long-term average streamflow conditions on the Kern River, as indicated by an average annual Kern River Index of 100 percent (**Figure 4**),
- About 104 percent of long-term average precipitation (NOAA Bakersfield Meadows Field Airport Station),
- Widely-available high-quality data available across the Subbasin,
- Time period with current water management practices, intensive groundwater banking operations, and more recent land use patterns,
- Begins in a time of relatively stable water levels (October 1994), and
- Overlaps a time period with consistently developed basin-wide contour maps by Kern County Water Agency (KCWA).

For the historical water budget, it is desirable to define a base period when natural hydrology represents average conditions. C2VSimFG-Kern incorporates this 20-year base period of WY1995 through WY2014 with a 10-year spin-up period (WY1985 to WY1994).

Kern County water agencies provided locally-derived water budget data for WY1993 to WY2015 for this study so that data input extended beyond the historical base period. Additional water budget data prior to WY1993 were also collected where available and input into the model.

The simulation period for C2VSimFG-Kern was set to WY1986 to WY2015 (October 1, 1985 through September 30, 2015), allowing a 10-year spin-before the start of the historical base period. The C2VSimFG-Beta simulation period ran from October 1973 through September 2015 (WY1974 to WY2015). The period from October 1973 to September 1985 was not included in the simulation due to concerns about lack of comparable data from these earlier periods.

3.3 Data Compilation

Participating agencies compiled water budget input data sets (using their staff, consultants or other resources) and provided them to Todd Groundwater. Where appropriate, Todd Groundwater developed data templates that conformed to IWFM model data needs and used them to facilitate obtaining input data from local agencies. This included monthly data for the following:

- Surface water imports and diversions (inflows and outflows) by source, conveyance and application area,
- Groundwater banking and managed aquifer recharge by water district or agency,
- Groundwater recovery pumping of groundwater bank recharge for export from the basin,
- Groundwater recovery pumping of managed aquifer recharge for local use,
- Urban area population and per capita water use, and
- Crop evapotranspiration (ET) rates based an analysis of satellite data (ITRC, 2017).

In addition, groundwater banking data were compiled for the large Kern Fan banking projects. Recently developed crop ET rates derived from remote sensing data were used to develop monthly crop ET rates for agricultural crops. Urban land use was restricted to developed areas, urban populations and per-capita water demands were updated, and urban wastewater recharge operations were added.

3.4 Surface Water

Kern County surface water diversions in C2VSimFG-Beta were grouped by project or water source, and some surface water deliveries were applied to large regions rather than to individual districts. In addition, some local surface water deliveries were missing from C2VSimFG-Beta. For C2VSimFG-Kern, the 43 Kern County surface water diversions from C2VSimFG-Beta were replaced with 113 surface water diversions developed with data provided by local agencies.

The Arvin-Edison WSD, Wheeler Ridge-Maricopa WSD and Tejon-Castaic WD overlie both the Kern County and White Wolf subbasins. Surface water deliveries for these districts were apportioned to either the Kern County and White Wolf subbasins, based on data provided by Arvin-Edison WSD and Wheeler Ridge-Maricopa WSD, so that surface water deliveries to those areas could be tracked separately for the water budgets.

3.4.1 River and Stream Inflow

Inflows to the Kern River and Poso Creek at the Subbasin boundary are based on historical gauge data. Kern River inflows at the First Point gauge and downstream gauges were verified and updated based on the annual Kern River Hydrographic Reports produced by the City of Bakersfield (COB, 1985-2015). C2VSimFG-Beta contained Poso Creek inflows for WY1961 to WY1986. Poso Creek inflows for WY1987 to WY2015, based from flow records for the Coffee Canyon and Trenton stream gauges, were added to C2VSimFG-Kern based on data provided by the local agencies.

3.4.2 Surface Water Diversions

Monthly surface water diversion data for WY1995 to WY2015 were collected for 21 agencies and recharge projects in Kern County. The data from each water district or agency included monthly surface water inflow by source and monthly surface water outflow by destination.

The monthly surface water inflow and outflow data collected for this study did not have sufficient detail to track this water and create an accurate historical water budget for each canal for each month. The data did provide sufficient information to identify monthly surface water diversions from each source and deliveries to each end use. Therefore,

- All diversions from the Kern River were exported from the model and treated as imports at delivery locations,
- Diversions from Poso Creek and the Kern River Flood Channel (or Main Drain) were diverted from the appropriate stream nodes, and
- All other surface water deliveries (State Water Project (SWP), Central Valley Project (CVP), oil field recovery water, etc.) were treated as imports.

Each C2VSim surface water diversion is linked to two groups of model elements: the elements of the end use and the elements receiving the recoverable losses. A single set of elements was used for both purposes in C2VSimFG-Kern. Model elements for agricultural, urban and refuge deliveries were selected by overlaying the model grid on delivery areas maps. Model elements for recharge diversions were selected by overlaying the model grid on recharge basin maps.

Monthly water delivery data for the SWP, CVP and Kern River were also provided by the agencies. Monthly turnout-level deliveries for the SWP were also compiled from the monthly SWP Report of Operations published by DWR. Monthly CVP deliveries were compiled from the USBR Report of Operations. Monthly Kern River flow and diversions were compiled from Kern River Hydrographic Reports. Water agencies in the Kern County Subbasin trade and wheel water in real time to maximize water utilization, minimize waste and energy consumption, and meet immediate water needs. Water delivery reports from water suppliers (such as the CVP and SWP) generally identify the owner of delivered water, not where it was actually delivered.

Some surface water conveyances discharge water into stream or river channels for re-diversion downstream. A key part of the surface water system in Kern County is the Kern River. Kern River operations data were reviewed for calendar years 1970 to 2015. While **Table 1** summarizes surface water deliveries, **Table 2** summarizes Kern River diversions by turnout location as applied in C2VSimFG-Kern.

3.4.3 Surface Water Deliveries

Water flow through the Kern River and its associated canal system is very complex. Water is diverted from the Kern River into a parallel canal system at several locations, with some diverted water flowing back to the river. Some water from the CVP and SWP are discharged into the Kern River for diversion downstream. Some water agencies are served from multiple diversion points along the Kern River. Several canals that receive water diverted from the Kern River also exchange water with other canals and receive some water from groundwater pump-in, so deliveries from many canals cannot be attributed to a single source. **Figure 5** shows the locations of the primary streams, regional surface water canals, and groundwater recharge locations in the Kern County Subbasin.

Each surface water diversion in C2VSim is allocated to a specified destination and water use. Five water use types are simulated in C2VSimFG-Kern: agricultural, urban, refuge, recharge and export. Agricultural and refuge diversions are applied to a group of model elements that corresponds to a surface water service area within a specific water agency or refuge. Urban diversions are allocated to an urban service area. Groundwater recharge diversions are allocated to the model element or elements where the receiving recharge basin is located. Three delivery fractions apportion each surface water diversion to application, loss to groundwater (recoverable loss), and loss to evaporation (non-recoverable loss). **Table 1** summarizes the annual surface water deliveries for agricultural use by water district in Kern County. **Table 3** summarizes surface water diversions for urban use, wastewater land disposal and wildlife refuge management in Kern County.

3.5 Groundwater Banking and Managed Aquifer Recharge Operations

In our preliminary discussions with the C2VSim developers at DWR, it was revealed that significant model uncertainty was related to incomplete data regarding groundwater banking and other managed aquifer recharge (MAR) operations in the Kern County Subbasin. Recognizing the importance of these groundwater banking projects for simulating groundwater conditions, the groundwater banking and MAR operations data was updated using the earliest available records.

3.5.1 Recharge and Recovery Data

A monthly time-series of recharge rates was determined for each recharge project. Recharge rates were allocated to individual recharge basins using the initial data whenever possible or were shared proportionally between basins based on historical rates. All Kern County recharge basin surface water deliveries were simulated as imports.

Recharge basin locations and recovery well locations were provided by each agency or project (**Figure 6**). The C2VSim finite element grid was overlaid onto a map of recharge basins to determine the model elements for each recharge location. Well location coordinates were added to C2VSimFG-Kern.

Monthly volumes for recharge at groundwater banking and managed aquifer recharge facilities were compiled for 16 agencies and projects (**Table 4**). This information originated from multiple sources, and included data provided by agencies, compiled from agency reports, and compiled from Kern River Hydrographic Reports. The data includes monthly recharge for years prior to 1995 for many projects. Several agencies and projects provided data for multiple recharge basins. Some groundwater wells used for recovery of banked water are also used for other purposes such as supplementing agricultural or urban surface water deliveries.

Recognizing that several of the large groundwater banking projects (especially those on the Kern Fan) pre-date the 20-year base period, and that future studies might simulate periods prior to 1985, all available historical data for groundwater banking operations was reviewed and updated. This included incorporating pre-1985 data for banking operations at

- Arvin-Edison WSD (1966-2015),
- Berrenda Mesa Project (1977-2015),
- Buena Vista WSD (1963-2015),
- City of Bakersfield 2800 Recharge Facilities (1973-2015),
- North Kern WSD (1956-2017), and
- Rosedale-Rio Bravo WSD (1980-2015).

3.5.2 Groundwater Recovery

Two types of recovery wells were added to the C2VSimFG-Kern. These include district-operated water wells that were used for out-of-district transfers or out-of-basin exports of groundwater, and wells used for recovering banked groundwater and distributing the pumped groundwater via the district's water conveyance system to provide water supply, typically for agricultural use, within the district. The locations of the specified groundwater recovery wells are shown on **Figure 6**. The specified groundwater recovery pumping input into C2VSimFG-Kern is summarized as follows:

- 229 time series for Kern County groundwater banking withdrawals were added,
- 313 simulated pumping wells and 225 pumping time series for local groundwater pumping by district-operated recovery wells were added, and
- Elemental agricultural, refuge and urban pumping was eliminated in areas where it has not historically occurred.

Recharge and withdrawal data for the Kern Fan banking projects, including the Kern Water Bank, Berrenda Mesa Project, Pioneer Project, and the City of Bakersfield 2800 Recharge Facilities were shared with the local banking authorities for verification. Banking data for district-specific groundwater banking projects were provided by these districts. A summary of the data input for groundwater recovery pumpage added to C2VSimFG-Kern is provided in **Table 5**.

3.5.3 Model Application

A separate diversion was created to deliver surface water to each recharge basin or set of geographically close jointly managed basins. A diversion time series of monthly application rates was then created for each recharge diversion from the available data. Each recharge diversion delivers water to the model elements coinciding with the receiving recharge basin(s). Recharge basins were simulated in C2VSimFG-Kern by setting the application delivery fraction to zero, the recoverable loss fraction to 94% and the evaporation loss to 6%.

Monthly groundwater recovery was generally provided by well field and destination (e.g., agriculture, urban, canal pump-in, or export). This information was used to develop a pumping time series for each well field and destination. Groundwater pumped for export from the Kern County Subbasin is summarized in **Table 6**. Recovery well locations and screen intervals were used to enter each recovery well into C2VSimFG-Kern. Recovery pumping time series were then allocated equally to all of the wells in each field.

Some well fields supply water to two different end uses, for example supplementing surface water deliveries within the district in some months and exporting water from the district in other months. This is handled in C2VSimFG-Kern by entering the well two times. Each entry is associated with a separate time series of pumping rates and delivery destination.

3.5.4 Groundwater Banking Obligations

The general operation of groundwater banking facilities is to recharge excess available surface water supplies during wet years by recharging to the groundwater and recovering this water by pumping in dry years when surface water supplies are limited. Groundwater banking programs store water in the Kern County Subbasin for use by local agencies and for export to out-of-basin entities.

For evaluating the groundwater sustainability, any water stored in the Kern County Subbasin that is contractually obligated to an out-of-basin entity does not contribute to the long-term groundwater sustainability because the owner of that water could call for its return at any time. However, this can be difficult to track because a common practice is to recover groundwater for local use to replace imported surface water that was sent to the out-of-basin entity.

C2VSimFG-Kern does not have a mechanism to track these complex contractual exchanges, so the tracking is done as a post processing step by assigning the portion of the groundwater recharge as an out-of-basin banking obligation.

The Kern County Subbasin GSAs provided the total out-of-basin banking obligation for their operations as of September 2014 for the historical assessment. As of September 2014, the out-of-basin banking obligation for the Kern County Subbasin totaled of 1,719,307 acre-feet, which, when averaged over the 20-year period, was 85,965 acre-feet per year (AFY). The 85,965 AFY is applied during post-processing of C2VSimFG-Kern historical water budget results.

3.6 Urban Water Demand

C2VSim calculates urban water demands for specified urban delivery zones, allocates specified surface water and groundwater supplies to meet these demands, and can optionally pump additional groundwater to satisfy unmet urban demands in each zone. Urban demands were represented with nine urban zones in C2VSimFG-Beta. These zones were reconfigured, and a tenth urban zone was added representing Metropolitan Bakersfield in C2VSimFG-Kern. Historical urban populations and per capita water use rates were reviewed and updated.

3.6.1 Urban Zones

C2VSimFG-Kern dynamically calculates urban water demands for urban zones using time-series data of urban populations and monthly per capita water use. The urban delivery zones of C2VSimFG-Beta were modified to better represent Kern County population centers, jurisdictional boundaries and urban water sources. Although Kern County urban water delivery systems are operated by many diverse entities, their water generally comes from two sources: surface water deliveries and agency-operated groundwater wells.

The nine Kern County urban zones in C2VSimFG-Beta for Kern County were numbered 97-105. The Urban Zone boundaries were adjusted, as shown on **Figure 7**, as follows:

- Portions of Urban Zones 97, 99, 100, and 102 in C2VSimFG-Beta were used to create Urban Zone 106 representing the Metropolitan Bakersfield area,
- Urban Zone 98 was extended southeast to near the Stockdale Highway to include unincorporated urban areas,
- The boundary of Urban Zone 99 was extended eastward to California State Route 65 to include small communities in this area, removing them from Urban Zone 100, and

- The northern boundary of Urban Zone 104 was moved north to correspond to the West Kern WD service area.

3.6.2 Urban Population and Per Capita Use

Historical annual urban populations for the urban zones were estimated using United States Census total population data from 1990, 2000 and 2010 (US Department of Commerce, 2018). Tabular historical census data and census block shapefiles were obtained from the IPUMS National Historical Geographic Information System Database (IPUMS 2018). These data were combined to produce maps of the geographic distributions of populations within Kern County. The historical populations for each Urban Zone were estimated by mapping census block centroids to the ten Urban Zones using ArcGIS. The 1990, 2000 and 2010 populations of each Urban Zone were then estimated as the sum of the populations of the associated census blocks. Populations for other years were estimated using interpolation and extrapolation. The population values by Urban Zone used for C2VSimFG-Kern are listed in **Table 7**.

3.6.3 Urban Water Use Specifications

Monthly historical urban water demands for Urban Zone 106 were calculated using water delivery data from the water purveyors in the Metropolitan Bakersfield area. Monthly historical urban water demands for the other urban zones in the Kern County Subbasin were estimated using available water use data from published urban water management plans for the communities served in those zones. The historical monthly water use in each zone was then divided by the historical population to obtain the monthly per capita urban water demand. Monthly historical per capita water demands for zones without urban water management data were estimated using the per capita water demand from zones with similar demographics.

The urban water use specifications indicate the portion of total urban water that is used indoors. In C2VSimFG-Kern, the portion used indoors becomes urban return flow, and the remainder is added to the urban root zone where it contributes to evapotranspiration and deep percolation. C2VSimFG-Beta included monthly urban water use specifications for each model subregion. The urban per capita water use was based on local water supply data and urban water management plans. **Table 8** lists the per capita water use data used for C2VSimFG-Kern.

3.6.4 Urban Wastewater

Urban wastewater for the Metropolitan Bakersfield area is treated at local wastewater treatment plants; however, wastewater disposal is primarily evaporation ponds or land disposal at locations outside of the Metropolitan Bakersfield area. C2VSimFG-Beta does not have a direct means to redirect wastewater to an outside location. Urban wastewater, based as the indoor use, is applied uniformly within the urban zone. To get around this limitation, application of wastewater for the Metropolitan Bakersfield area was turned off in C2VSimFG-Kern. The wastewater deliveries to evaporation ponds and land disposal areas from the wastewater treatment plants was assigned to the appropriate location using data provided by the plants. This conserved the water balance by not double counting wastewater, and it was applied at the appropriate locations for evaluating groundwater levels.

3.6.5 Model Application

Historical annual urban population estimates were placed in the C2VSimFG-Kern urban population input file. Historical monthly urban per capita water demand estimates for each urban zone were placed in the C2VSimFG-Kern urban per capita water use file. Urban demand was calculated by C2VSimFG-Kern and the water supply to meet these demands was met first by specified surface water and groundwater pumping deliveries for urban use. The remaining water demand in each model element was met with groundwater pumped from the aquifer portion of that element.

3.7 Agricultural Crop Water Demand

C2VSim dynamically calculates agricultural crop water demands and allocates supplies to meet these demands for each model element. Agricultural demands are calculated for 20 crops using historical crop acreage data and crop evapotranspiration (ETc) rates. Crop water demands in each model element are first met with stored soil moisture, surface water deliveries and specified groundwater deliveries. If the agricultural demands are not satisfied, the model can optionally calculate the additional groundwater pumping required to satisfy the unmet demands and extract that water from the groundwater component of the model element.

C2VSimFG-Beta contained one set of monthly ETc rates for each model subregion that were applied to all years despite climatic variation. New monthly ETc rates for three model subregions (northeast, northwest, south) in Kern County were calculated for 1993-2015 using monthly remote sensing imagery and detailed annual crop maps. ETc for 1974-1992 were estimated from 1993-2015 values by using the values for similar water year types based on the San Joaquin Index. Satellite data were not available for 2012, so ITRC was unable to provide METRIC data for 2012. In C2VSimFG-Kern, 2013 was applied as an appropriate proxy for ETc data in 2012 because of their hydrologic similarity.

A remote sensing study of historical ETc rates across the entire Kern County Subbasin by the Irrigation and Training Research Center (ITRC, 2017) provided detailed basin-wide agricultural demands that corresponded to the WY1995 to WY2014 base period. These data were used to develop monthly ETc rates for the Kern County portion of the model.

3.7.1 ET Rates

The Irrigation Training and Research Center (ITRC) at California Polytechnic State University, San Luis Obispo, has developed a procedure to use remote sensing imagery from Landsat satellites to calculate historic ETc rates (ITRC, 2017). The Mapping of Evapotranspiration with Internal Calibration (METRIC) method was originally developed by Richard Allen of the University of Idaho. ITRC made several modifications to the original METRIC method to better match California data and conditions (named the ITRC-METRIC method). These modifications include using grass for reference evapotranspiration (ETo), incorporating a semi-automated calibration procedure and spatially interpolating ETo rates. An example of the METRIC ET data for the total annual ET in 2013 is provided in **Figure 8**.

ITRC used Landsat imagery for 1994-2015 (except 2012 when no imagery was available) and the ITRC-METRIC method to develop monthly raster maps of ETc at 30 x 30-meter resolution for the Kern County portion of the Central Valley (ITRC, 2017). The monthly ETc raster maps were used with annual DWR crop maps to calculate the average ETc by crop type for the three Kern County C2VSim subregions. ITRC-METRIC raster data were used to determine the exact areas of applied irrigation and total annual ETc. A raster pixel was assumed to be irrigated if the total annual ETc was greater than 20 inches.

The following data processing steps were used to determine monthly ETc rates for each crop and C2VSim subregion:

- Create irrigation coverages – ITRC-METRIC monthly ETc raster data were summed to calculate total annual ETc for each year for each raster location. The ArcGIS Reclassify tool was then used on each annual ETc raster to create a binary polygon coverage for each year for 1994-2015 (except 2012), setting the attribute "IRR" to 1 if total annual ETc was over 20 in/year, and to 0 if total annual ETc was equal to or less than 20 in/year.

- Create land use coverages – Annual DWR land use rasters were converted to polygon coverages with the attribute "Crop" set to the corresponding integer crop value used in C2VSimFG-Kern. The land use rasters were checked against GIS maps produced by the Kern County Agricultural Commissioner and errors in the DWR land use rasters were corrected. DWR land use maps for 1994-1997 were missing large areas of data, so the 1998 land use map was used to approximate the land use for 1994-1997.
- Create monthly zone maps – One zone shapefile was created for each month by using the ArcGIS Union tool to combine a shapefile of the three C2VSim subregions with the irrigation coverage (produced in step 1) and the land use coverage (produced in step 2). Each monthly zone polygon shapefile has three attributes: C2VSim subregion, binary irrigation indicator, and a land use crop value. The dissolve function was used to combine zones with identical parameters.
- Calculate average monthly ETc for each zone – The ArcGIS Zonal Statistics by Table tool was used to calculate the average ETc value for each zone for each month. The individual pixels in each monthly ETc raster were averaged within each zone (produced in step 3). ITRC-METRIC data for 2013 were used in place of missing data for 2012.
- Combine tables – The MS Access Append function was used to combine the monthly ETc tables into a master table of monthly ETc by crop and C2VSim subregion.
- Output data – Data from the Access database was exported in a form consistent with the C2VSimFG-Kern input files. The output was also summarized to show the average monthly ETc for the irrigated area of each crop type in each model subregion.

The monthly ETc rates for the three Kern County subregions for WY 1993-2015 were then replaced with the monthly ETc rates calculated using ITRC-METRIC data. The annual ETc rates applied to C2VSimFG-Kern by crop are listed in **Table 9**.

3.7.2 Irrigation Periods

The C2VSim Irrigation Periods file contains monthly parameters for each crop and subregion that indicate whether or not the crop is irrigated in that month. C2VSimFG-Beta irrigation periods for the three Kern County subregions were adjusted to match crop irrigation practices from ITRC-METRIC water usage. Refuge irrigation periods for the three Kern County subregions were also adjusted to match Kern NWR practices. Simulated irrigation water usage for the C2VSimFG-Kern better reflects observed irrigation practices.

3.8 Model Modifications

In general, the scope of work was to revise the managed water supply and demand for the Kern County Subbasin. During the course of this revision, several issues were identified with the hydrogeological conceptual model and simulation parameters that affected the historical water budget. The following summarizes modifications made in C2VSimFG-Kern to improve the model performance. Other issues identified regarding the hydrogeological conceptual model, model setup and simulation parameters that were not addressed in C2VSimFG-Kern but are recommended to be modified for future model updates, are listed in Section 8.5. A summary of the changes that were made in C2VSimFG-Kern are provided below.

3.8.1 Streambed Parameters

In the Kern County Subbasin, the Kern River and Poso Creek are the two largest streams. Both have multiple stream gauges along their courses including ones near where they enter the Kern County Subbasin from the Sierra Nevada. These are the only two streams that are simulated in the model using the IWFM stream module. Both are predominantly losing streams where surface water recharges groundwater, except during limited periods near the major groundwater banking operations west of Bakersfield when multi-year periods of recharge operations produce high groundwater levels.

As a part of the C2VSimFG-Kern update, the simulated recharge from the Kern River and Poso Creek were compared to changes in stream gauge measurements and estimated streambed losses to evaluate how well the model was simulating streambed seepage. For much of the Kern River, the amount of streambed seepage is estimated based on daily weir information and is documented in the annual Kern River Hydrographic Reports. The streambed parameters used in C2VSimFG-Beta were not providing a comparable volume and distribution of seepage along the Kern River streambed. In dry years, streamflow as not getting far enough downstream whereas in wet years the seepage was too low. Similarly, the Poso Creek streambed seepage showed similar issues based on comparisons to differences in stream gauge data along its course.

To address this, the Kern River and Poso Creek streambed parameters were manually modified until a reasonable approximation of the measured streambed seepage was achieved by C2VSimFG-Kern. In general, the streambed conductance was lowered whereas the stream wetted perimeter was increased. This provided the best balance in matching the measured dry, average and wet years flows in both streams.

Part of this issue is that C2VSimFG-Beta uses a simple form of the stream module in the simulation. This approach appears to work sufficiently well for the continuously flowing streams in the northern parts of the Central Valley but is not sufficient for simulating the highly variable flows that occur on the Kern River and Poso Creek. It is recommended that future revisions to C2VSimFG-Kern further evaluate issues in simulating streamflow and seepage in the Kern River and Poso Creek (see Section 8.5). This may include incorporating more advanced streamflow simulation features that are available in IWFM but that have not been utilized in C2VSimFG.

3.8.2 Small Watershed Runoff

In reviewing the small watershed contributions, it was determined that the runoff was not representing the variable nature of runoff in an arid region. Although this was not part of the originally planned model revisions, it affected the model results. Todd Groundwater revised the corresponding model parameters to be more representative of the local arid conditions in Kern County.

Runoff of precipitation from the surrounding small watersheds was calculated within C2VSimFG-Kern using methodology included in IWFM that is based on the SCS Curve Method (NRCS, 2004). The C2VSimFG-Beta results showed a steady baseflow that contributed water to the Kern County Subbasin continuously and did not show the appropriate variation in runoff expected between wet, average and dry years in the arid environment.

Two major issues were identified and revised. First, the SCS curve number was changed to allow a higher percentage of runoff in wet years to capture the flashy nature of runoff from these watersheds during differing climatic conditions. Second, IWFM uses a localized soil moisture water budget; however, soil, ET and other parameters were set that allowed for the continuous outflow from the basins. These were changed to more appropriate values that limited baseflow from the very small watersheds while allowing baseflow from the larger watersheds. Parameters were varied to better match estimated watershed runoff from a local USGS study (Nady and Larragueta, 1983).

3.8.3 Root Zone Parameters

Areas of overly high root zone hydraulic parameters led to high volumes of deep percolation that required additional groundwater pumping to meet the overall water demand for irrigation. This issue was noted by local water district staff who recognized that the groundwater pumping and deep percolation from preliminary model results were significantly higher than what was found in practice. A review found areas of overlying hydraulic conductivity and other hydraulic parameters that caused this high percolation rate. Two types of issues were found. First, very high parameters were found in parts of the basin that were not consistent with local soil data. Second, the root zone parameters for lakebed and other heavy clay soil areas were too high. These areas were manually adjusted to be more in line with observed conditions. A more rigorous development of root zone parameters should be considered in the future as this issue demonstrates that it is a sensitive parameter.

3.8.4 Land Use Modifications

The agricultural land use and crop type distribution in the model for early period (1974-1990 and 1992-1996) from C2VSimFG-Beta used a regional distribution and did not accurately represent historical practices. This resulted in agricultural water use being distributed across the entire Kern County Subbasin including areas that did not have irrigated agriculture. To correct for this, land use and crop type data were modified to conform with irrigated agricultural areas in the early 1990s. The crop types were adjusted to be consistent with the Kern County Agricultural Commissioner reports for these years. This included capturing the appropriate crop types present in the Kern County Subbasin in the periods from 1974 through 1996. For example, there was a higher percentage of cotton produced during that period and a lower percentage of nut trees, which became one of the major crop types in the 2010s.

3.8.5 Westside Pumping Limits

Western Kern County contains large areas with poor groundwater quality. As a result, little or no agricultural or urban groundwater pumping occurs in this area. To simulate this, groundwater pumping was turned off in C2VSim-Kern in most of the area with poor groundwater quality. However, in the Westside District Water Authority Management Area, limited groundwater pumping does occur. The poor-quality water is mixed with surface water to supplement the imported water supply. To simulate this condition, the groundwater pumping rate in the Westside District Water Authority Management Area was estimated to be 10% of the surface water deliveries, and the automated groundwater pumping adjustment in C2VSimFG-Kern was turned off for these areas.

Subsequent to the completion of the historical model, GSP developers in the Westside area refined their estimate of pumping used to mix with delivered surface water to about 3,000 AFY, which is considerably lower than that used in the historical model. The Westside GSP developers included a management action to further refine the estimated groundwater use in the Westside GSP water districts. Therefore, the original assumption was left in this version of the historical model. The Westside District Water Authority Management Area GSP identifies a management action to further evaluate the groundwater pumping in their area. The results of their evaluation will be included in in future model updates.

3.8.6 Kern Wildlife Refuge pumping

C2VSimFG-Beta enabled groundwater pumping in the model elements representing the Kern National Wildlife Refuge. The Kern National Wildlife Refuge Water Management Plan (USBR, 2011) indicates that during the simulation time period, the refuge was sustained entirely on imported surface water and occasional diversions of Poso Creek flood waters. No groundwater was pumped at the refuge during the simulation period 1985-2015. Groundwater pumping was used at some time in the past. Groundwater pumping and automated groundwater pumping adjustment were turned off for all model elements in the Kern National Wildlife Refuge.

In addition to the Kern National Wildlife Refuge, former rice fields and other areas are currently used for sustaining ponds at private duck hunting clubs in the northwestern portion of the Kern County Subbasin. Water use data for these operations were not available during the development of the historical model. This water includes a combination of surface water and groundwater, and this volume is considered to be very small relative to the overall basin water use. GSP developers included a management action to further refine the estimated water use for these facilities that will be addressed in future updates.

3.9 C2VSimFG-Beta Modifications

Minor changes were made to the C2VSimFG-Kern hydrogeological conceptual model and natural water budget components and are listed in **Table 10**. The architecture of the model including layering, discretization, boundary conditions, and aquifer properties was not revised. Aquifer parameters were adjusted in several areas to better match observed historical conditions, especially in areas with high historic recharge volumes such as the Kern Fan. Extremely high soil hydraulic conductivities in a small set of elements were reduced to more reasonable values. Stream-bed conductance values were modified in some stream reaches to better match simulated stream gains and losses to observed values. Minor adjustments to small watershed parameters were also made to match surface runoff to observed values.

Due to the number of modifications that were identified with the hydrogeological conceptual model and aquifer parameters during the C2VSimFG-Kern update, it is recommended that a more rigorous model update be conducted that will update the hydrogeological conceptual model and aquifer parameters to be consistent with that presented in the Kern County Subbasin GSPs. In addition, further calibration of C2VSimFG-Kern is recommended to update aquifer parameters in the Kern County Subbasin. Future calibration is further discussed in Section 8.5.

4. HISTORICAL AND CURRENT WATER BUDGETS FROM C2VSIMFG-KERN

C2VSimFG-Kern was used to develop historical (WY1995 to WY2014) and current (WY2015) water budgets for the Kern County Subbasin. The following summarizes the simulated water budgets from C2VSimFG-Kern. A summary of these results is provided below.

4.1 Historical and Current Water Budget

The simulated historical and current water budgets based on C2VSimFG-Kern are presented in **Tables 11A** and **11B** and are presented graphically on **Figures 9**. **Figure 10** presents the average annual historical water budget for the Kern County Subbasin. The results for the historical water budget are summarized under the following categories that are defined as:

- **Deep Percolation** – Precipitation and applied water that reaches the groundwater after simulated transport across the unsaturated zone. The simulated historical 20-year average is a net inflow of 669,398 AFY.
- **Managed Recharge and Canal Seepage**- Combined groundwater recharge from managed aquifer recharge operations, groundwater banking, and seepage from canals and other conveyance. The simulated historical 20-year average for Managed Recharge and Canal Seepage is a net inflow of 583,598 AFY. On Figure 10, this total is subdivided between out-of-basin groundwater banking obligations (85,965 AFY) and the remaining local recharge of 497,633 AFY.
- **Net Groundwater-Surface Water (GW/SW) Interactions** - Net volumetric exchange of surface water and groundwater between the aquifer and streams: Positive represents a net groundwater recharge, and negative represents a net groundwater discharge to the stream. The simulated historical 20-year average is a net inflow of 98,606 AFY.
- **Small Watershed Inflow** – Runoff, small stream inflow and subsurface inflow from the small watersheds and areas surrounding the groundwater basin. The simulated historical 20-year average is a net inflow of 48,760 AFY.
- **Groundwater (GW) Pumping** - Total groundwater pumping by wells. Groundwater banking recovery pumping is specified as fixed input values and agricultural and municipal pumping is calculated by C2VSimFG-Kern based on demand minus surface water diversions. The simulated historical 20-year average is a net outflow of 1,590,373 AFY.
- **Subsurface Flow with Adjacent Groundwater (GW) Basins** - Net subsurface groundwater flow to and from the Kern County Subbasin with adjoining groundwater basins: negative is a net flow out of the Subbasin and positive is a net flow into the Subbasin. The simulated historical 20-year average is a net outflow of 87,102 AFY.
- **Change in Groundwater Storage** - Sum of the inflow components (positive numbers) plus the outflow components (negative numbers): positive is an increase in storage typified by a rise in groundwater levels whereas a negative is a decrease in storage typified by a decline in groundwater levels. The simulated historical 20-year average is a decline in groundwater storage of 277,114 AFY.

The simulated change in groundwater storage varies over the 20-year historical period and is closely related to climatic conditions and surface water supply availability (**Figure 11**). During the periods

WY1995 to WY1999, WY2005 to WY2006 and WY2011, the groundwater storage volume was stable to increasing and correlates to the above average rainfall and surface water availability during these times. During the periods WY2000 to WY2004, WY2007 to WY2010 and Y2012 to WY2015, groundwater storage volume decreased, correlated to periods of drought and low surface water availability. The simulated historical groundwater recharge also reflects this climatic pattern with high deep percolation to groundwater and steep increases in managed aquifer recharge and canal seepage during the above average rainfall periods and lower groundwater recharge during the drought years (**Figure 12**).

Groundwater pumping for agriculture shows a general increasing trend from WY1995 to WY2014; however, groundwater pumping is lower in above average rainfall years and higher during droughts (**Figure 13)**. This general increasing trend follows a comparable decreasing trend in surface water deliveries over this same period. As shown on **Figure 14**, surface water deliveries show a general decreasing trend from WY1995 to WY2014; however, the surface water deliveries are higher in the above average rainfall years and lower during the droughts.

4.2 Sustainable Yield

Section 354.18(b)(7) of the GSP Regulations requires that an estimate of the basin's sustainable yield be provided in the GSP (or in the coordination agreement for basins with multiple GSPs). SGMA defines "sustainable yield" as:

> "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."

SGMA does not incorporate sustainable yield estimates directly into sustainable management criteria. Sustainable yield is referenced in SGMA as part of the estimated basinwide water budget and as the outcome of avoiding undesirable results. Basinwide pumping within the sustainable yield estimate is neither a measure of, nor proof of, sustainability. Sustainability under SGMA is only demonstrated by avoiding undesirable results for the six sustainability indicators.

4.2.1 Determination of Sustainable Yield

To determine the sustainable yield for the Kern County Subbasin, the results of the C2VSimFG-Kern model were used with two methods to estimate the amount of groundwater pumping that would avoid the undesirable result of a reduction in groundwater storage over the historical base period 1995 to 2014. The results are shown in **Table 12** and are summarized below:

- **Sustainable Yield from Groundwater Pumping –** The model results produced an average annual groundwater pumping in the Kern County Subbasin of 1,590,373 AFY with a decline in groundwater storage of 277,114 AFY. Subtracting the groundwater storage decline from groundwater pumping produced a sustainable yield of approximately 1,313,000 AFY.

- **Sustainable Yield from Groundwater Recharge –** The model results produced an average annual groundwater recharge in the Kern County Subbasin of 1,400,362 AFY. The subsurface outflow from the GSA was estimated to be 87,102 AFY. Subtracting these outflow losses from the groundwater recharge produced a sustainable yield of approximately 1,313,000 AFY.

Sustainable yield estimates are part of SGMA's required basinwide water budget. In general, the sustainable yield of a basin is the amount of groundwater that can be withdrawn annually without causing undesirable results. This sustainable yield estimate can be helpful for evaluating the projects and programs needed to achieve sustainability. Although the SGMA regulations require a single value of sustainable yield calculated basinwide, it should be noted that the sustainable yield can be changed by implementation of recharge projects, variations in climate, or changes in stream flow conditions.

Using WY1995 to WY2014 as the base period, C2VSimFG-Kern results show declining groundwater levels and long-term reduction of groundwater storage. During this period, average annual inflow to the aquifer is 1,400,362 AFY, and outflow is 1,677,476 AFY (**Table 11A**). This yields an average annual deficit of 277,114 AFY. Based on these historical C2VSimFG-Kern results, the sustainable yield of the basin is approximately 1,313,000 AFY, with an estimated level of uncertainty on the order of plus or minus 10% to 20%.

4.2.2 Native Yield

Although not a SGMA requirement, the native yield is being used by Kern County GSAs for determining a portion of the groundwater allocation within the basin. The native yield is comparable to the sustainable yield except that the only recharge that is included in the calculation is the natural, unallocated portion of the groundwater recharge. For the Kern County Subbasin, this includes the groundwater recharge derived from precipitation and runoff from unallocated streams. The Kern River and Poso Creek, however, are allocated streams where specific agencies or parties have rights to specific volumes of flow.

The C2VSimFG-Kern model results over the historical base period WY1995 to WY2014 was again used for estimation of native yield. The model results were used to determine the amount of precipitation recharge over irrigated agricultural areas and the native/urban/undeveloped areas. The total and average annual volume of precipitation that percolates to groundwater during the WY1995 to WY2014 base period are listed in **Table 13**. The basinwide contribution is the relative proportion of the runoff along the basin margins from small, unallocated watersheds and inflow from the surrounding basin margin (from areas not defined as DWR groundwater basins). The results of this assessment based on the C2VSimFG-Kern results are shown in **Table 13** and are summarized below:

- The volume of precipitation that recharges the groundwater in the irrigated agricultural areas is 77,780 AFY.
- The volume of precipitation that recharges groundwater in the other areas is 132,981 AFY.
- The volume of inflow from unallocated small watersheds that recharges the groundwater in the irrigated agricultural areas is 48,760 AFY.

Totaling these inputs results in a native yield for the Kern County Subbasin of 259,520 AFY. The annual contribution per acre of approximately 0.144 acre-feet per acre is estimated by dividing the average annual contribution by the total area of the Kern County Subbasin (**Table 13**).

Similar to the sustainable yield, the native yield at this time is based on the available data. However, as data gaps are eliminated and management actions/plans are implemented, the native yield could change, and any changes to native yield will be included in future GSP amendments.

4.2.3 Application of Sustainable and Native Yield

In general, the sustainable yield of a basin is the amount of groundwater that can be withdrawn annually without causing undesirable results. The native yield is comparable to the sustainable yield except that the only recharge that is included in the calculation is the natural, unallocated portion of the groundwater recharge. The following estimates of the Kern County Subbasin sustainable and native yields are derived from the C2VSimFG-Kern historical model results for the purpose of supporting GSP assessment of the types and magnitude of projects and programs needed to achieve sustainability.

The C2VSimFG-Kern estimates of sustainable and native yield presented here are based on available data and the current level of model calibration. Therefore, these estimates are considered appropriate as guides to SGMA planning. However, the C2VSimFG-Kern sustainable and native yield estimates are initial water budget estimates that are not intended for determination of individual landowner allocations or groundwater rights. Additional technical and legal analysis, along with stakeholder involvement, is necessary to fully quantify the sustainable and native yields.

5. APPROACH FOR PROJECTED FUTURE WATER BUDGETS

Projected future Baseline water budgets for the Kern County Subbasin were developed using the C2VSimFG-Kern. These projected water budgets establish expected Baseline conditions to evaluate the impacts of GSP implementation. Three predictive scenarios were developed for the Kern County Subbasin, each representing a different expected future hydrologic condition, by adapting C2VSimFG-Kern as follows:

- Future Baseline Conditions: Repeat historical hydrology with expected future water supply,
- 2030 Climate Conditions: Adjust historical hydrology for 2030 climatic conditions and expected water supply, and
- 2070 Climate Conditions: Adjust historical hydrology for 2070 climatic conditions and expected water supply.

Projected future water budgets were developed for Baseline conditions and expected 2030 Climate Conditions and 2070 Climate Conditions over a 50-year planning and implementation horizon. These scenario models provide a basis of comparison for evaluating proposed sustainability management actions and projects over the SGMA planning and implementation horizon.

5.1 Assumptions

C2VSimFG-Kern was modified to incorporate projected future hydrology and land use using analog data from the historical C2VSimFG-Kern model. This approach meets GSP requirements using:

- A 50-year time-series of historical precipitation, evapotranspiration and stream flow information as the future Baseline hydrology conditions,
- The most recent land use, METRIC-based evapotranspiration, crop coefficient and urban population growth information as the Baseline condition for estimating future water demands,
- The most recent water supply projections as the Baseline condition for estimating future surface water supply,

- DWR Climate Change Guidance and Data Sets to incorporate estimated climate change conditions for the Kern County Subbasin,
- Specialized analysis of the Kern River watershed and estimated runoff volumes under climate change conditions,
- Specialized analysis of CVP deliveries to Kern County under climate change conditions incorporating implementation of the San Joaquin River Restoration Program, and
- Specialized analysis of SWP deliveries to Kern County under climate change conditions incorporating implementation of the OCAP Biological Opinion and recent changes in Table A and Article 21 allocations.

5.2 Projected Future SGMA Projects

Projected water budgets for the Kern County Subbasin were developed using the C2VSimFG-Kern to evaluate the performance of proposed management actions with respect to achieving groundwater sustainability. Participating agencies provided a list of projected future management actions to be implemented between WY2021 and WY2040. These projects were simulated under Baseline conditions, 2030 Climate Conditions and 2070 Climate Conditions through WY2070 using the C2VSimFG-Kern.

Proposed future projects and management actions were provided by GSAs. The types of proposed SGMA projects and management actions are summarized as follows:

- Demand Reduction is the volume of water reduced by changing the land use; these include:
    - Agricultural demand reduction projects through incentives or actions to reduce crop water use,
    - Fallowing of agricultural land and conversion of agricultural land to recharge basins, and
    - Conversion of agricultural land to urban land.
- New Supply groups together planned increases in imported water supplies; these include:
    - Increased surface water imports generally resulting from projected water purchases,
    - New water conveyance facilities including pipelines and reservoirs to increase flexibility, and
    - Expansion of surface water delivery areas to reduce groundwater usage.
- Other Supply groups together proposed projects to increase local water supplies; these include:
    - Recharging treated waste waters derived from both urban areas and oil production operations; increased recharge occurs in both existing and new locations,
    - Increased stream flow diversions; these include exercising riparian water rights and diverting flood flows,
    - Reallocation of water; generally reducing sales of surface water and banked groundwater and using this water within the agency, and
    - Brackish groundwater in areas not currently overdrafted will be treated and mixed with surface water to augment surface water supplies.

Some management actions are implemented gradually over many years, with savings increasing each year over the implementation period. Some management actions are implemented only in certain years (wet years, for example). The anticipated average-annual water supply benefit of the proposed SGMA projects and management actions steadily increases over the 20-year period from WY2021 to WY2040 to represent the implementation of the Kern County Subbasin GSPs. This increasing trend, as shown as the average-annual water supply benefit over five-year increments on **Figure 15**, is summarized as follows:

- about 116,000 AFY over the first five-year period (WY2021-WY2025),
- about 216,000 AFY over the second five-year period (WY2026-WY2030),
- about 343,000 AFY over the third five-year period (WY2031-WY2035), and
- about 361,000 AFY over the fourth five-year period (WY2036-WY2040).

The anticipated water supply benefit of the proposed SGMA projects and management actions included in the C2VSimFG-Kern projected future simulations is 422,000 AFY over the period from WY2041 to WY2070. Benefits of implementing these projects and management actions over the 20-year implementation period are summarized in **Figure 15**.

6. PROJECTED FUTURE BASELINE DEVELOPMENT

Projected water budgets are required by GSP regulations to represent future conditions over a 50-year GSP planning and implementation horizon. A Baseline condition was developed that projects water supply, demand and operations based on current land use and expected water supply availability over 50 years. The Baseline then serves as a basis of comparison for evaluating proposed sustainability management actions and projects for achieving sustainability over the planning and implementation horizon. Each predictive scenario model simulates the 50-year planning and implementation period WY2021 to WY2070. Development of the projected future Baseline conditions is summarized below.

6.1 Projected Future Time Period Development

WY1995 to WY2014 was chosen as a historical hydrology period because detailed demand and supply data are available for this period, and most Subbasin water delivery infrastructure was fully developed by the middle of this period. The average Kern River inflow for this period is also very close to the long-term average Kern River inflow.

The projected future simulation period is based on repeating the WY1995 to WY2014 historical study period. This period is only 20 years long, so a 50-year sequence of historical hydrology was developed by repeating data from this period in the sequence as shown in **Table 14**. The development of this sequence is summarized as follows:

- Simulation period WY2021 to WY2032 used the historical period WY2003 to WY2014,
- Simulation period WY2033 to WY2052 used the historical period WY1995 to WY2014, and
- Simulation period WY2053 to WY2070 used the historical period WY1995 to WY2012.

This sequence was developed to match long-term average flows on the Kern River, and to ensure that the Baseline does not end in an extreme drought or extreme wet year. By starting the projected future simulation time sequence with WY2003, the 50-year hydrology period has approximately 100 percent of the long-term average streamflow conditions on the Kern River, as indicated by an average annual Kern River Index of 100 percent. The sequence includes the appropriate range of hydrologic conditions including extremely wet years and extended periods of drought.

C2VSimFG-Kern simulation results for the last timestep of the historical simulation (September 30, 2015) were used as initial conditions for all projected future simulations, including initial conditions for the root zone, saturated and unsaturated aquifer zones, and small watersheds. Since the historical C2VSimFG-Kern simulation period ends with WY2015, all projected future scenarios also include estimated hydrology for WY2016 to WY2020. Model input data for WY2016 to WY2020 was developed by repeating model input data for recent years based on correlation with the San Joaquin Index (DWR, 2019).

6.2 Development of Key Baseline Data Sets

Key required components for the Projected Future Baseline, as summarized in the DWR *Water Budget Best Management Practices* guidance document (DWR, 2016B) include the following:

- The projected Baseline hydrology conditions were developed using 50-years of historical precipitation and streamflow following the sequence outlined in Section 6.1.
- Surface water supplies are based on available information from DWR and others to project future water imports from the SWP, CVC - Friant-Kern Canal (FKC) and Kern River diversions. For the Kern River, recent diversion practices based on entitlements were used to develop water use consistent with the Baseline hydrology.
- WY2013 land use was used as current land use for all scenarios as drought conditions likely reduced agricultural production in WY2014 and WY2015.
- Consumptive use for agriculture and undeveloped lands was based on the recent land use and METRIC-based evapotranspiration. Following DWR guidance, METRIC data over the Baseline period was varied according to varying hydrologic conditions (e.g., water year type).
- Urban water demand was based on projections from recent urban water management plans to meet regulations for future water use. Urban demand was estimated in the model based on projected urban population growth and per capita water demand information (including recent regulatory guidance).
- Small watershed inflows used the same parameters as the historical C2VSimFG-Kern model; however, volumes varied based on changes in the precipitation and ET under the 2030 and 2070 climate change conditions.

Time-series input data were first developed for the Baseline scenario model for WY2021 to WY2070. Development of this time-series input data generally involved repeating time-series data from the historical C2VSimFG-Kern in the appropriate sequence. The following time-series data were developed for each scenario:

- Precipitation rates,
- Evapotranspiration rates,
- Surface water inflow rates,
- Surface water diversion and delivery rates, and
- Specified groundwater pumping rates.

Baseline scenario model time-series data files were then modified following DWR guidelines to produce time-series input data for the 2030 Climate Conditions and 2070 Climate Conditions scenario models. C2VSim input data were modified only in Kern County. C2VSim input data for areas outside of Kern County were not modified.

The baseline data sets were incorporated into the model files to develop the projected future water demand and supply under Baseline, 2030 Climate and 2070 Climate conditions. A summary of the development of the projected future water demand and supply is discussed below.

6.3 Projected Future Water Demand

The projected future water demand was developed using fixed WY2013 land use areas with historical evapotranspiration rates for the Baseline and modified evapotranspiration rates for the 2030 and 2070 climate scenarios and increasing urban populations.

6.3.1 Agricultural Water Demand

Evapotranspiration rates for the Baseline scenario model were developed by repeating input evapotranspiration rates from C2VSimFG-Kern in the appropriate sequence. DWR provided monthly change factors for ETo values under 2030 and 2070 central tendency climatic conditions on a 6 km x 6 km VIC grid for calendar years 1915 through 2011. The VIC grid IDs for each C2VSim subregion in the Kern County Subbasin Zone of Interest were identified and area weighted monthly ETo change factors were calculated for each subregion. Baseline scenario ETc rates for each subregion were then multiplied by the appropriate area-weighted ETo change factors to produce time-series ETc rates for the 2030 Climate Conditions and 2070 Climate Conditions scenarios. Factors for calendar years 1959-1961 were used as analogs for calendar years 2012-2014.

6.3.2 Urban Water Demand

Urban water demand calculations include an indoor component and an outdoor component. Indoor urban water demands are based on the urban population and monthly per capita water demand. Future urban populations for Kern County urban areas were estimated using California Department of Finance population projections. Future per capita urban water demands were estimated using projections from urban water management plans and California urban water conservation regulations, including SB 606 and AB 1668. Future outdoor urban water demands are based on ETc rates, which were modified as described in the Agricultural Water Demand section above.

6.3.3 Groundwater Banking Recovery

Future groundwater banking recovery rates were developed by repeating historical recovery rates in the appropriate sequence. No adjustments were made to Baseline rates or to rates for 2030 and 2070 climatic conditions.

6.4 Projected Future Water Supply

Projected future precipitation, stream inflow and surface water import time series were developed following DWR guidelines. Baseline future water supplies were developed by repeating historical values in the appropriate sequence. Surface water diversions were then adjusted to account for operational changes. Baseline water supplies were then modified to simulate 2030 and 2070 central tendency climatic conditions.

6.4.1 Precipitation Rates

Precipitation rates for the Baseline scenario model were developed by repeating input precipitation rates from C2VSimFG-Kern in the appropriate sequence. DWR provided monthly change factors for precipitation under 2030 and 2070 central tendency climatic conditions on a 6 km x 6 km VIC grid for calendar years 1915 through 2011. The VIC grid ID for each C2VSim element in the Kern County Subbasin Zone of Interest was identified and the Baseline scenario precipitation rates were multiplied by the appropriate factors to produce time-series precipitation rates for the 2030 Climate Conditions and 2070 Climate Conditions scenarios. Factors for calendar years 1959-1961 were used as analogs for calendar years 2012-2014.

6.4.2 Surface Water Inflow Rates

Surface water inflow rates for Poso Creek and White River for the Baseline scenario model were developed by repeating input inflow rates from C2VSimFG-Kern in the appropriate sequence. DWR provided unimpaired streamflow change factor datasets for Central Valley streams, and an Excel spreadsheet tool to modify basin unimpaired streamflow using these change factors. The unimpaired streamflow change factors and spreadsheet were used to modify Baseline inflows to produce 2030 Climate Conditions and 2070 Climate Conditions scenario time series inflows for Poso Creek and White River.

Surface water inflow rates for Kern River at First Point for the Baseline scenario model were developed by repeating historical inflow rates from C2VSimFG-Kern in the appropriate sequence. Flows on the Kern River are regulated, so the unimpaired streamflow method was not appropriate for estimating future flows under 2030 and 2070 climatic conditions. Projected Kern River flows at First Point under 2030 and 2070 central tendency conditions were estimated by GEI (2018) for calendar years 1956-2010 hydrology. This analysis considered the impacts of changed runoff in each sub-watershed contributing to the Kern River to develop revised streamflow estimates for Kern River at First Point. Future scenario Kern River at First Point flows for calendar years 2011-2014 were estimated using flows for analog years with similar annual flows and monthly flow pattern. Analog years 1986, 1991, 1990 and 1961 respectively were used for 2011-2014 in the future scenarios.

6.4.3 Surface Water Deliveries

Surface water delivery rates for the Baseline scenario model were developed by first repeating input surface water delivery rates from the C2VSimFG-Kern in the appropriate sequence, and then modifying selected data sets. Surface water deliveries from in-basin sources such as Oil Field Recovery were held constant at WY2015 rates for all future scenarios.

The Kern County Subbasin is served by both the CVP and the SWP. Recent changes in CVP and SWP operations and their impacts on future surface water supplies are reflected in surface water diversion rates for the three scenarios. Future CVP deliveries will be affected by implementation of the San Joaquin River Restoration Program (SJRRP) that included the 2008 U.S. Fish & Wildlife Service biological opinion (BO) on the Long-Term Operational Criteria and Plan (OCAP) for coordination of the CVP and SWP. Future SWP deliveries will be affected by operational changes implemented between 2004 and 2008 including the OCAP BO, reduced Table A contract amounts and reduced Article 21 deliveries. DWR provided projected future deliveries from the CVP and SWP for WY1922 to WY2003, derived from CalSim-II modeling conducted for the Water Supply Investment Program (WSIP) (California Water Commission, 2016). DWR's CVP projections as provided do not fully incorporate these SJRRP operational changes. DWR's SWP delivery projections do not include the OCAP BO operational constraints, the reduced Table A amounts and reduced Article 21 water.

Future CVP delivery projections developed by the Friant Water Authority (FWUA) were used in place of DWR's CVP projections. FWUA (2018) used CalSim-II to develop projected surface water deliveries with SJRRP implementation under hydrological conditions representing the Current Baseline, 2030 and 2070 climate conditions by delivery class for WY1922 to WY2003, and estimated allocations to each CVP contractor. The 2015.c data set was used for Baseline scenario CVP deliveries, the 2030.c data set was used for 2030 Climate Conditions scenario CVP deliveries, and the 2070.c data set was used for the 2070 Climate Conditions scenario CVP deliveries. CVP deliveries for WY2004 to WY2014 were estimated using deliveries for analog years WY1951 to WY1961; these analog years have a similar distribution of water availability.

The SWP projections provided by DWR for WY1995 to WY2003 and historical deliveries for WY2004 to WY2014 were modified to incorporate the impacts of SWP operational changes in the three scenarios. 2019 SWP Table A contract amounts were used to allocate these SWP deliveries to individual districts. In summary:

- Baseline Hydrologic Conditions
    - WY1995 to WY2003 conditions are based on 2030-Level CALSIM increased by 3.03 %,
    - WY2004 to WY2007 conditions are based on historical data adjusted for OCAP BO, and
    - WY2008 to WY2014 conditions are based on historical data with the assumption that OCAP BO adjustments are already factored into the data.
- 2030 Climate Change Hydrologic Conditions
    - WY1995 to WY2003 conditions are based on the 2030-Level CALSIM Projection,
    - WY2004 to WY2007 conditions are based on OCAP BO adjustment reduced by 3.03 %, and
    - WY2008 to WY2014 conditions are based on historical data reduced by 3.03%.
- 2070 Climate Change Hydrologic Conditions
    - WY1995 to WY2003 conditions are based on the 2070-Level CALSIM Projection,
    - WY2004 to WY2007 conditions are based on OCAP BO adjustment reduced by 8.09%, and
    - WY2008 to WY2014 conditions are based on historical data reduced by 8.09%.

Within the Kern County Subbasin, water users engage in complex real-time water trading and wheeling activities to maximize water utilization, minimize waste and energy consumption, and meet immediate water needs. It would be difficult to project future surface water deliveries in the Kern County Subbasin without the use of a surface water allocation model that simulates these water trading and wheeling activities. Therefore, for this modeling effort, monthly future scenario agricultural, urban and recharge deliveries from sources originating outside the basin were estimated by adjusting historical deliveries by the ratio of (total scenario inflows)/(total historical inflows) for each month, where total inflows are the sum of CVP deliveries, SWP deliveries and Kern River at First Point. In addition, Kern River at First Point flows above historical flows under the 2030 Climate Conditions and 2070 Climate Conditions scenarios were proportionally added to selected recharge deliveries. This method is deemed adequate for subbasin-level future scenario analyses.

Some future scenario data sets did not cover the entire period from October 1994 through September 2014. In these cases, data from an analog historical period with similar water availability was used to fill in the missing data. The analog years for each data type are summarized as:

- For CVP deliveries (CalSim-II data), WY1951 to WY1961 were used as analogs for missing WY2004 to WY2014 data; these analog years have a similar distribution of water availability.
- Projected future Kern River at First Point flows for calendar years 1986, 1991, 1990 and 1961 were used as analogs to missing calendar years 2011 through 2014; each of these analog years had a similar historical annual flow volume and monthly distribution.

- For climatic data adjustment factors, calendar years 1959-1961 were used as analogs to missing calendar years 2012-2014.

6.5 Development of Climate Change Conditions

Input data for the C2VSimFG-Kern were modified to simulate three future climatic scenarios. Historical precipitation, evapotranspiration, land use, population, surface water inflow and surface water delivery rates were replaced with projected future values for WY2016 to WY2070 for Future Baseline Conditions. The Future Baseline Conditions for WY2021 to WY2070 were then modified to simulate 2030 Climate Conditions and 2070 Climate Conditions. Water management agencies in the Kern County Subbasin provided a broad suite of proposed water management and conservation projects to increase water supplies and reduce water management demands. These projects are added to the C2VSimFG-Kern to assess the long-term impacts of these projects under the Baseline, 2030 Climate Conditions and 2070 Climate Conditions scenarios.

Projected water budgets under Future Baseline Conditions, 2030 and 2070 Climate conditions are used to evaluate the potential effects of future Baseline and extended dry conditions with respect to achieving sustainability. DWR published a *Modeling Best Management Practices* Guidance Document (DWR, 2016B) that outlines DWR recommendations for developing and running predictive scenarios. The C2VSimFG-Kern was modified following these recommendations to develop the Baseline scenario model. DWR also issued the *Guidance for Climate Change Data Use During Sustainability Plan Development* Guidance Document (DWR 2018A) that outlines how DWR recommends that climate change be addressed under SGMA. Baseline scenario data sets were modified using DWR climate change data sets for Kern County following procedures outlined in the guidance documents to develop the 2030 Climate Conditions and 2070 Climate Conditions scenario models. The adjustment factors for Baseline, 2030 Climate Change and 2070 Climate Change for SWP deliveries were developed based on consistent CalSim operations studies at current, 2030 and 2070 climate levels developed for Bay Delta Conservation Plan evaluation and provided by DWR Bay Delta Office staff. The WSIP studies provided on DWR's SGMA web site were not used due to the unavailability of a Baseline study with assumptions consistent with the 2030 and 2070 climate change studies.

6.6 Groundwater Banking Assumptions

Groundwater banking operations are simulated in the C2VSimFG-Kern with surface water diversions to recharge basins and specified pumping rates for groundwater extractions. All surface water deliveries were adjusted under the Baseline, 2030 Climate Conditions and 2070 Climate Conditions scenarios. Surface water deliveries to recharge basins were first adjusted by the same ratio as other surface water deliveries, then increased if Kern River flows were greater than historical flows. Specified pumping rates for groundwater extraction were not modified.

The out-of-basin banking obligations were assumed to follow a similar pattern where groundwater banking recharge would be affected by the limitation on surface water deliveries, but that banking recovery would remain similar to historical volumes. Therefore, the historical groundwater banking obligations were adjusted under the Baseline, 2030 Climate Conditions and 2070 Climate Conditions scenarios by the same percentage as the surface water deliveries; however, the groundwater banking recovery was assumed to remain the same. Based on the historical banking obligations and using that as a foundation going forward, no banking partner has ever requested the full amount of the water banked at any particular time even in the most recent drought years. All the banking obligation agreements require limitations on amounts to be requested and delivered as well as "leave in" amounts that remain in the Kern County Subbasin. This historical management of banking obligations provides the Kern County Subbasin more flexibility for use of water as well as delivery of the obligations. For the projected future scenarios, the out-of-basin banking obligations were calculated as follows:

- For the Baseline scenarios, the out-of-basin banking obligations were calculated as 69,632 AFY based on surface water deliveries of about 81% of historical deliveries.
- For the 2030 Climate scenarios, the out-of-basin banking obligations were calculated as 67,913 AFY based on surface water deliveries of about 79% of historical deliveries.
- For the 2070 Climate scenarios, the out-of-basin banking obligations were calculated as 64,474 AFY based on surface water deliveries of about 75% of historical deliveries.

Tracking of banked groundwater obligations was done using the same post processing process as applied to the historical groundwater assessment by assigning the portion of the groundwater recharge as an out-of-basin banking obligation.

7. PROJECTED FUTURE C2VSIMFG-KERN SIMULATION RESULTS

The C2VSimFG-Kern was run for three scenarios that estimate hydrologic conditions of Baseline, 2030 Climate Conditions and 2070 Climate Conditions scenarios both with and without the proposed SGMA projects and management actions for a total of six projected future scenarios.

7.1 Projected Future Water Budgets

C2VSimFG-Kern calculates water budget components each month of the simulation period for each future scenario. Projected future water budgets developed based on the C2VSImFG-Kern simulation results with the proposed SGMA management actions were then compared to results for the future scenarios without the management actions to assess how these changes enhance groundwater sustainability within the Kern County Subbasin.

The average annual value of each water budget component summarizes the impacts over 50 years with current water demands. The water budget results for the six Projected Future Scenarios are presented in **Tables 16 through 21**, and include averages over three different periods, which include:

- **WY2021 to WY2040** – Implementation Period representing the 20-year period required by the SGMA regulations to implement projects and management actions to achieve sustainability.
- **WY2041 to WY2070** – Sustainability Period representing the 30-year hydrologic period following the Implementation Period to assess the long-term sustainability of the proposed projects and management actions with variable climatic conditions including periods with above average rainfall and extended droughts.
- **WY2021 to WY2070** – Simulation Period representing the entire 50-year projected future hydrologic conditions.

Changes to surface water diversions under the proposed projects and management actions included monthly increases or reductions to 37 model diversions and the addition of 7 new diversions. Ten new groundwater pumping wells were added to simulate a new groundwater pumping program. Agricultural land use was converted to native vegetation in ten management areas, and to urban land use in three management areas. The projects and management actions included in the C2VSimFG-Kern scenarios with SGMA projects are described in the individual GSPs and management area plans. These changes were applied to a series of six C2VSimFG-Kern scenarios for Baseline, 2030 Climate Conditions and 2070 Climate Conditions both with and without SGMA projects. The results of these simulations are summarized in **Table 15** below.

Baseline simulation results indicate that the Kern County Subbasin has an average annual overdraft of 324,326 AFY. By implementing the proposed projects and management actions, the Subbasin is forecasted to achieve sustainability by 2040 with an estimated 42,144 AFY of annual surplus. With adjustments to account for limitations in the simulation (discussed in Section 7.2.1), the adjusted change in storage increases to 85,578 AFY.

Collectively, the C2VSimFG-Kern simulation results indicate that the currently proposed SGMA projects and management actions, once fully implemented, provide a reasonable approach to achieve sustainable management of the groundwater basin and can be adaptively managed to meet future challenges as necessary. A brief summary of each of the six projected future water budgets from C2VSimFG-Kern is provided below.

Table 15: Summary of Simulated Change in Groundwater Storage Results over the 2041 to 2070 Sustainability Period

C2VSimFG-Kern Model Scenario	Change in Groundwater Storage (AFY)	
	C2VSimFG-Kern Model Results	Adjusted Model Results
Historic	-277,114	-277,114
Baseline	-324,326	-324,326
Baseline with Projects	42,144	85,578
2030 Climate Change	-380,900	-372,120
2030 Climate with Projects	-12,861	46,829
2070 Climate Change	-489,828	-472,336
2070 Climate with Projects	-118,273	-45,969

7.1.1 Baseline Condition Water Budgets

The Baseline Scenarios simulate how the Kern County Subbasin aquifer would respond if the recent hydrology were repeated with current expected surface water availability and current land use. The Baseline Scenarios were run both with and without SGMA projects.

For the Baseline Scenario without SGMA Projects, the groundwater budget for WY2021 to WY2040 (**Table 16**) repeats the 20-year historical hydrologic period so it provides a direct comparison of the differences between the projected future Baseline without SGMA Projects and the historical condition. The primary difference between historical conditions and the projected future Baseline is a nearly 20% decrease in imported surface water deliveries primarily from the SWP due to the OCAP Biological

Opinion. This is replaced with additional groundwater pumping. As a result, total net aquifer outflows increase by about 20,200 AFY and total net aquifer inflows decrease by about 76,500 AFY. This is mostly because of increased groundwater pumping and decreased managed aquifer recharge due to a decline in imported SWP water. Over this period, the average groundwater pumping is 1,581,000 AFY, which includes agricultural pumping, urban pumping and exported water. This results in an additional loss of groundwater storage of about 56,300 AFY over the 50-year projected future Baseline period.

The Baseline Scenario with SGMA Projects simulates the proposed SGMA projects and management actions (Section 5.2) applied to the Baseline Scenario. No other changes were made except for the addition of the SGMA projects to provide a direct comparison of the relative benefits of about 422,000 AFY of proposed SGMA projects and management actions. The groundwater budget for the Baseline Scenario with SGMA Projects is provided in **Table 17**. Comparing the groundwater budget for WY2041 to WY2070 (**Table 17**) with the same period from the Baseline Scenario (**Table 16**) provides an evaluation of groundwater conditions after the SGMA projects and management actions have been fully implemented. As a result, total net aquifer inflows increase about 135,400 AFY due to increased managed aquifer recharge and deep percolation. The total net aquifer outflows decrease about 231,100 AFY due mostly to decreased groundwater pumping with agricultural demand reduction management actions.

The change in groundwater storage for the Baseline Scenario with SGMA Projects improves by about 366,500 AFY compared to the Baseline Scenario without SGMA Projects. This change results in a net gain in groundwater in aquifer storage over the WY2041 to WY2070 sustainability period of about 42,100 AFY. A comparison of the annual change in groundwater storage over the 50-year hydrologic period is presented in **Figure 16**. The time series shows that change in groundwater storage has stabilized to slightly increasing over the period from WY2041 to WY2070.

A comparison of the average annual water budget components for the two different Baseline Scenarios is presented in **Figure 17**. Over the WY2041 to WY2070 period, the average groundwater pumping of 1,354,000 AFY for the Baseline Scenario with SGMA Projects (which includes agricultural pumping, urban pumping and exported water) is over 270,000 AFY less than in the Baseline Scenario.

7.1.2 2030 Climate Change Water Budgets

The 2030 Scenarios simulate how the Kern County Subbasin aquifer would respond assuming hydrologic conditions representing a potentially drier climate and are based on the DWR Climate Change Guidance and Resource Guide (DWR, 2018A and 2018B). The 2030 DWR climate change factors were applied to the Baseline Scenario conditions. Additional adjustments were made to the imported surface water supplies from the SWP, CVP and Kern River, accounting for about an additional 2% decrease from the Baseline Conditions. The 2030 Climate Change Scenarios were run both with and without SGMA projects. Results for climate change budgets are illustrated in **Figures 18, 19, and 20**.

The groundwater budget for the 2030 Climate Scenario without SGMA Projects for WY2041 to WY2070 (**Table 18**) is compared the same period for the Baseline Scenario without SGMA Projects to assess the relative change due to the climate change assumptions. The results show a net increase in aquifer inflows of about 44,700 AFY, however, the aquifer net outflows increase by about 101,200 AFY. This is mostly attributed to the climate shift to earlier rainfall making more surface water available for managed aquifer recharge during the winter but less available for irrigation in the summer, resulting in higher groundwater pumping. The net change in groundwater storage is an additional decline of about 56,600 AFY due to the climate change impacts.

The 2030 Climate Scenario with SGMA Projects simulates the proposed SGMA projects and management actions (Section 5.2) applied to the 2030 climate change conditions. No other changes were made to this scenario. The groundwater budget for the 2030 Climate Scenario with SGMA Projects is provided in **Table 19**. Comparing the groundwater budget for WY2041 to WY2070 (**Table 18**) between the two 2030 Climate Scenarios, the total net aquifer inflows increase about 118,700 AFY due to increased managed aquifer recharge and deep percolation. The total net aquifer outflows decrease about 249,300 AFY due mostly to decreased groundwater pumping with agricultural demand reduction management actions.

The change in groundwater storage for the 2030 Climate Scenario with SGMA Projects improves by about 368,000 AFY. This change results in a net decline in groundwater in aquifer storage over WY2041 to WY2070 of about 12,900 AFY. A comparison of the annual change in groundwater storage over the 50-year hydrologic period is presented in **Figure 20**. The time series shows that change in groundwater storage has stabilized to slightly increasing over the period from WY2041 to WY2070, but at a level below the results for the Baseline Scenario with SGMA Projects.

A comparison of the average annual water budget components for the two 2030 Climate Scenarios is presented in **Figure 18**. Over this period, the average groundwater pumping of 1,444,000 AFY for the 2030 Climate Scenario with SGMA Projects, which includes agricultural pumping, urban pumping and exported water, is over 290,000 AFY less than in the 2030 Climate Scenario without SGMA Projects.

7.1.3 2070 Climate Change Water Budgets

The 2070 Scenarios simulate how the Kern County Subbasin aquifer would respond assuming hydrologic conditions representing a potentially very dry climate and are based on the DWR Climate Change Guidance (DWR, 2018A and 2018B). The 2070 DWR climate change factors were applied to the Baseline Scenario Conditions. Additional adjustments were made to the imported surface water supplies from the SWP, CVP and Kern River, and these accounted for an additional 6% decrease from the Baseline Conditions. The 2070 Climate Change Scenarios were run both with and without SGMA Projects.

The groundwater budget for the 2070 Climate Scenario without SGMA Projects over WY2041 to WY2070 (**Table 20**) is compared the same period for the Baseline Scenario without SGMA Projects to assess the relative change due to the climate change assumptions. The results show a net increase in aquifer inflows of about 66,100 AFY, however, the net aquifer outflows increase by about 231,600 AFY. This is mostly attributed to an even greater climate shift to earlier rainfall making more surface water available for managed aquifer recharge during the winter but less available for irrigation in the summer resulting in higher groundwater pumping. The net change in groundwater storage is an additional decline of about 165,500 AFY due to the climate change assumptions.

The 2070 Climate Scenario with SGMA Projects simulates the proposed SGMA projects and management actions (Section 5.2) applied to the 2070 climate change conditions. No other changes were made to this scenario. The groundwater budget for the 2070 Climate Scenario with SGMA Projects is provided in **Table 21**. Comparing the groundwater budget for WY2041 to WY2070 (**Table 20**) between the two 2070 Climate Scenarios, the total net aquifer inflows increase about 106,300 AFY due to increased managed aquifer recharge and deep percolation. The total net aquifer outflows decrease about 265,300 AFY due mostly to decreased groundwater pumping due to agricultural demand reduction management actions.

The change in groundwater storage for 2070 Climate Scenario with SGMA Projects improves by about 371,600 AFY. This change results in a net decline of groundwater in aquifer storage over WY2041 to WY2070 of about 118,300 AFY. A comparison of the annual change in groundwater storage over the 50-year hydrologic period is presented in **Figure 20**. The time series shows that change in groundwater storage has stabilized to slightly increasing over the period from WY2041 to WY2070, but at a level below the results for the Baseline and 2030 Scenarios with SGMA Projects.

A comparison of the average annual water budget components for the two different 2070 Climate Scenarios is presented in **Figure 19**. Over this period, the average groundwater pumping of 1,559,000 AFY for the 2070 Climate Scenario with SGMA Projects, which includes agricultural pumping, urban pumping and exported water, is over 307,000 AFY less than in the 2070 Climate Scenario without SGMA Projects.

7.2 Projected Future Sustainability Assessment

To assess the sustainability of the proposed GSP plans, the C2VSimFG-Kern model future scenario input files were modified to incorporate all the proposed SGMA projects and management actions.

7.2.1 Change in groundwater storage

Groundwater sustainability for the Kern County Subbasin was assessed using annual changes in groundwater storage. As discussed in Section 7.1, the decline in groundwater storage of the three future Baseline scenarios is significantly mitigated by the implementation of the proposed SGMA projects and management actions. An assessment of the projected future groundwater storage change for the six projected future scenarios is summarized in **Table 22**.

The Change in Groundwater Storage presented in **Table 22** provides the net difference in aquifer inflows and outflows without consideration of subsurface flow to and from adjacent groundwater basins. This provides a measure of the natural and managed water supply within the groundwater basin without being influenced either positively or negatively by the subsurface flow. For the Kern County Subbasin, the net operational flow differs from the change in groundwater storage by about 50,000 to 75,000 AFY for the scenarios without SGMA projects, indicating that most of the groundwater storage change is due to conditions within the basin.

The Adjustments to Groundwater (GW) Storage Change are made to account for limitations in either the underlying conceptual model of C2VSimFG-Kern or the setup of the projected future scenarios. The two adjustments made to the projected future water budgets include:

- **Adjustment for Excess Basin Outflows** is the difference in simulated basin outflow that is attributed to addition of SGMA projects in Kern County without comparable SGMA projects added to adjacent basins. Adjustment assumes that this difference is due to limitation of the simulation, and that this difference would remain in Kern County Subbasin when SGMA projects from adjacent basins are included in the simulation.
- **Adjustment for Excess Kern River Outflow** is the increase in simulated groundwater outflows to the Kern River relative to Baseline condition that are attributed to SGMA projects and climate change. The model is not optimized for river management. Because the Kern River is a highly managed system, the assumption is that in practice this water would be recovered for beneficial use and not allowed to flow from the basin.

These adjustments resulted in an overall improvement in the change in groundwater storage for the projected future water budgets. For the scenarios that include the SGMA Projects, the change in groundwater storage improves by 43,400 AFY (Baseline), 59,700 AFY (2030 Climate Change), and 72,300 AFY (2070 Climate Change). As a result of these adjustments, the adjusted change in groundwater storage for the three scenarios with SGMA Projects varied as follows:

- the Baseline Scenario with SGMA Projects changes from an increase of 42,100 AFY to an increase of 85,600 AFY.
- the 2030 Climate Scenario with SGMA Projects changes from a decline of 12,900 AFY to an increase of 46,800 AFY.
- the 2070 Climate Scenario with SGMA Projects changes from a decline of 118,000 AFY to a decline of 46,000 AFY.

These adjustments indicate areas of improvement for C2VSimFG-Kern. Future updates to the model will address how to better simulate these conditions directly to limit the use of post-simulation adjustments.

7.2.2 Sustainability Assessment

As defined by SGMA, the sustainable yield of a basin is the amount of groundwater that can be withdrawn annually without causing undesirable results. Although the SGMA regulations require that a single value of sustainable yield must be calculated basinwide, it should be noted that the sustainable yield can be changed with implementation of recharge projects, variations in climate, or changes in stream flow conditions. For the projected future scenarios, both the climate and the managed water supply operations are significantly affected which would lead to a change in the sustainable yield for the basin.

For the sustainability assessment, the sustainable yield was recalculated using the method described in Section 4.2, and the results are presented in **Table 23**. Without the SGMA projects and management actions, the percentage of the Average Annual Difference to the total groundwater pumping provides context to compare the significance of the level of groundwater pumping for the basin. For the scenarios without SGMA projects and management actions, the groundwater pumping exceeds the sustainable yield on the order of 25% to 34% (**Table 23**). However, with the proposed SGMA projects and management actions, the groundwater pumping is less than the sustainable yield of the Subbasin for the Baseline and 2030 climate scenarios and is within 3% of the sustainable yield for the 2070 climate scenario (**Table 23**). This assessment indicates that the proposed SGMA projects and management actions for the Kern County Subbasin are of sufficient magnitude that, if fully implemented, would lead to groundwater sustainability for the Kern County Subbasin after WY2040.

7.2.3 Minimum Thresholds and Measurable Objectives

Another requirement of SGMA is for groundwater levels not to cross their minimum thresholds to the extent that undesirable results would occur in the basin, and moreover, that proposed SGMA projects and management actions would lead to meeting the measurable objectives. The Kern County Subbasin GSAs have defined 186 representative monitoring well (RMW) locations spread across the Kern County Subbasin. A minimum threshold and measurable objective have been assigned each of the 186 locations, and the hydrographs for all 186 locations are provided in **Attachment A**. The RMW locations are shown on **Figure 21**.

The C2VSimFG-Kern results were used to assess whether the simulated groundwater levels would meet the minimum threshold and measurable objective for each monitoring well. Because C2VSimFG-Kern is not fully calibrated, the results are presented as relative change (which does not require calibration) instead of simulated groundwater levels using the superposition method. Future change in groundwater level was determined for each of the 186 locations for each of the six projected future simulations. The change was calculated from the simulated March 2015 groundwater levels from the model. The change in groundwater level was then applied to the measured March 2015 groundwater level at the monitoring location. The result was to superimpose the simulated change in groundwater levels from the projected future C2VSimFG-Kern scenarios relative to the measured March 2015 groundwater level.

Figure 22 provides four representative examples of the simulated hydrographs using this method. Hydrographs of the simulated groundwater levels relative to the minimum thresholds and measurable objectives for all 186 locations were provided to the various GSAs and water districts for inclusion in their respective GSPs. In general, across most areas of the basin, groundwater levels fall near or below the minimum thresholds without the SGMA projects but are typically above the minimum threshold for the simulations that include the SGMA projects.

The groundwater hydrographs for some locations, especially along the eastern and western basin margins, show an unusual pattern that is likely influenced by issues with the hydrogeological conceptual model incorporated into C2VSimFG-Kern for these locations. The hydrographs for these areas are not considered to be representative of actual conditions that would physically occur. This is a limitation to the model. It is recommended that a more rigorous model update be conducted to revise the hydrogeological conceptual model to be consistent with that presented in the Kern County Subbasin GSPs. In addition, further calibration of C2VSimFG-Kern is recommended to update aquifer parameters in the Kern County Subbasin. The recommendations for revisions to the hydrogeological conceptual model and additional calibration are further discussed in Section 8.5.

8. VALIDATION OF C2VSIMFG-KERN PERFORMANCE

The C2VSimFG-Kern performs well within the central part the Kern County Subbasin. The model does not perform as well east of the Friant-Kern Canal or west of the California Aqueduct. The geologic and hydrogeologic conceptual models within the central part of the Kern County Subbasin appear to be generally realistic. The geologic and hydrogeologic conceptual models appear to be very poor in the areas where the model does not perform well.

8.1 C2VSimFG-Kern Validation

One of the concerns for the modeling is the overall calibration of C2VSimFG-Beta in Kern County. As discussed above, the assumption is that C2VSimFG-Beta was developed using reasonable care in developing the geologic framework and developing a consistent regional methodology for determining aquifer properties. An identified weakness of the C2VSimFG-Beta is the quality of data used in developing the overall water balance such as the extent of the groundwater banking operations in Kern County. The issues with the water balance are considered the primary contributing factor affecting the calibration of the C2VSimFG-Beta; the hydrogeologic conceptualization is reasonably accurate for a regional planning analysis.

To address these concerns, a validation analysis was performed for C2VSimFG-Kern by comparing simulations results to field measured groundwater level data collected during the Study Period and comparing those to a similar set of residuals from the C2VSimFG-Beta model. The statistical results of this analysis should be comparable, if not better, for C2VSimFG-Kern compared to the C2VSimFG-Beta results.

The analysis used 42,058 groundwater levels measurements collected from 558 monitoring wells in the Kern County Subbasin. The data were collected by Kern County Water Agency, the Kern Fan Monitoring Committee, the DWR Water Data Library, and local agencies. For each location, the residual was calculated as the simulated groundwater level minus the measured groundwater level based on the well measurement data. A brief summary of the statistical measures used to evaluate the calibration results (shown on **Table 24**) is provided below:

- The residual mean is computed by dividing the sum of the residuals by the number of residual data values. The closer this value is to zero, the better the calibration especially as related to the water balance and estimating the change in aquifer storage. The residual mean of 17.3 feet for C2VSimFG-Kern is an improvement of 47% over the 32.6 feet from C2VSimFG-Beta.
- The absolute residual mean is the arithmetic average for the absolute value of the residual, so it provides a measure of the overall error in the model. The absolute residual mean of 37.4 feet for C2VSimFG-Kern is an improvement of 34% over the 56.8 feet from C2VSimFG-Beta.
- The residual standard deviation evaluates the scatter of the data. A lower standard deviation indicates a closer fit between the simulated and observed data. The standard deviation is 45.5 feet for C2VSimFG-Kern, which is an improvement of 16% over the 54.0 feet from C2VSimFG-Beta.
- The Root Mean Square (RMS) Error is the square root of the arithmetic mean of the squares of the residuals and provides another measure of the overall error in the model. The RMS Error is 50.0 feet for C2VSimFG-Kern, which is an improvement of 32% over the 73.5 feet from C2VSimFG-Beta.
- The correlation coefficient ranges from 0 to 1 and is a measure of the closeness of fit of the data to a 1 to 1 correlation. A correlation of 1 is a perfect correlation. The correlation coefficient of 0.76 for C2VSimFG-Kern is an improvement of 47% over the 0.52 from C2VSimFG-Beta.
- Another statistical measure is the ratio of the standard deviation of the mean error divided by the range of observed groundwater elevations. This ratio shows how the model error relates to the overall hydraulic gradient across the model. The ratio for C2VSimFG-Kern is 0.061 feet, which is an improvement of 34% over the 0.092 from C2VSimFG-Beta.

Considering these results in context with the overall range of measurements of 616 feet, the residual mean of 17.3 feet represents a relative percentage difference of less than 3%. For the absolute residual mean of 37.4 feet, the relative percentage difference is about 6%. Despite this improvement in model performance, the model is not considered fully calibrated. However, C2VSimFG-Kern is reasonably validated for assessing groundwater level changes on the subbasin scale for the purposes of SGMA planning.

8.2 Sensitivity Analysis

The C2VSimFG-Kern model was not formally calibrated. Some physical parameters were adjusted to improve model performance in specific areas. A sensitivity analysis was conducted on the adjusted model to understand how variations in model parameters affect model results. Eight physical parameter sets were systematically varied, and model results compared to the base model for a selected group of groundwater hydrographs. C2VSimFG-Kern parameter sensitivities evaluated for Kern County Subbasin include:

- Horizontal hydraulic conductivity of aquifer (Kh)
- Vertical hydraulic conductivity of aquifer (Kv)
- Vertical hydraulic conductivity of Corcoran Clay aquitard (Kcorc)
- Streambed conductance of Kern River (Cstm)
- Specific storage of aquifer (Ss)
- Specific yield of aquifer (Sy)
- Soil hydraulic conductivity in root zone (Ksoil)
- Soil pore size distribution index in root zone (λ)

The Root Mean Squared Error between observed and simulated values was calculated for the original parameter set and after varying each parameter set upward and downward by a set factor. Results are presented in **Figure 23**. This sensitivity analysis shows that the hydrologic parameter values in the C2VSimFG-Kern model are generally within an acceptable range. A full model calibration would likely improve model performance.

8.3 Peer Review Process

Todd Groundwater worked with Woodard and Curran (W&C) throughout the model development process as W&C conducted an on-going peer review of model input files. W&C staff have developed several IWFM-based models and worked with DWR to develop C2VSimFG-Beta. Their reviews helped ensure that the model update used best practices when incorporating new data. The peer review process was documented in a series of meeting summaries to the KGA and KRGSA. The updated C2VSimFG-Kern input files for the Kern County Subbasin were shared with DWR for incorporation into future C2VSim public releases.

The more general assumptions in C2VSimFG-Beta were replaced with local data and knowledge that are regionally or locally significant for WY1995 to WY2015. This update employed a phased approach with regular peer reviews.

1) Phase 1 revisions address components of Regional Significance that require significant changes to the overall model input file structure. These include:
    a) Surface water delivery volumes, application areas and use by water district,
    b) Groundwater banking recharge, recovery and application of recovered water,
    c) Evapotranspiration rates and irrigation demand based on ITRC METRIC data (ITRC 2017),
    d) Urban population and per capita demand, including addition of an urban zone for Metropolitan Bakersfield, and
    e) Addition of groundwater extraction wells for groundwater banking projects.
2) Interim Review
    a) The Woodard & Curran Peer Review Team
    b) Kern County Subbasin water districts and purveyor's local data review
    c) Stakeholder input
3) Phase 2 revisions address components of Local Significance that generally require modifications of input data and parameters within the existing C2VSim model input file structure. These include:

a) Local water sources and demands of significance to individual Districts/GSAs,
b) District pumping for in-district delivery via surface water canals where significant,
c) District recharge operations utilizing canals, stream channels, and basins,
d) Wastewater disposal and land application, and
e) Review and limited adjustment of model parameters.

4) Interim Review by same reviewers listed in item 2
5) Phase 3 revisions include addressing comments and incorporating new data from the Interim Reviews
6) Interim Review by same reviewers listed in item 2
7) Tabulate model-derived water budgets for Peer-Review and GSP Use

In each update phase, historical and current water budgets for zones representing water agency service areas were produced with the revised C2VSimFG-Kern model incorporating corrected local data. These water budgets were shared with participating agencies for review, to ensure that C2VSimFG-Kern correctly represented local water balances. Where necessary, participating agencies provided additional data which was incorporated into C2VSimFG-Kern.

8.4 Internal Review Process

Todd Groundwater and Hydrolytics LLC worked collaboratively on this model revision, water budget development and the projected future scenarios. Throughout this work, efforts were applied to improve data management to develop a systematic process for generating model input files. Using this approach, internal review could be conducted with each firm reviewing the contributions from the other. The goal was to accurately represent the data provided by the Kern County agencies in the model.

Due to schedule constraints, a thorough internal review of the projected future model scenarios was not completed prior to the submission of the Public Review Draft of the model results in August 30, 2019. A thorough review of all input for the projected future scenarios was conducted in September and October 2019. During this review, several issues were identified and corrected. As a result, the results in this report vary from those provided in the August 2019 Public Review Draft. Although the numbers changed, the overall conclusions from the C2VSimFG-Kern simulations remained essentially the same.

8.5 Recommendations for Future Improvements to C2VSimFG-Kern

The C2VSimFG-Kern performs well in the Kern County Subbasin, producing simulated water budget components that generally match historical values compiled by local agencies. C2VSimFG-Kern simulated groundwater levels provide a reasonable approximation of observed groundwater levels in the central part of the Kern County Subbasin. The model is well suited for estimating the impacts of management actions on the Subbasin groundwater storage and is also well suited as a planning tool in meeting compliance of SGMA.

During the model update, several outstanding issues were identified that should be addressed in future updates to C2VSimFG-Kern. The following actions and model improvements are recommended:

- **Improve streamflow simulations of the Kern River and Poso Creek.** Flows in the Kern River channel, including local stream-groundwater interactions, are not well replicated and surface water diversions are not dynamically simulated. Some rejected recharge occurs in the Kern Fan area in very wet years, with significant outflow of groundwater to the Kern River especially in the Kern Fan banking area (i.e., rejected recharge). This has been an ongoing issue and needs to be addressed for the projected future water budgets so that banking recharge volumes can be better matched in the model. It is recommended that future revisions to C2VSimFG-Kern further evaluate issues in simulating streamflow and seepage in the Kern River and Poso Creek (see Section 8.5). This may include incorporating more advanced streamflow simulation features that are available in IWFM but that have not been previously utilized in developing C2VSim models by DWR. Changing the stream simulation feature may require development of a local Kern County Subbasin model.

- **Improve the geologic and hydrogeologic conceptual model of the Kern County portion of the Central Valley.** A hydrogeologic conceptual model is a framework for understanding where groundwater exists, where it flows, and how groundwater interacts with surface water bodies and the land surface. A geologic conceptual model provides a framework for understanding the geologic features that control groundwater movement. Quantitative analysis of Kern County Subbasin groundwater flow is severely hampered by the lack of detailed geologic and hydrogeologic conceptual models of the areas outside the central alluvial basin. Geologic and hydrogeologic conceptual models will provide a foundation for the quantitative analysis of the groundwater flow system, and the framework for modeling the system. Key steps are:
    - Develop detailed geologic and hydrogeologic conceptual models of the Kern County Subbasin.
    - Differentiate the four Principal Aquifers that have been identified in the Kern County Subbasin based on definitions from local management area GSPs.
    - Identify the locations and characteristics of natural features that affect groundwater recharge and movement (faults, ridges, clays).
    - Understand water occurrence and movement in areas outside the central Kern County Subbasin.
    - Develop water quality maps (natural constituents and anthropogenic constituents).
    - Modify the Kern County Subbasin model to conform to the updated conceptual models.
- **Simulation of deep percolation and small watersheds.** Unreasonably high deep percolation (return flows) of the applied water in some areas has led to unreasonably elevated pumping rates to compensate. One problem is high root zone hydraulic parameter values in certain areas that were identified and corrected to better reflect local soil conditions. Because the excess pumping was returning to groundwater, the change has little effect on the basin change in storage, but the pumping and deep percolation are now more in line with local estimates. Root zone hydraulic parameters should be redeveloped throughout the subbasin to assure model values are representative of actual values.
- **Root Zone Parameters,** Areas of overly high root zone hydraulic parameters led to high volumes of deep percolation that required additional groundwater pumping to meet the overall water demand for irrigation. A review found areas of overlying high soil hydraulic conductivity and other soil parameters produced percolation rate that were too high. These areas were manually adjusted to be more in line with observed conditions. A more rigorous development of root zone parameters should be considered in the future as this issue demonstrates that it is a sensitive parameter.

- **Investigate development of a stand-alone Kern County Subbasin model.** The C2VSim model provided by DWR and updated with local data is adequate for GSP preparation. However, this model may not meet all of the groundwater modeling needs of Kern County Subbasin stakeholders. In addition, running a full Central Valley simulation model imposes longer model run times and reduces model flexibility. Stakeholders should undertake a comprehensive study to develop a list of their integrated (groundwater and surface water) modeling needs, and then decide whether further improving C2VSimFG-Kern or developing a new integrated hydrologic model is the best way to address the Subbasin modeling needs. This decision should be made before the end of 2020 to allow sufficient time to develop a new model or improve C2VSimFG-Kern in time for use in development of the 2025 GSP.
- **Adjust the finite element grid to honor water management boundaries.** The C2VSimFG-Kern model grid is a randomly generated grid that does not conform to any local features other than natural surface water channels. This limits the spatial accuracy of model inputs and the precision and flexibility of water budget outputs. Adjusting the grid to match district and agency boundaries, historical delivery areas, water management units within districts, and geologic and hydrologic features would greatly enhance model capabilities.
- **Quantify boundary flows.** Significant uncertainty exists regarding the rates and timing of groundwater flows into the Kern County Subbasin from surrounding watersheds, and groundwater flows from the Kern County Subbasin to Kings and Tulare counties to the north. Reliable estimates of boundary flows will improve model performance in boundary areas.
- **Kern County Subbasin Boundary.** The GSAs in the basin should consider when DWR updates the Bulletin 118 in 2020 to investigate the “actual” Kern County Subbasin and to remove those peripheral lands where aquifer connectivity does not exist.
- **Utilize more complex water management features of IWFM.** The Kern Update process modified information within the existing C2VSimFG-Beta model structure to improve model performance within the Kern County Subbasin. The IWFM application has several features that could be further utilized to improve model performance.
    - Adjust the agricultural crops to better match the Kern County crop mix (for example, create separate crop categories for carrots, young and mature almonds, young and mature pistachios, etc.).
    - Implement multi-cropping with semiannual or quarterly land use.
    - Some C2VSim data are organized by DWR subregions, which represent heterogeneous areas with homogeneous data. Developing Kern County Subbasin subregions and organizing model input data by these subregions may provide a better representation of local hydrologic conditions.
- **Calibrate the improved model for the Kern County Subbasin**. DWR did not fully calibrate the Kern County portion of the C2VSim model, owing to both poor historical input data and a lack of calibration data sets. The Kern Update process significantly improved the historical data in the model, developed some calibration data sets, and included limited adjustment of model parameters. The updated model performs adequately in the central part of the Kern County Subbasin and poorly in areas outside the central part of the basin. Once the above improvements are completed, the Kern County portion of the resulting model should be fully calibrated to ensure that it performs well throughout the Kern County Subbasin.

9. CONCLUSIONS

This brief summary provides an overview of the findings and conclusions of the modeling results for the Kern County Subbasin using C2VSimFG-Kern.

9.1 Findings of the C2VSimFG-Kern Application and Results

The subbasin-wide update of C2VSimFG-Kern incorporated data from many local agencies. Each participating agency provided data for their jurisdiction for use in improving the model. This included managed water supply data (e.g., surface water deliveries, land use, irrigation demand, return flows, and groundwater banking), stream and groundwater monitoring data, geologic data, and other relevant data. This information was compiled and used to improve C2VSimFG-Kern performance in the Kern County Subbasin.

The historical water budget analysis indicates that the Kern County Subbasin was in a state of overdraft equivalent to the long-term decline in groundwater storage from WY1995 to WY2014 of 277,144 AFY. Projected Future simulations indicate that the proposed SGMA projects and management actions in the Kern County GSPs are sufficient for the Kern County Subbasin to achieve sustainability under Baseline and 2030 Climate Change conditions.

C2VSimFG-Kern was used to evaluate the change in groundwater in storage for projected future conditions using a baseline condition that projects current water supply, water demand and land use over a 50-year period based on historical hydrology. The baseline was adapted following DWR climate change guidance to develop 2030 and 2070 climate change simulations. The proposed SGMA projects and management actions were compiled from all of the Kern County Subbasin GSAs and management areas. The total projects total about 421,000 AFY after implementation. This assessment indicates that the proposed SGMA projects and management actions for the Kern County Subbasin are of sufficient magnitude that, if fully implemented, would lead to groundwater sustainability for the Kern County Subbasin after WY2040.

The historical C2VSimFG-Kern performs well in the Kern County Subbasin, producing simulated water budget components and groundwater levels that generally match historical values compiled by local agencies. C2VSimFG-Kern simulated groundwater levels provide a reasonable statistical approximation of observed groundwater levels in the Kern County Subbasin that show significant improvement relative to C2VSimFG-Beta. Therefore, C2VSimFG-Kern is well suited as a planning tool to estimate the impacts of the proposed SGMA projects and management actions on groundwater conditions in the Kern County Subbasin.

The C2VSimFG-Kern model development and the water budget analysis were designed to fulfill the GSP requirement for a coordinated subbasin-wide water budget analysis, while also providing information required to fulfill other GSP requirements. The C2VSimFG-Kern was provided to DWR so the Kern County Subbasin revisions can be incorporated into their master version of the C2VSim model.

9.2 C2VSimFG-Kern Compliance with Coordination Agreement Requirements

Subbasin GSAs coordinated on the development and application of the C2VSimFG-Kern to ensure that the model was incorporating comparable data sets and the best available information; as such, the model meets numerous technical requirements for Subbasin-wide coordination, including for

Coordination Agreements in §357.4. As demonstrated throughout this memorandum, the C2VSimFG-Kern model documents the use of "the same data and methodologies" for water budget development.

Specifically, groundwater extraction data were coordinated through the use of ET METRIC data for all irrigated lands over the entire Subbasin to estimate private irrigation pumping. Monthly metered data from District, municipal, and banking pumping were incorporated as available. Surface water supply data were provided in similar units and formats using consistent templates for data collection and management in the model. Total water use and change in groundwater in storage were developed through consistent methodologies as applied in the C2VSimFG-Kern model. Calibration targets also incorporated consistent data sets for groundwater elevation data throughout the Subbasin as compiled in the DWR Water Data Library, KCWA water level database, and supplemented with local data, as needed. This memorandum documents coordination efforts in subsequent sections that demonstrates compliance with GSP requirements in §354.18, §357.4, and other portions of the regulations.

9.3 Limitations and Uncertainty of C2VSimFG-Kern

The C2VSimFG-Kern performs well in the Kern County Subbasin, producing simulated water budget components that generally match historical values compiled by local agencies. C2VSimFG-Kern simulated groundwater levels provide a reasonable approximation of observed groundwater levels in the central part of the Kern County Subbasin. The model is well suited to estimating the impacts of management actions on subbasin groundwater storage.

The C2VSimFG-Kern update was limited in scope, and some model components do not perform well. These components do not reduce model capabilities with respect to GSP development but limit the usefulness of the model for other types of studies. Flows in the Kern River channel, including local stream-groundwater interactions, are not well replicated and surface water diversions are not dynamically simulated. The Kern County Subbasin portion of the C2VSimFG-Kern is not calibrated, and although the land surface water budget components are generally accurate, groundwater conditions and stream flows are poorly simulated in much of the Subbasin. Some rejected recharge occurs in the Kern Fan area in very wet years, but this is not significant as it is a very small volume.

The C2VSimFG-Kern is a reliable and defensible tool to support planning future groundwater conditions and estimating the potential hydrological impacts of future climate conditions and management actions at the subbasin level. It is currently the best available quantitative tool for assessing projected future groundwater conditions under SGMA. DWR recommends updating and refining models used in GSPs to incorporate new data including that in annual GSP updates. Refining Kern County Subbasin hydrologic modelling tools to replicate district-level historical conditions will provide a reliable means of assessing future effects of management actions at the district level for future GSP development.

9.4 Applicability of C2VSimFG-Kern Simulation Results

Based on the model validation, C2VSimFG-Kern provides a useful planning tool to evaluate potential future trends in groundwater in the Kern County Subbasin. The model validation demonstrated the capability of C2VSimFG-Kern to reasonably simulate the groundwater elevations and trends during the period from WY1995 through WY2015 based on the comparison to measured data.

The ability to reasonably simulate historical conditions provides confidence that C2VSimFG-Kern can be used to simulate potential future conditions. The model has the capability to simulate the most beneficial application of water projects that would provide the long-term benefit to the area. For the future case scenarios, the general practice is to evaluate model results with respect to long-term trends. Therefore, as a planning tool, it is most beneficial to run the model in relation to a base case and to evaluate the relative difference between the model scenario and the base case. The base case would assume a selected set of climatic, hydrologic and pumping conditions. Commonly, the calibration base period is assumed to repeat; however, any number of variations can be constructed.

It is important to note that in some cases the model results may vary from those measured in individual wells due to the geologic complexity of the Kern County Subbasin. However, the model is capable of evaluating the impacts of changes in pumping and water use practices in the Kern County Subbasin that are useful for SMGA planning purposes.

The conclusions and recommendations presented herein are professional opinions based on the C2VSimFG-Kern revisions and simulations as described herein. The findings and professional opinions presented in this letter are presented within the limits prescribed by the client contract, in accordance with generally accepted professional engineering, geologic and modeling practices, to support development of GSPs within the Kern County Subbasin. There is no other warranty, either expressed or implied, regarding the conclusions, recommendations, and opinions presented in this report.

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TABLES

TABLE 1 - Summary of data input for surface water diversion to agriculture by water district applied to C2VSimFG-Kern Historical Simulation

Water Year	Arvin-Edison WSD	Belridge WSD	Berrenda Mesa WSD	Buena Vista WSD	Cawelo WD	Kern River Canal Co.	Henry Miller WD	Kern Delta WD	Kern-Tulare WD	Lost Hills WD	North Kern WSD	Rosedale Rio Brave WSD	Semi-tropic WSD	Shafter-Wasco ID	So. San Joaquin MUD	Wheeler Ridge - Maricopa WSD	Olcese WD	TOTAL
	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
1986	144,722	106,293	90,909	162,444	78,084	14,994	43,242	183,471	27,131	103,268	198,865	0	74,487	149,252	112,888	177,348	1,493	1,668,891
1987	127,333	106,293	90,909	142,274	89,117	12,113	43,242	137,458	27,131	123,981	112,432	0	53,753	172,161	76,193	161,949	1,493	1,477,832
1988	114,321	106,293	90,909	141,152	77,106	4,203	43,242	135,078	27,131	111,872	81,580	0	47,071	164,192	71,243	154,030	1,417	1,370,840
1989	114,591	106,293	90,909	150,341	85,190	11,096	43,242	140,360	27,131	122,044	61,797	0	50,495	190,990	94,729	178,129	1,480	1,468,817
1990	70,816	106,293	90,909	124,845	67,867	14,757	43,242	114,531	27,131	88,963	51,926	0	34,381	49,992	73,000	170,693	1,480	1,130,826
1991	40,698	106,293	90,909	100,517	50,621	10,416	43,242	117,287	27,131	9,553	28,931	0	40,595	7,926	11,683	31,030	1,480	718,312
1992	52,839	106,293	90,909	108,874	54,406	9,909	43,242	118,190	27,131	52,853	34,291	0	45,851	94,467	65,310	96,514	1,480	1,002,559
1993	137,479	93,344	85,549	151,653	75,490	11,596	43,973	174,003	26,034	77,793	181,920	5,040	72,120	226,462	108,767	137,221	1,425	1,609,869
1994	171,856	110,017	93,092	125,084	62,968	13,862	53,471	132,865	28,017	87,636	117,580	2,362	47,111	110,951	83,680	151,368	1,685	1,393,606
1995	134,559	110,993	78,521	189,797	73,155	6,600	29,047	159,595	27,333	85,963	174,020	5,591	62,105	235,347	108,778	153,783	1,425	1,636,611
1996	166,288	112,412	115,132	184,597	90,229	11,591	39,539	179,052	28,749	145,349	202,199	5,722	72,231	313,420	128,865	189,454	1,987	1,986,816
1997	185,820	143,146	97,233	197,871	88,202	11,134	50,584	179,388	29,998	122,140	191,871	4,563	67,407	313,717	124,456	188,455	1,778	1,997,763
1998	120,808	79,387	85,885	152,455	69,758	4,959	30,260	124,464	24,422	80,845	153,662	4,756	53,064	240,072	89,373	148,174	849	1,463,194
1999	152,909	101,786	93,199	142,271	86,667	10,085	53,858	141,626	28,093	108,563	146,395	4,679	57,625	307,686	110,686	166,018	1,248	1,713,394
2000	158,008	111,057	87,200	135,689	87,894	12,833	44,302	152,338	29,948	119,828	133,872	3,920	61,358	315,833	119,597	179,278	1,382	1,754,337
2001	158,432	91,642	65,734	76,718	70,873	10,048	31,379	113,044	30,109	68,302	74,725	0	48,772	70,879	98,104	136,390	1,588	1,146,739
2002	158,197	107,617	63,705	78,735	75,042	9,058	31,724	116,181	25,443	67,574	62,006	0	55,121	165,448	103,849	133,652	1,702	1,255,054
2003	139,412	103,724	64,267	96,601	75,749	8,371	33,941	161,162	24,120	62,007	106,436	1,000	55,511	265,110	106,779	120,733	2,041	1,426,964
2004	155,531	118,543	68,902	86,119	78,558	9,383	39,101	138,664	25,541	67,607	99,610	1,739	58,351	174,605	106,537	138,771	1,637	1,369,199
2005	136,887	105,523	69,372	125,522	78,101	6,037	39,248	169,747	21,445	60,844	207,612	2,784	58,711	294,595	109,716	127,846	1,939	1,615,929
2006	140,411	115,146	84,869	149,851	96,249	5,317	46,538	172,882	22,525	73,422	199,626	0	68,468	332,115	120,106	150,416	2,048	1,779,988
2007	158,526	118,036	102,971	91,196	70,811	4,574	48,482	112,341	23,348	83,116	89,195	552	37,391	146,826	75,642	164,924	1,496	1,329,426
2008	157,604	114,525	86,217	70,032	62,437	4,380	18,156	145,633	22,788	74,554	86,051	0	47,623	29,675	87,776	168,211	1,700	1,177,361
2009	145,184	113,385	86,439	73,530	67,340	4,340	12,129	126,039	21,803	83,740	84,727	0	44,265	30,808	116,967	159,502	1,781	1,171,979
2010	132,462	117,589	88,556	102,109	76,351	3,604	29,694	166,787	19,272	88,191	171,744	1,543	65,238	168,870	120,394	159,162	1,756	1,513,322
2011	130,306	121,808	87,344	121,329	88,617	4,617	39,642	192,069	20,213	92,149	173,305	4,466	74,413	337,724	124,678	156,216	1,530	1,770,425
2012	148,146	130,559	87,953	96,407	89,745	3,988	41,553	195,763	21,682	91,720	81,584	1,329	35,369	227,901	81,602	168,753	1,783	1,505,837
2013	159,887	138,131	93,311	33,558	49,978	3,585	18,533	94,682	22,252	93,322	23,343	0	26,194	81,279	58,923	170,033	1,966	1,068,977
2014	144,605	123,390	82,731	410	41,223	2,645	2,246	70,367	14,067	82,546	11,290	0	8,303	5,748	14,249	152,372	1,238	757,429
2015	114,350	117,357	81,535	134	38,195	2,663	0	68,228	10,274	80,631	9,901	0	0	12,226	3,020	145,842	1,462	685,817

TABLE 2 - Summary of data input for surface water diversion from Kern River at different diversion and turnouts applied to C2VSimFG-Kern Historical Simulation

Water Year	Kern River to Beardsley Canal	Kern River to Carrier Canal at Rocky Point	Kern River to Carrier Canal at Calloway Weir	Kern River to CVC at Turnout #4	Kern River to River Canal	Kern River to Rio Vista at River Walk	Kern River to Rosedale Channel	Kern River to North Lake	Kern River to Pioneer Canal	Kern River to Berrenda Mesa WSD	Kern River to Pioneer Project	Kern River to Kern Water Bank	Kern River to Kern Water Bank Canal	Kern River to 2800 Acre Facility	Kern River to Buena Vista WSD BSA	Kern River to Aqueduct at Intertie	TOTAL
	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
1986	291,715	199,035	238,877	181,392	0	0	65,684	0	63,232	0	0	0	0	97,866	86,736	0	1,224,537
1987	190,539	76,888	179,876	58,811	0	0	19,893	0	756	0	0	0	0	21,592	86,736	0	635,091
1988	111,679	25,813	163,938	21,851	0	0	345	0	0	0	0	0	0	0	86,736	0	410,362
1989	98,796	28,696	168,926	23,291	0	0	0	0	0	0	0	0	0	0	86,736	0	406,445
1990	77,389	5,373	128,753	6,577	0	0	0	0	0	0	0	0	0	0	86,736	0	304,828
1991	69,736	180,189	56,331	13,944	0	0	5,869	0	0	0	0	0	0	0	86,736	0	412,805
1992	71,521	194,315	690	11,008	0	0	3,598	0	0	0	0	0	0	0	86,736	0	367,868
1993	213,099	241,104	43,555	59,099	50,897	0	54,936	0	27,803	0	0	0	0	64,852	64,488	0	819,833
1994	187,380	213,631	18,103	26,829	67	0	0	0	0	9,882	0	0	0	28,046	38,745	0	522,683
1995	256,234	248,113	65,360	144,230	136,516	0	91,721	0	40,366	23,822	45,284	0	0	60,476	103,429	11,850	1,227,401
1996	315,988	255,792	105,845	108,405	119,999	0	78,824	0	14,286	17,382	55,074	0	0	24,037	92,768	0	1,188,400
1997	288,746	280,471	123,771	130,336	123,333	0	62,841	0	23,271	14,977	45,600	0	0	27,212	134,320	52,848	1,307,726
1998	312,857	244,337	143,422	131,398	23,346	0	95,706	0	51,802	18,483	69,637	0	0	95,160	115,019	188,048	1,489,215
1999	214,847	180,856	71,974	46,274	58,082	0	33,938	0	839	6,915	21,343	0	0	17,891	77,220	0	730,179
2000	175,718	169,844	38,793	31,596	38,147	0	20,213	0	0	1,396	15,929	0	0	30,660	47,882	0	570,178
2001	130,052	188,404	23,762	14,050	4,631	0	3,177	0	2,179	0	0	0	0	0	32,686	0	398,941
2002	91,980	203,010	4,149	23,609	7,878	0	581	0	199	431	871	0	0	0	29,404	0	362,112
2003	164,112	206,448	15,893	14,088	31,451	0	12,306	0	0	1,045	0	0	0	0	38,307	0	483,650
2004	153,148	198,769	29,338	18,247	2,301	589	1,503	165	0	2,545	2,005	0	0	0	39,412	0	448,022
2005	236,776	228,885	73,215	62,146	60,019	0	141,022	1,442	1,942	39,702	102,111	21,548	23,125	77,127	72,865	0	1,141,925
2006	257,590	247,806	53,872	122,931	33,872	3,942	87,318	1,442	9,962	24,636	116,108	25,165	34,358	42,587	97,955	0	1,159,544
2007	135,525	189,169	1,049	10,483	7,752	2,746	0	0	0	13,099	17,809	7,507	0	4,568	47,914	0	437,621
2008	137,813	229,304	53,824	22,700	0	544	0	0	0	0	0	0	0	0	34,549	0	478,734
2009	139,246	238,103	31,342	28,635	115	712	109	0	0	0	0	0	0	0	18,418	0	456,680
2010	196,135	241,876	70,315	68,944	60,087	820	10,816	776	1,775	1,165	0	0	0	13,748	66,441	0	732,898
2011	298,003	266,684	75,784	160,243	90,048	1,752	101,209	787	20,479	26,223	121,857	23,951	47,187	84,876	98,416	0	1,417,499
2012	148,513	241,953	20,495	55,303	409	1,001	10,998	0	0	7,594	20,162	582	0	7,871	45,173	0	560,054
2013	45,141	153,474	706	25,758	0	247	0	0	0	3,529	0	0	0	155	0	0	229,010
2014	26,041	122,044	0	8,356	0	283	0	0	0	0	0	0	0	0	0	0	156,724
2015	16,883	104,841	0	0	0	195	0	0	0	0	0	0	0	0	0	0	121,919

TABLE 3 - Summary of data input for surface water diversions for various purposes applied to C2VSimFG-Kern Historical Simulation

Water Year	Metro Bakersfield Urban Surface Water Supply	Metro Bakersfield Wastewater Land Disposal	Kern Nat'l Wildlife Refuge SWP Supply	Kern Nat'l Wildlife Refuge Surface Water Inflows from Poso Creek	TOTAL
	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
1986	24,416	29,235	0	1,611	30,846
1987	25,298	30,832	0	247	31,079
1988	28,563	32,304	0	65	32,369
1989	27,818	33,785	0	136	33,921
1990	27,426	35,756	0	0	35,756
1991	20,959	36,837	0	123	36,960
1992	25,867	37,801	0	10	37,811
1993	30,261	38,774	120	852	39,746
1994	29,111	39,684	16,861	95	56,640
1995	27,248	40,709	12,097	896	53,702
1996	28,261	41,667	12,776	4,536	58,979
1997	19,216	40,832	7,964	13,811	62,607
1998	11,036	40,355	12,268	90,926	143,549
1999	26,996	39,629	14,827	1,876	56,332
2000	30,963	41,497	7,489	58	49,044
2001	28,611	41,559	13,179	0	54,738
2002	30,185	42,043	19,299	1	61,343
2003	32,206	42,962	20,945	22	63,929
2004	56,861	43,735	23,461	0	67,196
2005	43,727	44,021	23,310	9,025	76,356
2006	40,294	44,614	21,829	11,734	78,177
2007	55,334	44,643	21,607	2,440	68,690
2008	56,335	44,936	17,728	18	62,682
2009	58,834	45,416	19,494	9	64,919
2010	61,314	45,527	21,808	536	67,871
2011	64,388	46,429	26,599	7,691	80,719
2012	68,013	46,666	18,451	9	65,126
2013	66,998	45,513	23,701	0	69,214
2014	55,692	44,645	13,877	0	58,522
2015	44,981	43,256	9,203	0	52,459

TABLE 4 - Summary of data input for surface water diversion to groundwater banking and managed aquifer recharge for different facilities applied to C2VSimFG-Kern Historical Simulation

Water Year	Arvin-Edison WSD	Berrenda Mesa Project	Buena Vista WSD	Cawelo WD	Kern Delta WD	Kern River GSA	North Kern WSD	Rosedale-Rio Bravo WSD	Semi-tropic WSD	West Kern WD	City of Bakers-field	Pioneer Project	Kern Water Bank	TOTAL
	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
1986	63,708	0	28,948	0	0	107,936	115,498	103,384	0	25,559	164,861	0	0	609,894
1987	18,800	0	7,487	0	0	62,084	47,206	47,731	0	23,249	50,585	0	0	257,142
1988	1,434	0	227	0	0	49,926	11,171	19,026	0	24,594	18,294	0	0	124,672
1989	3,358	0	3,532	0	0	58,640	804	27,984	0	28,604	14,148	0	0	137,070
1990	4,660	0	0	0	0	35,825	0	11,530	0	22,368	9,564	0	0	83,947
1991	2,404	0	0	0	0	54,577	1,224	5,931	0	14,754	19,768	0	0	98,658
1992	3,886	0	799	0	0	48,497	10,236	11,880	0	10,368	23,482	0	0	109,148
1993	99,714	0	19,229	0	0	83,472	25,220	88,065	0	24,420	126,544	0	0	466,664
1994	28,968	0	11,485	0	0	60,217	12,333	26,016	0	29,233	67,418	0	0	235,670
1995	87,910	17,808	49,623	0	0	98,122	149,948	119,339	0	28,201	143,019	62,274	121,465	877,709
1996	69,472	23,398	18,253	0	0	102,034	103,277	116,704	0	37,351	75,468	51,330	232,355	829,642
1997	58,069	9,801	38,015	7,524	0	103,578	102,050	108,711	0	18,555	53,470	38,169	132,457	670,399
1998	97,098	9,493	63,868	9,136	0	90,233	196,469	136,250	0	23,133	149,426	57,357	236,320	1,068,783
1999	81,398	11,489	8,904	6,110	0	83,858	69,080	78,941	0	29,249	41,516	21,884	116,663	549,092
2000	95,786	1,027	238	3,446	0	74,926	163	44,501	0	23,082	51,444	22,032	36,551	353,196
2001	38,774	0	99	2,683	0	59,411	0	5,653	0	8,747	22,005	1,253	10,029	148,654
2002	4,437	0	1,065	2,596	0	63,427	0	1,404	0	19,467	11,840	0	13,439	117,675
2003	44,030	0	424	3,314	4,177	73,362	367	27,154	0	17,766	20,133	0	5,369	196,096
2004	7,160	3,172	0	5,172	1,380	65,335	3,039	9,626	0	3,513	22,480	10,768	53,070	184,715
2005	100,311	19,663	33,153	7,882	7,274	98,474	74,241	151,136	0	29,552	164,991	93,466	308,092	1,088,235
2006	90,722	28,268	22,966	4,219	1,224	95,246	138,698	174,051	0	14,385	113,166	64,388	308,877	1,056,210
2007	20,012	15,292	0	5,241	488	51,678	80,467	20,348	0	4,209	31,534	19,386	70,553	319,208
2008	4,409	0	0	5,069	0	53,118	0	0	92	0	8,787	0	0	71,475
2009	34,000	0	3,000	5,239	0	48,217	2,596	2,354	0	5,075	18,730	0	0	119,211
2010	101,606	323	19,127	6,252	11,038	97,829	18,377	76,399	0	10,419	40,113	0	8,272	389,755
2011	99,559	19,373	73,880	29,630	46,690	158,694	147,576	227,775	17,276	24,880	144,869	132,320	397,029	1,519,551
2012	27,799	20,055	0	7,162	54,573	83,460	60,613	88,019	1,865	30,166	37,046	27,293	83,991	522,042
2013	3,947	5,750	0	9,345	14,726	46,298	5,078	5,622	22	2,500	11,518	0	0	104,806
2014	3,518	0	0	2,102	0	46,654	0	0	0	0	9,176	0	0	61,450
2015	401	0	0	5,893	0	40,368	4,768	0	22	0	18,840	0	0	70,292

TABLE 5 - Summary of data input for groundwater recovery pumping for local water supply by water district applied to C2VSimFG-Kern Historical Simulation

Water Year	Arvin-Edison WSD	Berrenda Mesa Project	Buena Vista WSD	City of Bakers-field	Cawelo WD	KCWA ID4	Kern Delta WD	Kern Water Bank	Lost Hills UD	North Kern WSD	Olcese WD	Pioneer Project	Rosedale Rio Brave WSD	Semi-tropic WSD	West Kern WD	Wheeler Ridge - Maricopa WSD	TOTAL
	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
1986	1,955	0	0	0	0	0	0	0	274	0	101	0	0	0	12,073	0	14,403
1987	21,660	0	0	0	0	0	0	0	278	41,963	101	0	0	0	12,195	0	76,196
1988	27,486	0	960	0	0	0	0	0	281	67,609	138	0	0	0	12,316	0	108,790
1989	38,231	0	2,507	0	0	0	0	0	285	79,674	132	0	0	0	12,438	0	133,266
1990	78,769	0	2,605	0	957	0	0	0	292	73,635	132	0	0	0	12,560	0	168,949
1991	82,566	0	2,511	0	4,666	0	0	0	307	80,432	132	0	0	0	12,546	0	183,160
1992	94,444	0	4,146	0	7,124	0	0	0	306	72,926	132	0	0	0	12,533	5,419	197,029
1993	21,035	0	222	0	3,469	0	0	0	308	3,950	66	0	0	0	12,530	150	41,730
1994	67,679	0	1,732	0	7,805	0	0	0	321	37,251	123	0	0	0	12,078	2,705	129,693
1995	14,191	0	73	0	4,628	0	0	0	322	4,176	66	0	0	0	11,638	0	35,094
1996	1,095	0	175	0	2,475	0	0	0	322	4,726	143	0	0	2,373	13,642	0	24,950
1997	0	0	0	0	2,406	0	0	0	322	4,261	112	0	0	5,824	13,962	0	26,887
1998	245	0	0	0	1,008	0	0	0	307	318	232	0	0	1,499	13,404	76	17,089
1999	915	0	0	0	2,099	0	0	0	333	773	105	0	0	1,241	14,692	2,806	22,963
2000	2,119	0	855	0	6,406	0	0	0	336	15,864	81	0	0	689	17,125	0	43,475
2001	100,492	19,482	6,115	13,950	8,533	0	0	86,404	350	61,988	103	52,034	0	0	15,714	6,507	371,673
2002	86,809	3,436	4,453	13,972	10,047	0	0	24,664	360	70,804	94	9,578	0	2,082	16,247	0	242,545
2003	30,906	0	1,619	3,211	5,484	1,892	0	53,591	364	21,811	56	16,181	0	2,828	17,733	24	155,699
2004	75,399	0	3,848	7,147	8,920	3,345	0	27,736	393	49,888	120	1,985	0	2,879	20,809	41	202,510
2005	25,104	589	430	0	3,563	0	0	21,553	400	6,121	111	12,951	0	2,145	20,843	0	93,809
2006	174	0	228	0	4,202	0	0	0	416	2,645	77	0	0	156	22,108	0	30,007
2007	101,515	23,022	5,858	10,000	11,039	6,220	0	167,291	419	88,841	149	54,150	2,302	0	23,107	0	493,914
2008	141,081	27,850	6,066	13,400	12,222	9,478	9,744	246,249	423	100,465	115	77,533	7,470	0	22,340	0	674,436
2009	128,043	29,745	5,315	9,086	742	5,582	15,117	166,703	389	111,798	144	78,033	6,001	449	21,629	0	578,777
2010	37,081	15,117	841	3,896	2,078	1,886	4,466	97,576	362	20,897	112	41,021	0	375	21,334	0	247,041
2011	445	0	290	0	146	0	0	0	378	683	115	0	0	500	20,801	1,037	24,395
2012	43,589	6,362	1,835	3,960	2,058	1,319	3,148	94,381	393	103,236	107	14,257	0	0	21,107	14,579	310,330
2013	123,971	1,379	4,261	5,571	20,994	2,252	19,809	171,627	373	146,543	118	41,743	14,231	0	19,494	16,518	588,883
2014	146,319	23,891	3,269	7,997	18,120	30,884	34,160	183,235	359	133,769	472	78,603	21,604	0	33,129	16,020	731,830
2015	123,618	26,298	1,267	3,516	24,146	38,294	32,918	154,687	358	118,342	109	56,634	17,237	0	20,344	13,857	631,624

TABLE 6 - Summary of data input for groundwater pumping for basin export by water district applied to C2VSimFG-Kern Historical Simulation

Water Year	Arvin-Edison WSD to Aqueduct	DWR to Aqueduct	North Kern WSD to Friant-Kern Canal	Rosedale Rio Brave WSD to CVC	Semi-tropic WSD to Aqueduct	Wheeler Ridge - Maricopa WSD to Aqueduct	County of Kern to BVARA	TOTAL
	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
1986	0	0	0	0	0	0	0	2,056
1987	0	0	0	0	0	0	673	63,724
1988	0	0	0	0	0	0	6,301	96,193
1989	0	0	0	0	0	0	5,879	120,544
1990	0	0	0	0	0	0	8,836	156,097
1991	0	0	0	0	0	0	22,114	170,307
1992	0	0	0	0	0	0	25,025	184,191
1993	0	0	0	0	0	0	7,521	28,892
1994	0	0	0	0	0	0		117,295
1995	0	2,319	0	0	0	0	4,748	23,134
1996	0	0	0	0	0	0	0	10,986
1997	0	0	0	0	0	0	0	12,603
1998	0	0	0	0	0	0	0	3,378
1999	0	0	0	0	0	0	0	7,938
2000	0	0	0	0	0	0	56	26,013
2001	0	0	0	0	1,457	638	10,024	355,608
2002	0	0	0	0	21,819	0	22,402	225,938
2003	12,380	0	0	0	0	0	9,886	137,602
2004	11,573	0	0	0	8,965	0	13,643	181,308
2005	13,939	0	0	0	19,103	0	6,071	72,567
2006	0	0	0		0	0	0	7,482
2007	7,609	0	7,276	0	6,282	0	10,437	470,388
2008	42,615	0	4,612	0	92,169	0	17,351	651,673
2009	43,080	0	5,880	0	86,194	7,243	7,786	556,758
2010	56,229	0	73	0	37,995	12,404	7,019	225,345
2011	16,065	0	0	0	0	0	369	3,217
2012	10,010	0	6,803	0	0	1,340	1,889	288,831
2013	15,111	0	7,471	12,116	5,610	3,815	9,786	569,016
2014	45,195	0	12,071	28,818	95,611	18,236	21,567	698,342
2015	67,142	0	9,752	26,314	89,453	26,943	23,330	610,923

TABLE 7 - Summary of population data input by urban zone applied to C2VSimFG-Kern Historical Simulation

Water Year	Urban Zone 97	Urban Zone 98	Urban Zone 99	Urban Zone 100	Urban Zone 102	Urban Zone 103	Urban Zone 104	Urban Zone 105	Urban Zone 106	Total	Annual Growth Rate
	Population	Population	Population	Population	Population	Population	Population	Population	Population	Population	percent
1985	18,266	4,545	54,766	199	11,589	1,845	15,756	443	229,085	336,493	
1986	18,506	4,565	56,021	184	11,631	1,868	16,127	443	245,095	354,441	5.3%
1987	18,747	4,586	57,277	170	11,673	1,892	16,498	443	261,105	372,389	5.1%
1988	18,987	4,607	58,532	155	11,715	1,915	16,869	442	277,114	390,337	4.8%
1989	19,227	4,627	59,788	141	11,758	1,939	17,240	442	293,124	408,285	4.6%
1990	19,467	4,648	61,043	126	11,800	1,962	17,611	442	309,134	426,233	4.4%
1991	19,808	4,662	64,110	132	12,190	2,023	17,570	475	316,532	437,502	2.6%
1992	20,150	4,676	67,178	138	12,581	2,084	17,528	507	323,930	448,771	2.6%
1993	20,491	4,690	70,245	144	12,971	2,145	17,487	540	331,328	460,041	2.5%
1994	20,832	4,704	73,313	150	13,362	2,206	17,445	572	338,726	471,310	2.4%
1995	21,174	4,718	76,380	156	13,752	2,268	17,404	605	346,124	482,579	2.4%
1996	21,515	4,732	79,447	161	14,142	2,329	17,363	637	353,522	493,848	2.3%
1997	21,856	4,746	82,515	167	14,533	2,390	17,321	670	360,920	505,117	2.3%
1998	22,197	4,760	85,582	173	14,923	2,451	17,280	702	368,318	516,387	2.2%
1999	22,539	4,774	88,650	179	15,314	2,512	17,238	735	375,716	527,656	2.2%
2000	22,880	4,788	91,717	185	15,704	2,573	17,197	767	383,114	538,925	2.1%
2001	23,154	4,887	94,141	193	16,313	2,601	17,609	742	395,409	555,047	3.0%
2002	23,429	4,985	96,564	200	16,922	2,628	18,020	717	407,703	571,169	2.9%
2003	23,703	5,084	98,988	208	17,532	2,656	18,432	692	419,998	587,291	2.8%
2004	23,977	5,182	101,412	215	18,141	2,683	18,844	667	432,292	603,413	2.7%
2005	24,252	5,281	103,836	223	18,750	2,711	19,256	643	444,587	619,536	2.7%
2006	24,526	5,379	106,259	230	19,359	2,738	19,667	618	456,882	635,658	2.6%
2007	24,800	5,478	108,683	238	19,968	2,766	20,079	593	469,176	651,780	2.5%
2008	25,074	5,576	111,107	245	20,578	2,793	20,491	568	481,471	667,902	2.5%
2009	25,349	5,675	113,530	253	21,187	2,821	20,902	543	493,765	684,024	2.4%
2010	25,623	5,773	115,954	260	21,796	2,848	21,314	518	506,060	700,146	2.4%
2011	25,815	5,802	117,403	261	21,959	2,862	21,474	519	512,386	708,482	1.2%
2012	26,009	5,831	118,871	261	22,124	2,877	21,635	521	518,791	716,919	1.2%
2013	26,204	5,860	120,357	262	22,290	2,891	21,797	522	525,275	725,458	1.2%
2014	26,400	5,889	121,861	263	22,457	2,905	21,961	523	531,841	734,102	1.2%
2015	26,598	5,919	123,385	263	22,626	2,920	22,125	525	538,489	742,850	1.2%

TABLE 8 - Summary of data input of per-capita water use by urban zone applied to C2VSimFG-Kern Historical simulation

Water Year	Urban Zone 97	Urban Zone 98	Urban Zone 99	Urban Zone 100	Urban Zone 102	Urban Zone 103	Urban Zone 104	Urban Zone 105	Urban Zone 106
	gdpc	gdpc	gdpc	gdpc	gdpc	gdpc	gdpc	gdpc	gdpc
1985	228	196	245	159	180	159	293	159	508
1986	228	196	245	159	180	159	293	159	480
1987	228	196	245	159	180	159	293	159	450
1988	228	196	245	159	180	159	293	159	439
1989	228	196	245	159	180	159	293	159	419
1990	228	196	245	159	180	159	293	159	438
1991	228	196	245	159	180	159	293	159	409
1992	228	196	245	159	180	159	293	159	417
1993	228	196	245	159	180	159	293	159	414
1994	228	196	245	159	180	159	293	159	421
1995	228	196	245	159	180	159	293	159	381
1996	228	196	245	159	180	159	293	159	401
1997	228	196	245	159	180	159	293	159	348
1998	228	196	245	159	180	159	293	159	304
1999	228	196	248	159	159	159	237	159	388
2000	228	196	248	159	159	159	237	159	367
2001	228	196	248	159	159	159	237	159	364
2002	228	196	248	159	159	159	237	159	362
2003	228	196	248	159	159	159	237	159	358
2004	228	196	248	159	159	159	237	159	386
2005	228	196	248	159	159	159	237	159	314
2006	228	196	248	159	159	159	237	159	338
2007	228	196	248	159	159	159	237	159	375
2008	228	196	248	159	159	159	237	159	367
2009	228	196	248	159	159	159	237	159	344
2010	228	196	248	159	159	159	237	159	328
2011	228	196	248	159	159	159	237	159	351
2012	228	196	248	159	159	159	237	159	378
2013	228	196	248	159	159	159	237	159	330
2014	228	196	248	159	159	159	237	159	314
2015	228	196	248	159	159	159	237	159	261

TABLE 9 - Summary of data input for crop evapotranspiration (ET) by crop type based on METRIC satellite data applied to C2VSimFG-Kern Historical Simulation

Water Year	Grain	Cotton	Sugar Beets	Cotton	Dry Beans	Saf-flower	Other Field Crops	Alfalfa	Pasture	Tomoto-Processed	Tomato-Fresh	Curcubits	Onions & Garlic	Potatoes	Other Truck	Almonds & Pistachios	Orchards	Citrus	Vineyards	Idle	Rice	Refuge	Urban	Native
Units	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr	in/yr
1985	30.0	31.6	34.6	35.4	30.8	28.0	27.9	38.9	35.8	28.8	27.3	24.9	28.7	27.6	29.3	31.6	29.7	36.5	25.0	27.4	35.8	31.6	28.1	27.5
1986	28.2	28.9	36.4	32.8	28.0	26.2	29.2	39.3	35.5	29.8	28.8	27.7	26.5	26.2	27.9	35.1	33.6	36.8	26.9	27.1	39.3	36.2	27.8	26.8
1987	33.8	35.2	39.5	33.3	31.0	26.3	31.4	44.5	33.2	34.2	28.3	27.2	31.3	30.9	31.2	41.4	37.1	43.4	32.1	30.6	40.7	32.2	32.3	33.0
1988	33.8	35.2	39.5	33.3	31.0	26.3	31.4	44.5	33.2	34.2	28.3	27.2	31.3	30.9	31.2	41.4	37.1	43.4	32.1	30.6	40.7	32.2	32.3	33.0
1989	33.8	35.2	39.5	33.3	31.0	26.3	31.4	44.5	33.2	34.2	28.3	27.2	31.3	30.9	31.2	41.4	37.1	43.4	32.1	30.6	40.7	32.2	32.3	33.0
1990	33.8	35.2	39.5	33.3	31.0	26.3	31.4	44.5	33.2	34.2	28.3	27.2	31.3	30.9	31.2	41.4	37.1	43.4	32.1	30.6	40.7	32.2	32.3	33.0
1991	30.0	31.6	34.6	35.4	30.8	28.0	27.9	38.9	35.8	28.8	27.3	24.9	28.7	27.6	29.3	31.6	29.7	36.5	25.0	27.4	35.8	31.6	28.1	27.5
1992	33.8	35.2	39.5	33.3	31.0	26.3	31.4	44.5	33.2	34.2	28.3	27.2	31.3	30.9	31.2	41.4	37.1	43.4	32.1	30.6	40.7	32.2	32.3	33.0
1993	28.2	28.9	36.4	32.8	28.0	26.2	29.2	39.3	35.5	29.8	28.8	27.7	26.5	26.2	27.9	35.1	33.6	36.8	26.9	27.1	39.3	36.2	27.8	26.8
1994	29.5	34.0	36.9	37.0	31.9	24.0	36.5	37.6	31.4	32.4	27.3	27.4	34.1	28.7	31.6	37.2	37.5	38.7	29.1	33.3	26.6	23.9	27.0	27.3
1995	30.1	32.4	35.8	34.4	30.7	26.6	30.7	36.6	32.6	29.4	29.0	28.1	33.1	27.4	30.2	35.8	35.5	35.8	28.7	32.2	31.6	36.3	27.5	29.6
1996	35.0	37.1	39.7	39.2	38.2	32.6	35.8	42.3	38.7	36.1	32.7	28.7	35.3	30.4	33.0	39.3	40.1	39.4	32.1	32.8	34.1	36.4	30.2	31.0
1997	31.3	35.5	39.1	37.7	33.9	29.3	37.2	43.5	36.0	33.2	28.1	28.8	29.7	28.8	30.1	33.7	34.0	38.1	26.1	30.6	34.1	34.0	28.1	31.1
1998	28.2	28.9	36.4	32.8	28.0	26.2	29.2	39.3	35.5	29.8	28.8	27.7	26.5	26.2	27.9	35.1	33.6	36.8	26.9	27.1	39.3	36.2	27.8	26.8
1999	30.0	31.6	34.6	35.4	30.8	28.0	27.9	38.9	35.8	28.8	27.3	24.9	28.7	27.6	29.3	31.6	29.7	36.5	25.0	27.4	35.8	31.6	28.1	27.5
2000	31.1	34.6	36.0	33.2	29.4	28.7	33.8	44.0	38.6	32.2	32.3	27.3	30.5	29.4	29.5	37.0	34.6	41.0	28.9	27.6	41.2	31.4	32.3	33.0
2001	31.9	33.4	36.3	32.0	29.3	27.2	32.1	44.5	33.8	30.2	29.9	26.5	28.8	28.1	28.8	39.9	36.0	40.7	29.7	28.0	41.7	30.8	30.5	31.6
2002	33.8	35.2	39.5	33.3	31.0	26.3	31.4	44.5	33.2	34.2	28.3	27.2	31.3	30.9	31.2	41.4	37.1	43.4	32.1	30.6	40.7	32.2	32.3	33.0
2003	33.0	35.5	35.6	33.2	33.5	28.0	31.7	42.9	30.6	31.0	26.2	27.8	29.7	27.2	28.4	39.6	32.8	38.8	30.4	29.7	37.0	32.1	28.5	30.4
2004	34.5	36.6	37.3	33.5	33.3	32.8	35.6	46.4	36.1	33.1	26.4	26.1	32.4	30.3	33.1	44.2	36.7	40.0	33.1	35.5	39.0	31.5	30.1	32.4
2005	31.8	35.4	40.6	30.5	31.8	27.8	33.0	40.7	32.3	28.4	23.7	26.8	29.6	28.4	28.0	35.1	30.2	34.8	28.0	29.6	37.3	34.1	28.2	30.0
2006	30.9	33.7	33.7	31.4	31.3	24.9	31.1	41.4	33.2	25.4	26.9	29.5	26.9	31.9	28.2	33.9	28.6	35.0	27.6	27.3	39.6	39.3	27.9	29.0
2007	34.3	36.5	33.9	36.1	31.6	28.9	35.3	44.1	35.3	29.4	24.4	26.7	29.1	27.8	32.5	34.5	29.6	37.6	29.6	29.7	38.0	34.0	27.7	31.5
2008	35.2	34.1	30.6	35.3	29.7	25.1	36.0	43.8	37.2	28.0	25.1	25.7	29.7	29.1	31.3	33.2	31.5	37.9	29.6	26.9	34.2	29.9	28.3	31.4
2009	35.3	34.1	25.1	34.2	32.4	32.6	33.9	42.2	30.9	26.5	24.4	24.9	27.1	29.3	29.6	34.5	31.9	37.8	30.4	28.9	35.8	30.5	27.9	32.0
2010	31.6	28.9	25.8	30.2	28.5	23.7	29.8	38.7	26.8	23.2	23.4	26.2	25.4	26.5	27.0	37.3	31.0	35.5	32.3	28.3	33.7	30.8	27.1	30.2
2011	30.1	28.2	23.9	28.3	27.0	21.8	29.6	36.0	25.1	22.6	27.0	24.4	25.5	25.8	25.2	36.2	32.0	33.6	30.9	26.6	38.1	33.6	26.9	32.7
2012	30.2	27.3	22.5	28.7	26.3	23.0	31.0	35.8	26.1	22.6	28.1	24.3	25.8	26.1	26.1	36.6	31.7	33.9	31.2	26.0	38.4	33.8	27.5	33.0
2013	35.7	35.5	28.0	34.7	32.7	33.2	36.4	44.0	33.1	27.2	30.7	29.1	32.4	30.1	30.1	43.6	35.5	39.9	38.6	29.5	36.3	36.8	29.1	35.2
2014	33.9	33.6	25.2	32.9	28.4	28.8	36.0	40.4	28.8	25.2	28.2	28.3	28.6	28.7	29.8	42.5	33.0	37.8	34.1	28.5	36.0	35.8	29.2	34.2
2015	33.4	34.2	28.3	36.3	31.9	33.9	37.0	43.2	29.0	24.0	26.4	27.1	34.8	27.5	30.7	38.8	31.8	38.3	31.0	28.1	29.6	32.2	27.9	32.4
Average	**32.4**	**33.4**	**33.0**	**33.4**	**30.9**	**27.8**	**32.9**	**41.5**	**33.0**	**28.8**	**27.5**	**26.9**	**29.3**	**28.5**	**29.5**	**37.3**	**33.3**	**37.7**	**30.3**	**29.1**	**37.1**	**33.6**	**28.8**	**31.3**
BETA	**21.6**	**39.8**	**39.2**	**32.3**	**31.1**	**34.9**	**36.4**	**48.0**	**50.4**	**31.6**	**40.6**	**32.0**	**36.5**	**35.4**	**31.6**	**48.1**	**45.9**	**42.5**	**42.0**	**57.1**	**50.2**	**76.1**	**52.0**	**57.1**
Difference	**10.8**	**-6.4**	**-6.3**	**1.1**	**-0.2**	**-7.2**	**-3.5**	**-6.5**	**-17.4**	**-2.8**	**-13.0**	**-5.0**	**-7.2**	**-6.9**	**-2.1**	**-10.9**	**-12.6**	**-4.8**	**-11.7**	**-28.0**	**-13.1**	**-42.6**	**-23.2**	**-25.8**

TABLE 10 - Summary of C2VSimFG-Beta modifications in the Kern County Revision applied to C2VSimFG-Kern by IWFM model input file

File Name	Change to Model Input File
C2VSimFG.in	
*	Change simulation starting time to 09/30/1985_24:00
C2VSimFG_Unsat.dat	
*	Replaced initial condition values with more representative values for revised starting
C2VSimFG_SWatersheds.dat	
*	Modified parameters to improve stream discharge match to historical values
C2VSimFG_Groundwater1985.dat	
*	Added hydrologic flow barrier at White Wolf Fault
*	Set Corcoran Clay thickness to 0 ft in areas where it is not present
*	New 10/1/1985 initial condition
*	Modified hydraulic conductivity and specific storage in Layer 1 in the Kern Water Bank
*	Kern County observation wells
C2VSimFG_ElemPump.dat	
*	FRACSK and DSTSK modified for Kern County elements with limited pumping
C2VSimFG_WellSpec.dat	
*	Added Kern County groundwater water bank recovery wells
*	Added Kern County In-District and Urban wells
C2VSimFG_PumpRates.dat	
*	Added Kern County groundwater water bank recovery pumping
*	Added Kern County In-District and Urban pumping
C2VSimFG_StreamInflow.dat	
*	Exteneded Poso Creek inflow through WY2015
C2VSimFG_DiverionSpec.dat	
*	Removed all Kern County diversions and renumbered remaining diversions to 1-371
*	Added Kern County diersions 372-484
C2VSimFG_Diverions.dat	
*	Removed all Kern County diversions and renumbered remaining diversions to 1-371
*	Added Kern County diersions 372-484
*	Updated diversion data for all diversions to Kern County
C2VSimFG_BypassSpecs.dat	
*	Removed bypass #17
C2VSimFG_RootZone.dat	
*	Native return flow is sent to either nearby stream nodes as runoff or out-of-model as ET
C2VSimFG_IrrPeriod.dat	
*	Adjusted Kern County irrigation periods
C2VSimFG_ReturnFlowFrac.dat	
*	Modified Kern County Ag return flow fraction
C2VSimFG_Urban.dat	
*	Added zone 106 for Metro Bakersfield and adjusted other Kern County zone areas
*	Applied estimated September 1985 initial condition

TABLE 10 - Summary of C2VSimFG-Beta modifications in the Kern County Revision applied to C2VSimFG-Kern by IWFM model input file

File Name	Change to Model Input File
C2VSimFG_Urban_Area.dat	
*	Changed Kern County oil fields from urban to native vegetation
C2VSimFG_Urban_PerCapWaterUse.dat	
*	Updated population for Kern County Urban Zones based on 1990, 2000, 2010 Census
*	Developed demands from historical data and water management plans
C2VSimFG_Urban_Population.dat	
*	Updated population for Kern County Urban Zones based on 1990, 2000, 2010 Census
C2VSimFG_Urban_WaterUseSpecs.dat	
*	Set fractions for SRs 19-21 based on local info
C2VSimFG_NonPondedCrop.dat	
*	Return flow = 0 for Kern County
C2VSimFG_NonPondedCrop_Area.dat	
*	Revided crop distributions to match historical distribution
C2VSimFG_PondedCrop_Area.dat	
*	Modified distribution of rice to be limited to areas in northwest Kern County with
C2VSimFG_NativeVeg_Area.dat	
*	Rebalanced native veg distribution after redistribution of non-ponded crop area to

Table 11A - Historical Groundwater Budget for the Kern County Subbasin for Water Years 1995 to 2014 based on the C2VSimFG-Kern Historical Simulation

Water Year	Deep Percolation	Managed Recharge and Canal Seepage	Net GW/SW Interactions	GW Pumping	Small Watershed Inflow	Subsurface Flow with Adjacent GW Basins	Change in Groundwater Storage
Units	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
1995	880,480	944,800	185,777	-946,782	122,287	-75,299	1,111,263
1996	801,572	926,537	106,692	-1,247,471	41,190	-84,675	543,845
1997	766,667	771,510	126,405	-1,068,169	50,548	-87,372	559,587
1998	1,034,867	1,097,180	121,413	-884,593	155,312	-87,515	1,436,665
1999	755,674	633,676	39,704	-1,109,310	32,155	-85,211	266,692
2000	617,018	462,522	91,454	-1,375,733	25,956	-83,759	-262,541
2001	551,880	222,131	66,647	-1,839,000	24,633	-81,896	-1,055,605
2002	466,463	202,687	76,147	-1,760,186	18,882	-83,943	-1,079,950
2003	502,831	297,019	118,149	-1,492,816	34,003	-85,638	-626,452
2004	488,327	284,862	83,294	-1,860,344	27,959	-89,250	-1,065,153
2005	799,614	1,147,287	132,785	-1,108,382	93,557	-89,912	974,946
2006	839,390	1,125,277	44,657	-1,149,877	40,846	-96,591	803,702
2007	560,860	403,611	26,260	-2,099,953	17,882	-91,566	-1,182,908
2008	463,721	146,763	78,841	-2,341,780	36,058	-86,260	-1,702,659
2009	485,234	186,548	73,848	-2,206,377	21,586	-85,764	-1,524,923
2010	599,434	467,683	141,715	-1,470,205	58,145	-94,664	-297,892
2011	1,073,963	1,530,123	259,404	-984,968	118,303	-94,981	1,901,842
2012	713,826	580,590	88,581	-1,583,369	19,020	-93,041	-274,395
2013	538,356	156,704	59,483	-2,447,479	19,043	-83,619	-1,757,511
2014	447,782	84,456	50,857	-2,830,674	17,832	-81,081	-2,310,831
Total	**13,387,959**	**11,671,966**	**1,972,113**	**-31,807,470**	**975,198**	**-1,742,039**	**-5,542,280**
Average	**669,398**	**583,598**	**98,606**	**-1,590,373**	**48,760**	**-87,102**	**-277,114**

Table 11B - Current Groundwater Budget for the Kern County Subbasin for Water Year 2015 based on the C2VSimFG-Kern Historical Simulation

Water Year	Deep Percolation	Managed Recharge and Canal Seepage	Net GW/SW Interactions	GW Pumping	Subsurface Flow within GW Basin	Subsurface Flow with Adjacent GW Basins	Change in Groundwater Storage
Units	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
2015	429,983	89,744	46,344	-2,740,237	0	-51,201	-2,225,366

NOTES:

Deep Percolation	Precipitation and applied water that reaches the groundwater after simulated transport across the unsaturated zone
Managed Recharge and Canal Seepage	Combined groundwater recharge from managed aquifer recharge operations, groundwater banking, and seepage from canals and other conveyance
Net GW/SW Interactions	Net volumetric exchange of surface water and groundwater from streams: Positive represents a net groundwater recharge, and negative represents a net groundwater discharge to the stream
GW Pumping	Total groundwater pumping by wells. Groundwater banking recovery pumping is specified input whereas agricultural and municipal pumping is calculated by C2VSim based on demand
Subsurface Flow within GW Basin	Net subsurface groundwater flow into a neighboring water district or area within the Kern County Subbasin: negative is a net flow out of the district and positive is a net flow into the district
Subsurface Flow with Adjacent GW Basins	Net subsurface groundwater flow from the Kern County Subbasin with an adjoining groundwater basin: negative is a net flow out of the Basin and positive is a net flow into the Basin
Change in Groundwater Storage	Sum of the inflow components (positive numbers) plus the outflow components (negative numbers): positive is an increase in storage typified by a rise in GW levels whereas a negative is a decrease in storage typified by a decline in GW levels

TABLE 12: Estimated sustainable yield for Kern County Subbasin for WY1995 to WY2014 Base Period based on C2VSimFG-Kern Historical Simulation

Water Year	Total Average Annual Volume	Agricultural Average Annual Volume	Agricultural Average Annual Volume per Ag Acre	Urban Average Annual Volume
Units	Acre-ft	Acre-ft	ft/acre	Acre-ft
	Sustainable Yield from Groundwater Pumping			
Groundwater Pumping	1,590,373	1,239,931	1.59	176,146
Percentage of Pumping		78%		11%
Change in Groundwater in Storage	-277,114	-216,051	-0.28	-30,692
Percentage of Pumping		-17%		-17%
Sustainable Yield	**1,313,259**	**1,023,880**	**1.31**	**145,453**
Average Annual Difference	**-277,114**	**-216,051**	**-0.28**	**-30,693**
Percent Difference	**-21%**	**-21%**	**-21%**	**-21%**
	Sutainable Yield from Basin Recharge and Outflow			
Groundwater Recharge	1,400,362	1,091,789	1.40	155,101
Subsurface Outflow	-87,102	-67,909	-0.09	-9,647
Sustainable Yield	**1,313,260**	**1,023,880**	**1.31**	**145,453**
Average Annual Difference	**-277,114**	**-216,051**	**0**	**-30,692**
Percent Difference	**0**	**0**	**0**	**0**

NOTES:

Sustainable Yield from Groundwater Pumping	Approach assumes that adjusting total groundwater pumping by the change in storage provides an reasonable approximation of the Basin Sustainable
Sutainable Yield from Basin Recharge and Outflow	Approach assumes that the Basin Sustainable Yield can be reasonably approximated by adding up the different recharge components and non-

TABLE 13: Estimate of potential native yield for Kern County Subbasin for WY1995 to WY2014 based on C2VSimFG-Kern Historical Simulation

	Ag Precipitation Recharge			Other Area Precipitation Recharge			Small Watershed Inflows			
Water Year	Precipitation in Agricultural Area	Precipitation to ET Demand	Precipitation to Groundwater in Agricultural Area	Precipitation in Other Areas	Precipitation to ET Demand	Precipitation to Groundwater in Other Areas	Small Watershed Subsurface Inflow	Small Watershed Runoff Percolation	Small Watershed Recharge to Groundwater	Native Yield
Units	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
1995	702,794	521,974	180,820	1,108,386	824,558	283,828	17,540	104,746	122,287	586,934
1996	381,496	351,540	29,956	526,809	422,541	104,268	17,512	23,679	41,190	175,414
1997	482,117	356,589	125,528	637,266	487,128	150,138	17,524	33,024	50,548	326,214
1998	966,485	663,632	302,853	1,492,576	1,024,918	467,658	17,840	137,472	155,312	925,823
1999	433,456	400,669	32,786	589,454	464,061	125,393	17,812	14,343	32,155	190,334
2000	384,158	357,496	26,661	476,308	398,994	77,315	17,757	8,200	25,956	129,933
2001	431,757	353,840	77,917	579,440	488,081	91,358	17,722	6,911	24,633	193,908
2002	255,111	227,877	27,234	382,463	317,069	65,394	17,679	1,203	18,882	111,510
2003	400,953	331,300	69,653	599,314	506,451	92,863	17,683	16,320	34,003	196,519
2004	301,023	275,258	25,765	422,514	339,652	82,862	17,661	10,298	27,959	136,586
2005	653,833	486,132	167,701	964,382	785,465	178,917	17,808	75,750	93,557	440,175
2006	499,756	447,319	52,437	657,647	546,950	110,697	17,783	23,063	40,846	203,981
2007	216,658	227,752	-11,095	292,814	241,483	51,331	17,725	157	17,882	58,119
2008	189,035	170,649	18,385	305,703	248,514	57,189	17,697	18,361	36,058	111,633
2009	268,010	221,348	46,663	405,160	336,116	69,044	17,674	3,913	21,586	137,293
2010	457,031	346,082	110,949	683,456	543,580	139,876	17,731	40,414	58,145	308,969
2011	649,878	441,717	208,161	1,023,701	692,781	330,919	17,932	100,370	118,303	657,382
2012	335,227	299,191	36,036	446,686	372,675	74,012	17,851	1,169	19,020	129,067
2013	214,951	203,005	11,946	303,560	246,644	56,916	17,787	1,257	19,043	87,906
2014	167,800	152,566	15,234	263,824	214,181	49,642	17,713	120	17,832	82,708
Total	**8,391,529**	**6,835,938**	**1,555,591**	**12,161,462**	**9,501,842**	**2,659,620**	**354,429**	**620,769**	**975,198**	**5,190,409**
Average	**419,576**	**341,797**	**77,780**	**608,073**	**475,092**	**132,981**	**17,721**	**31,038**	**48,760**	**259,520**
Use (ft/acre)	**0.54**	**0.44**	**0.10**	**0.59**	**0.46**	**0.13**	**0.01**	**0.02**	**0.03**	**0.144**

NOTES:

Simulation of Recharge	IWFM applies two processes to simulate the movement of water from the surface to the groundwater. The root zone simulates calculates the volume of water that will percolate below the root zone based on local soil properties. This water bases to the unsaturated zone that applies a 1-D vadose zone flow that simulates the rate that water will reach the groundwater based on subsurface properties and soil moisture content.
Percolation from Agricultural Area	Total volume of rainfall and applied water calculated to meet the total agricultural demand that percolates below the root zone in irrigated agricultural areas based on C2VSim simulation.
Percolation from Urban Area	Total volume of rainfall and applied water calculated to meet urban outdoor use that percolates below the root zone in urban areas based on C2VSim simulation.
Percolation from Native, Undeveloped or Fallow Areas	Total volume of rainfall and applied water that percolates below the root zone in native, undeveloped and fallow areas based on C2VSim simulation.
Percolation to Unsaturated Zone	Total volume of rainfall and applied water that percolates below the root zone from all areas based on C2VSim simulation.
GW Recharge from Unsaturated Zone	Volume of water going from the unsaturated zone to groundwater
GW Banking, Managed Recharge and Canal Seepage	Managed aquifer recharge and groundwater banking is simulated in C2VSim by applying a high recoverable loss factor for surface water diversions. For Kern County, these operations generally assumes that 88% to 94% of surface water deliveries physically recharge groundwater. This recharge is applied directly to the groundwater without passing through the unsaturated zone.
Net GW/SW Interactions	Net volumetric exchange between surface water in Kern River or Poso Creek and the groundwater. A positive number is surface water to groundwater, and a negative is groundwater discharge to the stream. This recharge is applied directly to the groundwater without passing through the unsaturated zone.
Total GW Recharge	Total volume to water reaching the groundwater as recharge

Table 14 - Hydrologic year correlation with relevant river indices for projected-future simulation period

Project Year	Hydrology Year	Annual Kern River Index	San Joaquin River Index
2021	**2003**	71	Below Normal
2022	**2004**	56	Dry
2023	**2005**	159	Wet
2024	**2006**	147	Wet
2025	**2007**	35	Critical
2026	**2008**	71	Critical
2027	**2009**	65	Below Normal
2028	**2010**	126	Above Normal
2029	**2011**	201	Wet
2030	**2012**	45	Dry
2031	**2013**	28	Critical
2032	**2014**	24	Critical
2033	**1995**	191	Wet
2034	**1996**	136	Wet
2035	**1997**	162	Wet
2036	**1998**	236	Wet
2037	**1999**	60	Above Normal
2038	**2000**	66	Above Normal
2039	**2001**	54	Dry
2040	**2002**	58	Dry
2041	**2003**	71	Below Normal
2042	**2004**	56	Dry
2043	**2005**	159	Wet
2044	**2006**	147	Wet
2045	**2007**	35	Critical
2046	**2008**	71	Critical
2047	**2009**	65	Below Normal
2048	**2010**	126	Above Normal
2049	**2011**	201	Wet
2050	**2012**	45	Dry
2051	**2013**	28	Critical
2052	**2014**	24	Critical
2053	**1995**	191	Wet
2054	**1996**	136	Wet
2055	**1997**	162	Wet
2056	**1998**	236	Wet
2057	**1999**	60	Above Normal
2058	**2000**	66	Above Normal
2059	**2001**	54	Dry
2060	**2002**	58	Dry
2061	**2003**	71	Below Normal
2062	**2004**	56	Dry
2063	**2005**	159	Wet
2064	**2006**	147	Wet
2065	**2007**	35	Critical
2066	**2008**	71	Critical
2067	**2009**	65	Below Normal
2068	**2010**	126	Above Normal
2069	**2011**	201	Wet
2070	**2012**	45	Dry

Table 16 - Projected Future Groundwater Budget for Kern County Subbasin under Baseline Conditions with NO SGMA Projects based on C2VSimFG-Kern Simulation

Water Year	Deep Percolation	Managed Recharge and Canal Seepage	Net Stream GW/SW Interaction	Net Small Watershed Recharge	GW Pumping	Subsurface Flow with Adjacent GW Basins	Change in Groundwater Storage
Units	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
SUMMARY: WY2021 to WY2070 Simulatation Period							
Total	31,276,668	27,591,218	6,284,636	2,457,805	-80,359,227	-3,647,996	**-16,396,918**
Average	625,533	551,824	125,693	49,156	-1,607,185	-72,960	**-327,938**
SUMMARY: WY2021 to WY2040 Implementation Period							
Total	12,059,157	10,900,930	2,570,048	948,239	-31,618,403	-1,527,102	**-6,667,151**
Average	602,958	545,046	128,502	47,412	-1,580,920	-76,355	**-333,358**
SUMMARY: WY2041 to WY2070 Sustainability Period							
Total	19,217,510	16,690,288	3,714,588	1,509,566	-48,740,823	-2,120,894	**-9,729,767**
Average	640,584	556,343	123,820	50,319	-1,624,694	-70,696	**-324,326**
Annual Simulation Results for WY2021 to WY2070 Simulation Period							
2021	421,248	253,922	124,080	38,770	-1,605,058	-83,845	-850,883
2022	466,065	311,661	80,807	28,596	-1,881,001	-79,540	-1,073,415
2023	670,267	894,337	186,631	97,803	-1,082,942	-77,289	688,801
2024	782,933	971,636	250,700	67,141	-1,004,008	-81,747	986,650
2025	487,829	334,264	74,696	18,060	-1,956,094	-78,483	-1,119,730
2026	440,342	154,936	78,551	36,473	-2,258,997	-69,511	-1,618,207
2027	522,430	255,426	73,629	21,942	-1,995,091	-69,397	-1,191,063
2028	569,509	496,227	141,957	35,496	-1,490,383	-70,383	-317,575
2029	1,025,597	1,528,921	110,823	119,558	-891,968	-80,187	1,812,744
2030	692,430	587,522	63,468	19,157	-1,382,783	-79,634	-99,841
2031	550,146	164,041	109,295	19,161	-2,366,434	-73,780	-1,597,574
2032	459,496	111,528	66,581	18,134	-2,763,485	-65,268	-2,173,015
2033	742,600	875,129	188,075	126,420	-1,059,514	-71,675	801,034
2034	617,059	786,754	201,477	42,156	-1,422,316	-78,762	146,370
2035	691,055	727,363	294,732	52,652	-1,120,121	-82,586	563,094
2036	848,018	1,151,100	175,108	103,683	-890,760	-84,597	1,302,552
2037	617,636	539,499	102,463	32,114	-1,230,808	-82,549	-21,645
2038	517,060	379,550	106,226	26,241	-1,390,747	-77,398	-439,070
2039	495,144	190,829	65,868	25,370	-1,883,912	-72,405	-1,179,106
2040	442,293	186,285	74,884	19,311	-1,941,979	-68,067	-1,287,273
2041	466,980	254,002	124,912	34,980	-1,621,935	-66,834	-807,894
2042	519,154	311,722	81,095	28,467	-1,928,066	-66,378	-1,054,007
2043	723,193	894,377	183,602	100,835	-1,131,893	-66,724	703,389
2044	829,429	971,656	217,998	68,630	-1,055,212	-73,234	959,267
2045	520,072	334,263	67,722	18,136	-2,005,971	-71,742	-1,137,519
2046	465,742	154,936	78,954	36,599	-2,308,492	-64,094	-1,636,355
2047	542,433	255,426	73,991	22,117	-2,044,767	-65,020	-1,215,821
2048	587,534	496,227	142,442	35,645	-1,539,937	-66,665	-344,754
2049	1,038,285	1,528,924	111,871	121,871	-940,873	-77,190	1,782,886
2050	704,906	587,522	63,577	19,216	-1,430,758	-77,175	-132,713
2051	567,160	164,041	109,977	19,218	-2,411,967	-71,447	-1,623,019
2052	480,958	111,528	66,775	18,007	-2,776,754	-63,069	-2,162,556
2053	756,460	875,129	189,903	127,393	-1,105,182	-69,591	774,112
2054	629,422	786,754	203,667	42,236	-1,466,597	-76,937	118,546
2055	697,412	727,363	297,238	52,738	-1,163,909	-81,081	529,760
2056	955,260	1,151,202	186,248	169,221	-887,932	-83,323	1,490,676
2057	663,489	539,499	104,143	33,376	-1,272,005	-81,579	-13,077
2058	543,714	379,550	107,428	26,454	-1,432,264	-76,504	-451,623
2059	516,904	190,829	65,982	25,586	-1,924,204	-71,122	-1,196,025
2060	461,832	186,285	75,033	19,353	-1,923,734	-66,838	-1,248,069
2061	483,873	254,002	125,183	34,990	-1,662,322	-65,509	-829,782
2062	535,495	311,722	81,199	28,658	-1,968,451	-64,883	-1,076,261
2063	747,374	894,377	185,862	103,344	-1,173,248	-65,287	692,423
2064	797,596	971,656	227,478	42,092	-1,131,322	-72,135	835,365
2065	518,644	334,263	69,814	18,276	-2,046,917	-70,907	-1,176,825
2066	472,700	154,936	79,262	36,483	-2,350,004	-63,321	-1,669,944
2067	550,095	255,426	74,266	22,151	-2,087,215	-64,426	-1,249,703
2068	654,126	496,227	142,653	60,396	-1,488,744	-65,173	-200,515
2069	1,067,944	1,528,924	112,385	123,705	-984,856	-76,302	1,771,799
2070	719,324	587,522	63,930	19,394	-1,475,294	-76,404	-161,529

Table 17 - Projected Future Groundwater Budget for Kern County Subbasin under Baseline Conditions WITH SGMA Projects based on C2VSimFG-Kern Simulation

Water Year	Deep Percolation	Managed Recharge and Canal Seepage	Net GW/SW Interactions	Small Watershed Inflow	GW Pumping	Subsurface Flow with Adjacent GW Basins	Change in Groundwater Storage
Units	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
SUMMARY: WY2021 to WY2070 Simulatation Period							
Total	33,771,527	32,630,931	5,233,643	2,457,805	-69,157,708	-5,025,601	**-89,422**
Average	675,431	652,619	104,673	49,156	-1,383,154	-100,512	**-1,788**
SUMMARY: WY2021 to WY2040 Implementation Period							
Total	13,100,548	12,612,730	2,239,160	948,239	-28,535,055	-1,719,340	**-1,353,732**
Average	655,027	630,637	111,958	47,412	-1,426,753	-85,967	**-67,687**
SUMMARY: WY2041 to WY2070 Sustainability Period							
Total	20,670,979	20,018,200	2,994,483	1,509,566	-40,622,653	-3,306,261	**1,264,311**
Average	689,033	667,273	99,816	50,319	-1,354,088	-110,209	**42,144**
Annual Simulation Results for WY2021 to WY2070 Simulation Period							
2021	430,153	302,373	123,650	38,770	-1,594,606	-83,189	-782,849
2022	475,303	349,553	80,614	28,596	-1,862,120	-78,565	-1,006,617
2023	770,374	1,002,929	168,647	97,803	-1,009,264	-78,404	952,085
2024	855,058	1,086,448	198,849	67,141	-944,665	-84,319	1,178,512
2025	503,643	350,298	70,663	18,060	-1,861,303	-81,925	-1,000,565
2026	440,243	214,542	77,894	36,473	-2,187,564	-73,190	-1,491,603
2027	518,989	316,584	73,092	21,942	-1,919,158	-73,183	-1,061,733
2028	578,749	623,230	137,529	35,496	-1,407,567	-75,335	-107,901
2029	1,194,895	1,696,947	83,255	119,558	-744,743	-87,273	2,262,638
2030	750,668	608,048	58,365	19,157	-1,257,759	-87,531	90,947
2031	555,404	180,833	107,613	19,161	-2,187,295	-83,584	-1,407,869
2032	453,293	125,476	66,634	18,134	-2,567,449	-76,460	-1,980,378
2033	824,902	1,059,059	172,274	126,420	-840,738	-84,135	1,257,782
2034	653,828	917,135	178,991	42,156	-1,197,621	-93,181	501,309
2035	827,370	931,556	238,868	52,652	-872,560	-98,679	1,079,205
2036	1,116,969	1,381,739	113,563	103,683	-633,072	-102,650	1,980,231
2037	725,584	594,384	63,749	32,114	-1,023,020	-100,141	292,669
2038	511,919	433,966	84,887	26,241	-1,154,051	-95,834	-192,873
2039	489,540	224,450	65,153	25,370	-1,627,860	-92,035	-915,382
2040	423,665	213,184	74,871	19,311	-1,642,642	-89,729	-1,001,340
2041	445,485	305,376	122,807	34,980	-1,354,885	-89,185	-535,423
2042	498,858	354,364	80,832	28,467	-1,639,112	-89,772	-766,363
2043	812,155	1,090,304	140,266	100,835	-882,848	-92,437	1,168,274
2044	892,628	1,153,766	138,151	68,630	-836,920	-100,949	1,315,306
2045	524,833	355,672	49,525	18,136	-1,730,147	-100,070	-882,051
2046	454,216	218,616	78,021	36,599	-2,055,875	-92,126	-1,360,549
2047	532,454	320,562	73,425	22,117	-1,809,154	-93,438	-954,033
2048	593,653	668,774	137,874	35,645	-1,324,186	-97,255	14,505
2049	1,234,198	1,750,812	79,492	121,871	-710,054	-110,080	2,366,239
2050	768,780	619,092	54,500	19,216	-1,197,582	-110,438	153,567
2051	578,825	192,400	107,098	19,218	-2,110,155	-106,461	-1,319,074
2052	479,637	135,929	66,695	18,007	-2,470,952	-99,536	-1,870,221
2053	850,038	1,095,469	170,484	127,393	-813,603	-107,867	1,321,915
2054	682,383	948,274	168,655	42,236	-1,143,633	-117,748	580,168
2055	858,469	966,141	223,989	52,738	-849,900	-123,451	1,127,986
2056	1,291,577	1,415,721	105,108	169,221	-638,704	-126,824	2,216,098
2057	807,949	600,599	52,465	33,376	-1,027,113	-123,865	343,411
2058	541,774	439,164	78,391	26,454	-1,146,168	-119,115	-179,499
2059	503,264	229,194	64,724	25,586	-1,627,673	-114,273	-919,179
2060	435,869	217,320	75,042	19,353	-1,597,610	-111,590	-961,617
2061	449,783	308,906	122,761	34,990	-1,363,117	-110,530	-557,207
2062	501,922	357,723	80,757	28,658	-1,643,414	-110,538	-784,892
2063	820,754	1,111,099	135,039	103,344	-898,437	-113,406	1,158,393
2064	871,279	1,174,447	124,818	42,092	-868,913	-122,551	1,221,172
2065	511,277	358,753	43,942	18,276	-1,750,481	-120,972	-939,204
2066	454,845	222,078	77,969	36,483	-2,077,330	-112,479	-1,398,433
2067	531,138	323,961	73,264	22,151	-1,832,363	-113,339	-995,189
2068	672,372	689,792	138,150	60,396	-1,265,870	-116,258	178,583
2069	1,286,647	1,771,462	77,455	123,705	-733,283	-129,909	2,396,076
2070	783,917	622,428	52,784	19,394	-1,223,170	-129,799	125,553

Table 18 - Projected Future Groundwater Budget for Kern County Subbasin under 2030 Climate Conditions with NO SGMA Projects based on C2VSimFG-Kern Simulation

Water Year	Deep Percolation	Managed Recharge and Canal Seepage	Net GW/SW Interactions	Small Watershed Inflow	GW Pumping	Subsurface Flow with Adjacent GW Basins	Change in Groundwater Storage
Units	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
SUMMARY: WY2021 to WY2070 Simulatation Period							
Total	30,885,159	30,404,998	6,083,382	2,517,393	-85,792,996	-3,318,618	**-19,220,714**
Average	617,703	608,100	121,668	50,348	-1,715,860	-66,372	**-384,414**
SUMMARY: WY2021 to WY2040 Implementation Period							
Total	11,956,360	12,006,382	2,488,942	967,011	-33,772,959	-1,439,420	**-7,793,706**
Average	597,818	600,319	124,447	48,351	-1,688,648	-71,971	**-389,685**
SUMMARY: WY2041 to WY2070 Sustainability Period							
Total	18,928,799	18,398,617	3,594,440	1,550,382	-52,020,037	-1,879,198	**-11,427,008**
Average	630,960	613,287	119,815	51,679	-1,734,001	-62,640	**-380,900**
Annual Simulation Results for WY2021 to WY2070 Simulation Period							
2021	422,205	264,773	147,393	42,134	-1,686,375	-82,161	-892,031
2022	486,382	352,708	97,994	31,229	-1,966,104	-77,718	-1,075,519
2023	670,731	968,807	192,300	100,122	-1,194,263	-75,163	662,531
2024	724,438	1,015,022	177,313	64,551	-1,153,552	-78,823	748,944
2025	451,579	327,176	67,822	18,068	-2,002,002	-75,206	-1,212,569
2026	443,127	213,524	132,483	37,800	-2,325,127	-67,041	-1,565,234
2027	508,495	246,268	115,977	23,732	-2,151,549	-65,434	-1,322,507
2028	572,490	566,005	191,408	39,445	-1,651,430	-65,956	-348,038
2029	1,218,648	1,901,727	112,842	122,295	-1,104,305	-76,600	2,174,607
2030	553,673	532,639	51,185	19,641	-1,476,524	-74,857	-394,243
2031	521,194	199,452	76,829	18,143	-2,339,207	-68,717	-1,592,305
2032	453,699	143,631	46,557	17,968	-2,788,464	-60,558	-2,187,167
2033	743,629	915,198	182,822	122,210	-1,190,116	-67,058	706,686
2034	615,276	872,000	147,377	45,764	-1,543,359	-73,439	63,619
2035	736,533	843,258	281,587	55,297	-1,297,450	-77,197	542,029
2036	863,933	1,264,065	123,884	102,926	-1,044,324	-79,069	1,231,416
2037	542,139	510,531	72,919	32,384	-1,342,279	-75,848	-260,154
2038	507,189	428,732	81,591	27,413	-1,503,202	-70,781	-529,059
2039	482,914	213,280	87,387	26,084	-2,017,703	-65,709	-1,273,748
2040	438,087	227,586	101,273	19,804	-1,995,626	-62,086	-1,270,964
2041	462,417	263,946	147,623	39,151	-1,702,404	-60,765	-850,032
2042	532,326	354,460	98,221	31,228	-2,012,621	-59,960	-1,056,345
2043	717,292	967,381	179,212	103,193	-1,243,088	-59,869	664,119
2044	766,402	1,015,346	117,742	65,724	-1,204,632	-65,643	694,939
2045	477,463	326,770	51,863	18,138	-2,051,621	-63,896	-1,241,282
2046	465,642	213,337	132,843	37,870	-2,374,509	-57,074	-1,581,891
2047	526,192	246,482	116,132	23,946	-2,201,023	-56,606	-1,344,877
2048	584,963	564,936	191,656	39,636	-1,700,745	-57,895	-377,449
2049	1,218,687	1,904,385	99,805	124,949	-1,152,654	-69,447	2,125,726
2050	560,761	533,577	47,140	19,693	-1,524,426	-68,362	-431,617
2051	531,733	199,452	76,920	18,193	-2,385,216	-62,565	-1,621,483
2052	469,853	139,904	46,651	17,931	-2,807,543	-54,827	-2,188,030
2053	748,982	916,702	183,503	123,682	-1,235,658	-61,582	675,628
2054	618,472	870,588	145,806	45,880	-1,587,472	-68,329	24,946
2055	736,517	843,485	279,382	55,392	-1,341,090	-72,519	501,167
2056	954,438	1,263,249	134,078	169,164	-1,037,331	-74,710	1,408,888
2057	579,927	508,121	73,014	33,640	-1,384,414	-71,487	-261,199
2058	532,403	431,547	81,726	27,628	-1,544,662	-66,368	-537,727
2059	503,820	214,669	87,386	26,299	-2,057,978	-61,126	-1,286,930
2060	456,299	228,154	101,178	19,792	-1,984,645	-57,872	-1,237,094
2061	478,968	264,126	147,695	39,158	-1,742,970	-56,708	-869,739
2062	546,856	353,554	98,263	31,426	-2,052,889	-55,984	-1,078,775
2063	740,448	969,075	181,599	104,939	-1,284,313	-56,141	655,606
2064	735,683	1,013,851	124,774	41,649	-1,277,235	-62,203	576,518
2065	478,349	327,088	54,630	18,289	-2,092,701	-60,730	-1,275,076
2066	473,836	213,074	132,845	37,782	-2,406,519	-57,164	-1,606,144
2067	537,374	246,454	116,277	23,923	-2,231,035	-58,641	-1,365,648
2068	660,267	565,258	192,661	65,542	-1,647,974	-59,014	-223,263
2069	1,254,195	1,903,367	104,892	126,664	-1,191,285	-71,013	2,126,821
2070	578,235	536,275	48,924	19,883	-1,559,383	-70,699	-446,765

Table 19 - Projected Future Groundwater Budget for Kern County Subbasin under 2030 Climate Conditions WITH SGMA Projects based on C2VSimFG-Kern Simulation

Water Year	Deep Percolation	Managed Recharge and Canal Seepage	Net GW/SW Interactions	Small Watershed Inflow	GW Pumping	Subsurface Flow with Adjacent GW Basins	Change in Groundwater Storage
Units	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
SUMMARY: WY2021 to WY2070 Simulatation Period							
Total	32,838,979	35,447,299	4,941,607	2,517,393	-73,869,518	-4,735,936	**-2,860,202**
Average	656,780	708,946	98,832	50,348	-1,477,390	-94,719	**-57,204**
SUMMARY: WY2021 to WY2040 Implementation Period							
Total	12,873,160	13,719,306	2,153,021	967,011	-30,545,188	-1,641,666	**-2,474,378**
Average	643,658	685,965	107,651	48,351	-1,527,259	-82,083	**-123,719**
SUMMARY: WY2041 to WY2070 Sustainability Period							
Total	19,965,818	21,727,994	2,788,586	1,550,382	-43,324,331	-3,094,271	**-385,823**
Average	665,527	724,266	92,953	51,679	-1,444,144	-103,142	**-12,861**
Annual Simulation Results for WY2021 to WY2070 Simulation Period							
2021	436,607	313,191	146,335	42,134	-1,676,044	-81,420	-819,196
2022	495,680	391,450	97,863	31,229	-1,947,388	-76,701	-1,007,874
2023	777,040	1,077,709	179,601	100,122	-1,117,722	-76,444	940,302
2024	808,215	1,130,101	141,980	64,551	-1,088,738	-81,861	974,238
2025	462,701	343,315	61,517	18,068	-1,906,220	-78,953	-1,099,574
2026	439,400	273,084	131,767	37,800	-2,253,887	-70,713	-1,442,550
2027	504,308	306,757	115,891	23,732	-2,068,551	-69,760	-1,187,619
2028	576,402	692,833	189,187	39,445	-1,565,005	-71,313	-138,447
2029	1,371,389	2,070,178	67,647	122,295	-932,879	-84,094	2,614,536
2030	584,511	553,212	37,888	19,641	-1,345,295	-83,321	-233,371
2031	528,715	216,234	76,879	18,143	-2,159,236	-78,674	-1,397,939
2032	447,278	157,578	46,694	17,968	-2,586,970	-72,132	-1,989,585
2033	822,633	1,099,092	179,078	122,210	-954,120	-79,949	1,188,943
2034	642,235	1,002,883	120,224	45,764	-1,314,339	-88,379	408,386
2035	882,067	1,046,864	225,239	55,297	-1,036,291	-94,244	1,078,932
2036	1,079,981	1,496,375	67,732	102,926	-748,234	-98,400	1,900,379
2037	618,298	565,459	31,639	32,384	-1,137,009	-94,427	16,344
2038	503,029	481,733	53,082	27,413	-1,262,856	-89,986	-287,584
2039	473,864	246,867	81,296	26,084	-1,751,020	-86,330	-1,009,239
2040	418,807	254,393	101,481	19,804	-1,693,383	-84,564	-983,462
2041	444,811	315,197	147,563	39,151	-1,429,438	-83,810	-566,526
2042	514,255	397,576	97,317	31,228	-1,723,016	-83,907	-766,546
2043	816,698	1,163,940	134,478	103,193	-969,015	-86,356	1,162,938
2044	847,571	1,197,675	50,668	65,724	-949,162	-94,611	1,117,864
2045	471,125	348,281	32,446	18,138	-1,769,470	-93,309	-992,789
2046	446,314	276,979	132,424	37,870	-2,116,321	-86,037	-1,308,771
2047	507,943	310,952	116,190	23,946	-1,951,408	-86,246	-1,078,625
2048	570,746	737,315	190,434	39,636	-1,454,664	-89,846	-6,380
2049	1,365,299	2,126,760	34,358	124,949	-846,645	-103,976	2,700,745
2050	579,883	565,192	23,802	19,693	-1,287,166	-103,007	-201,604
2051	538,250	227,799	76,822	18,193	-2,083,539	-98,472	-1,320,948
2052	464,011	164,305	46,977	17,931	-2,493,990	-92,183	-1,892,949
2053	839,476	1,136,728	177,834	123,682	-921,588	-100,638	1,255,494
2054	659,537	1,032,674	98,253	45,880	-1,258,249	-110,065	468,030
2055	903,882	1,081,677	208,421	55,392	-1,002,340	-116,311	1,130,721
2056	1,216,310	1,529,332	56,914	169,164	-718,274	-120,237	2,133,209
2057	673,501	569,268	16,245	33,640	-1,122,622	-115,686	54,346
2058	522,020	489,739	44,186	27,628	-1,253,276	-110,474	-280,179
2059	481,112	252,996	77,161	26,299	-1,749,204	-105,946	-1,017,581
2060	429,670	259,054	101,488	19,792	-1,652,713	-103,828	-946,537
2061	447,419	318,905	147,790	39,158	-1,437,034	-102,731	-586,494
2062	515,397	400,090	96,110	31,426	-1,726,653	-102,439	-786,068
2063	822,203	1,186,122	125,545	104,939	-982,407	-105,263	1,151,138
2064	812,383	1,217,000	39,194	41,649	-986,296	-114,017	1,009,913
2065	461,447	351,690	27,964	18,289	-1,789,318	-112,105	-1,042,033
2066	449,867	280,211	132,607	37,782	-2,125,316	-106,826	-1,331,675
2067	511,035	314,307	116,486	23,923	-1,960,796	-107,878	-1,102,923
2068	651,081	758,626	191,836	65,542	-1,393,447	-109,878	163,759
2069	1,417,188	2,146,388	28,009	126,664	-861,456	-124,760	2,732,032
2070	585,382	571,217	19,064	19,883	-1,309,505	-123,427	-237,386

Table 20 - Projected Future Groundwater Budget for Kern County Subbasin under 2070 Climate Conditions with NO SGMA Projects based on C2VSimFG-Kern Simulation

Water Year	Deep Percolation	Managed Recharge and Canal Seepage	Net GW/SW Interactions	Small Watershed Inflow	GW Pumping	Subsurface Flow with Adjacent GW Basins	Change in Groundwater Storage
Units	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
SUMMARY: WY2021 to WY2070 Simulatation Period							
Total	30,266,907	32,824,218	5,541,096	2,495,122	-92,372,522	-3,271,463	**-24,516,680**
Average	605,338	656,484	110,822	49,902	-1,847,450	-65,429	**-490,334**
SUMMARY: WY2021 to WY2040 Implementation Period							
Total	11,792,918	12,994,527	2,263,192	960,586	-36,385,358	-1,447,672	**-9,821,843**
Average	589,646	649,726	113,160	48,029	-1,819,268	-72,384	**-491,092**
SUMMARY: WY2041 to WY2070 Sustainability Period							
Total	18,473,988	19,829,691	3,277,904	1,534,536	-55,987,164	-1,823,791	**-14,694,837**
Average	615,800	660,990	109,263	51,151	-1,866,239	-60,793	**-489,828**
Annual Simulation Results for WY2021 to WY2070 Simulation Period							
2021	408,652	250,550	140,163	38,275	-1,842,475	-83,663	-1,088,499
2022	472,102	369,832	95,673	30,903	-2,096,387	-78,608	-1,206,496
2023	673,989	1,058,910	189,890	97,206	-1,367,109	-76,560	576,325
2024	744,177	1,122,749	154,523	64,640	-1,269,966	-81,123	734,995
2025	434,940	339,216	62,383	18,095	-2,093,637	-77,242	-1,316,253
2026	469,752	316,670	142,130	42,165	-2,392,400	-68,542	-1,490,227
2027	468,805	219,342	111,136	22,713	-2,302,101	-66,245	-1,546,351
2028	565,266	622,490	194,932	37,491	-1,777,664	-66,172	-423,661
2029	1,232,895	2,021,954	94,628	120,391	-1,272,882	-75,969	2,121,016
2030	512,383	510,545	46,067	18,406	-1,606,048	-73,952	-592,602
2031	514,885	217,243	80,080	18,510	-2,404,879	-69,108	-1,643,271
2032	420,919	109,243	41,157	17,864	-2,961,316	-59,737	-2,431,871
2033	717,704	983,283	185,465	124,666	-1,366,638	-66,770	577,711
2034	636,472	1,011,310	124,135	48,403	-1,629,020	-73,691	117,609
2035	742,442	926,830	240,059	52,829	-1,506,120	-76,785	379,255
2036	840,589	1,369,821	66,325	95,355	-1,236,377	-78,889	1,056,824
2037	511,349	550,855	51,377	33,462	-1,460,435	-75,693	-389,084
2038	525,422	516,749	68,512	30,839	-1,615,455	-70,944	-544,878
2039	486,185	261,453	84,925	29,526	-2,078,540	-66,064	-1,282,515
2040	413,990	215,482	89,632	18,846	-2,105,907	-61,915	-1,429,871
2041	434,872	249,759	141,456	34,801	-1,861,023	-59,685	-1,059,819
2042	506,082	371,490	95,431	30,811	-2,143,228	-58,424	-1,197,837
2043	701,042	1,057,536	164,332	99,819	-1,415,545	-58,898	548,287
2044	765,882	1,123,035	84,872	65,709	-1,321,033	-65,596	652,868
2045	457,199	338,796	43,022	18,140	-2,143,265	-63,760	-1,349,868
2046	491,322	316,422	142,576	42,210	-2,441,728	-56,475	-1,505,673
2047	486,516	219,663	111,300	22,758	-2,350,989	-55,383	-1,566,136
2048	575,922	621,390	195,292	37,553	-1,826,869	-56,367	-453,078
2049	1,207,108	2,024,646	76,576	122,702	-1,321,171	-67,189	2,042,673
2050	516,604	511,479	41,647	18,437	-1,653,603	-66,049	-631,485
2051	524,249	217,243	80,184	18,541	-2,450,881	-61,709	-1,672,374
2052	436,390	105,521	41,256	17,846	-2,980,914	-52,973	-2,432,875
2053	721,385	984,833	185,983	125,947	-1,412,037	-60,560	545,551
2054	637,035	1,010,015	122,314	48,546	-1,673,215	-67,888	76,808
2055	739,029	926,775	240,837	53,236	-1,549,608	-71,550	338,718
2056	916,865	1,369,239	78,789	163,750	-1,223,884	-73,970	1,230,789
2057	542,683	548,446	53,332	34,610	-1,503,509	-70,686	-395,124
2058	550,193	519,512	70,081	31,051	-1,656,729	-65,944	-551,837
2059	506,313	262,783	85,481	29,722	-2,118,584	-60,956	-1,295,243
2060	434,143	216,084	89,721	18,987	-2,098,596	-57,233	-1,396,893
2061	453,048	249,994	141,478	34,761	-1,901,319	-55,229	-1,077,267
2062	522,814	370,621	95,685	30,984	-2,183,537	-54,157	-1,217,590
2063	725,002	1,059,135	169,499	100,139	-1,456,460	-54,936	542,379
2064	737,845	1,121,596	96,738	41,720	-1,390,161	-62,039	545,700
2065	456,525	339,078	47,370	18,277	-2,183,880	-60,597	-1,383,226
2066	498,361	316,005	142,585	41,907	-2,483,011	-53,520	-1,537,673
2067	496,804	219,419	111,431	22,808	-2,393,461	-52,693	-1,595,690
2068	655,939	621,712	196,418	66,128	-1,787,044	-52,309	-299,157
2069	1,243,827	2,023,476	87,110	124,017	-1,364,360	-64,030	2,050,039
2070	532,988	513,990	45,107	18,619	-1,697,522	-62,987	-649,805

Table 21 - Projected Future Groundwater Budget for Kern County Subbasin under 2070 Climate Conditions WITH SGMA Projects based on C2VSimFG-Kern Simulation

Water Year	Deep Percolation	Managed Recharge and Canal Seepage	Net GW/SW Interactions	Small Watershed Inflow	GW Pumping	Subsurface Flow with Adjacent GW Basins	Change in Groundwater Storage
Units	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft	Acre-ft
SUMMARY: WY2021 to WY2070 Simulatation Period							
Total	31,799,129	37,863,262	4,293,932	2,495,122	-79,755,674	-4,729,641	**-8,033,910**
Average	635,983	757,265	85,879	49,902	-1,595,113	-94,593	**-160,678**
SUMMARY: WY2021 to WY2040 Implementation Period							
Total	12,589,633	14,705,737	1,891,043	960,586	-32,975,395	-1,657,287	**-4,485,720**
Average	629,482	735,287	94,552	48,029	-1,648,770	-82,864	**-224,286**
SUMMARY: WY2041 to WY2070 Sustainability Period							
Total	19,209,496	23,157,525	2,402,889	1,534,536	-46,780,279	-3,072,354	**-3,548,190**
Average	640,317	771,917	80,096	51,151	-1,559,343	-102,412	**-118,273**
Annual Simulation Results for WY2021 to WY2070 Simulation Period							
2021	416,859	299,174	140,033	38,275	-1,829,917	-83,068	-1,018,646
2022	482,771	408,716	95,545	30,903	-2,075,055	-77,724	-1,134,857
2023	778,119	1,167,829	176,974	97,206	-1,283,726	-78,065	858,337
2024	824,224	1,237,834	116,452	64,640	-1,201,267	-84,296	957,582
2025	444,081	355,471	55,004	18,095	-1,995,258	-81,218	-1,203,834
2026	466,475	376,346	141,087	42,165	-2,313,156	-72,774	-1,359,861
2027	464,976	279,425	111,024	22,713	-2,213,764	-70,681	-1,406,307
2028	569,538	749,332	192,740	37,491	-1,685,558	-71,949	-208,410
2029	1,366,993	2,190,420	41,284	120,391	-1,077,423	-84,620	2,557,045
2030	534,178	531,150	29,555	18,406	-1,464,690	-82,917	-434,320
2031	519,704	234,003	79,675	18,510	-2,224,205	-79,250	-1,451,562
2032	415,122	123,188	41,020	17,864	-2,750,519	-71,829	-2,225,156
2033	783,412	1,166,531	179,799	124,666	-1,109,329	-80,416	1,064,663
2034	658,731	1,142,196	88,031	48,403	-1,395,221	-89,128	453,011
2035	863,103	1,130,070	184,994	52,829	-1,232,204	-94,328	904,464
2036	1,029,800	1,602,138	12,470	95,355	-917,373	-98,485	1,723,905
2037	570,198	605,678	8,505	33,462	-1,243,785	-94,402	-120,345
2038	523,835	569,446	34,689	30,839	-1,363,512	-90,407	-295,110
2039	479,164	294,676	72,792	29,526	-1,805,973	-86,949	-1,016,764
2040	398,352	242,115	89,372	18,846	-1,793,459	-84,780	-1,129,554
2041	414,818	301,192	141,646	34,801	-1,568,913	-83,592	-760,049
2042	491,990	414,742	93,845	30,811	-1,840,528	-83,323	-892,462
2043	790,613	1,254,107	115,429	99,819	-1,116,588	-86,323	1,057,057
2044	836,403	1,305,369	17,905	65,709	-1,045,824	-95,401	1,084,162
2045	449,154	360,429	22,817	18,140	-1,852,116	-93,998	-1,095,574
2046	471,989	380,169	142,402	42,210	-2,176,184	-86,568	-1,225,983
2047	471,984	283,737	111,550	22,758	-2,085,163	-85,737	-1,280,870
2048	554,428	793,776	194,145	37,553	-1,568,985	-88,857	-77,939
2049	1,321,092	2,246,987	3,572	122,702	-987,606	-102,881	2,603,867
2050	524,857	543,145	12,030	18,437	-1,398,511	-101,367	-401,409
2051	526,155	245,563	79,307	18,541	-2,147,741	-98,008	-1,376,184
2052	430,658	129,919	41,236	17,846	-2,649,533	-91,211	-2,121,085
2053	792,109	1,204,216	177,747	125,947	-1,064,253	-100,431	1,135,335
2054	668,348	1,172,104	66,220	48,546	-1,336,993	-110,282	507,943
2055	860,469	1,164,599	170,576	53,236	-1,194,626	-115,992	938,261
2056	1,144,616	1,635,346	2,390	163,750	-873,811	-120,178	1,952,112
2057	610,598	609,490	-6,003	34,610	-1,226,393	-115,425	-93,124
2058	546,965	577,365	26,400	31,051	-1,353,145	-110,712	-282,076
2059	486,798	300,706	68,354	29,722	-1,802,615	-106,347	-1,023,382
2060	409,456	246,809	89,277	18,987	-1,751,495	-103,792	-1,090,757
2061	418,628	304,951	141,821	34,761	-1,574,579	-102,407	-776,824
2062	495,173	417,295	92,534	30,984	-1,842,095	-101,824	-907,934
2063	793,354	1,276,196	108,214	100,139	-1,128,328	-105,241	1,044,334
2064	805,281	1,324,749	9,903	41,720	-1,082,528	-114,909	984,217
2065	440,536	363,793	19,730	18,277	-1,870,357	-113,021	-1,141,042
2066	471,618	383,251	141,837	41,907	-2,193,139	-104,993	-1,259,519
2067	473,770	286,942	111,773	22,808	-2,105,041	-103,867	-1,313,616
2068	625,100	815,113	195,615	66,128	-1,516,065	-105,894	79,999
2069	1,353,276	2,266,438	1,701	124,017	-1,005,088	-121,015	2,619,328
2070	529,258	549,028	8,916	18,619	-1,422,036	-118,758	-434,973

TABLE 22: Assessment of change in groundwater storage from C2VSimFG-Kern model results for historical and future scenarios for the Kern County Subbasin

Scenario	Model Results 2041-2070 Sustainability Period		Adjustments to GW Storage Change 2041-2070 Sustainability Period		
	Change in Groundwater Storage	**Change in Net Operational Budget**	**Adjustment for Excess Basin Outflows**	**Adjustment for Excess Kern River Outflow**	**Adjusted Change in GW Storage**
units	**AFY**	**AFY**	AFY	AFY	**AFY**
Historic	**-277,114**	**-190,012**	0	0	**-277,114**
Baseline	**-324,326**	**-253,629**	0	0	**-324,326**
Base Projects	**42,144**	**152,353**	26,327	17,108	**85,578**
2030 Climate	**-380,900**	**-318,260**	0	8,780	**-372,120**
2030 Projects	**-12,861**	**90,282**	27,056	32,634	**46,829**
2070 Climate	**-489,828**	**-429,035**	0	17,492	**-472,336**
2070 Projects	**-118,273**	**-15,861**	28,077	44,227	**-45,969**

NOTE:

"Change in *Groundwater Storage* " DOES include subsurface flow with adjacent basins

"*Operational Storage* " DOES NOT include subsurface flow with adjacent basins

"Adjustment for *Excess Basin Outflows* " is the difference in simulated basin outflow that is attributed to addition of SGMA projects in Kern County without comparable SGMA projects added to adjacent basins**.** Adjustment assumes that this difference is due to limitation of simulation, and that this difference would remain in Kern County when SGMA projects from adjacent basin are included in simulation.

"Adjustment for *Excess Kern River Outflow* " is the increase in simulated groundwater outflows to Kern River relative to Baseline condition that are attributed to SGMA Projects and Climate Change. Model is not optimized for river management. Since the Kern River is a highly managed system, the assumption is that in practice this water would be recovered for beneficial use rather than be a loss of water from the basin.

"*Adjusted Change in GW Storage* " Change in GW Storage plus modifications listed as adjustments to provide a more realistic Change in GW Storage estimate for the simulation.

TABLE 23: Evaluation of Sustainable Yield for Projected-Future scenarios based on C2VSimFG-Kern Model Results for Kern County Subbasin

Scenario	C2VSimFG-Kern Model Results 2041-2070 Sustainability Period					
	Groundwater Pumping	Change in Groundwater in Storage	GW Storage Adjustments	Sustainable Yield	Average Annual Difference of Pumping to Yield	Percent Difference of Pumping to Sustainable Yield
units	**AFY**	**AFY**	**AFY**	**AFY**	**AFY**	**AFY**
Historic	**1,590,373**	**-277,114**	**0**	**1,313,259**	**-277,114**	**-21%**
Baseline	**1,624,694**	**-324,326**	**0**	**1,300,369**	**-324,326**	**-25%**
Baseline Projects	**1,354,088**	**42,144**	**43,434**	**1,439,666**	**85,578**	**6%**
2030 Climate	**1,734,001**	**-380,900**	**8,780**	**1,361,881**	**-372,120**	**-27%**
2030 Projects	**1,444,144**	**-12,861**	**59,690**	**1,490,974**	**46,829**	**3%**
2070 Climate	**1,866,239**	**-489,828**	**17,492**	**1,393,902**	**-472,336**	**-34%**
2070 Projects	**1,559,343**	**-118,273**	**72,304**	**1,513,373**	**-45,969**	**-3%**

NOTES:

Groundwater Pumping	Total groundwater pumping by wells. Groundwater banking recovery pumping is specified input whereas agricultural and municipal pumping is calculated by C2VSim based on demand
Change in Groundwater in Storage	Sum of the inflow components (positive numbers) plus the outflow components (negative numbers): positive is an increase in storage typified by a rise in GW levels whereas a negative is a decrease in storage typified by a decline in GW levels
Adjusted Banking	Adjustment that assumes that recharge operations are affected by reductions in imported water sources, but
GW Storage Adjustments	Adjustment to GW Storage that reflect artifacts of the simulation. For Kern County, adjustments made to reflect no SGMA projects simulated north of Kern County, and that Kern River operations are not optimized to
Sutainable Yield	Sustainable yield is defined is the amount of pumping that can be sustained in the groundwater basin without the undesirable effect of a decline in groundwater storage that serves as a proxy for other undesirable effects
Average Annual Difference	The difference between the sustainable yield and the simulated groundwater pumping. A negative value is pumping in excess of the sustainable yield
Percent Difference	The percentage of the Average Annual Difference to the total groundwater pumping to provide context and a method to compare the significance of the difference in the pumping copmared to the sustainable yield.

TABLE 24: Summary of Statistical Analysis for Validation of C2VSimFG-Kern Historical Simulation

Validation Measure	C2VSimFG-Kern	C2VSimFG-Beta	Percent Change
Units	Feet	Feet	Percent
Residual Mean	17.3 ft	32.6 ft	47%
Residual Standard Deviation	45.5 ft	54.0 ft	16%
Absolute Residual Mean	37.4 ft	56.8 ft	34%
Root Mean Square (RMS) Error	50 ft	73.5 ft	32%
Scaled Absolute Residual Mean	0.061	0.092	34%
Correlation Coefficient	0.76	0.52	47%
Number of Monitor Wells	558	558	same
Number of Observations	42,075	42,075	same

Notes

Observation Point	Location in the model where measured data from well is compared to simulated model results
Residual	Difference between measured and simulated groundwater elevations at an observation point
Residual Mean	Statistical measure of fit of simulated to measured data using sum of the residuals divided by the number of residual data values
Residual Standard Deviation	Statistical evaluation of the scatter of the data by calculating standard deviation of residuals
Absolute Residual Mean	Statistical measure of fit of simulated to measured data using sum of the absolute value residuals divided by the number of residual data values
Root Mean Square (RMS) Error	Statistical measure of fit of simulated to measured data using square root of the quotient of sum of squares of residuals by the number of observations
Scaled Absolute Residual Mean	Statisical measure to provide scale of validation using ratio of the absolute residual mean divided by the range of observed groundwater elevations
Correlation Coefficient	Scaled measure of the closeness of fit of simulated to measured data from -1 to 1 correlation with 1.0 a perfect correlation
Number of Monitor Wells	Number of wells where measured groundwater level data was compared to C2VSimFG-Kern simulation results for model validation
Number of Observations	Number of groundwater level measurements that were compared to C2VSimFG-Kern simulation results for model validation

FIGURES

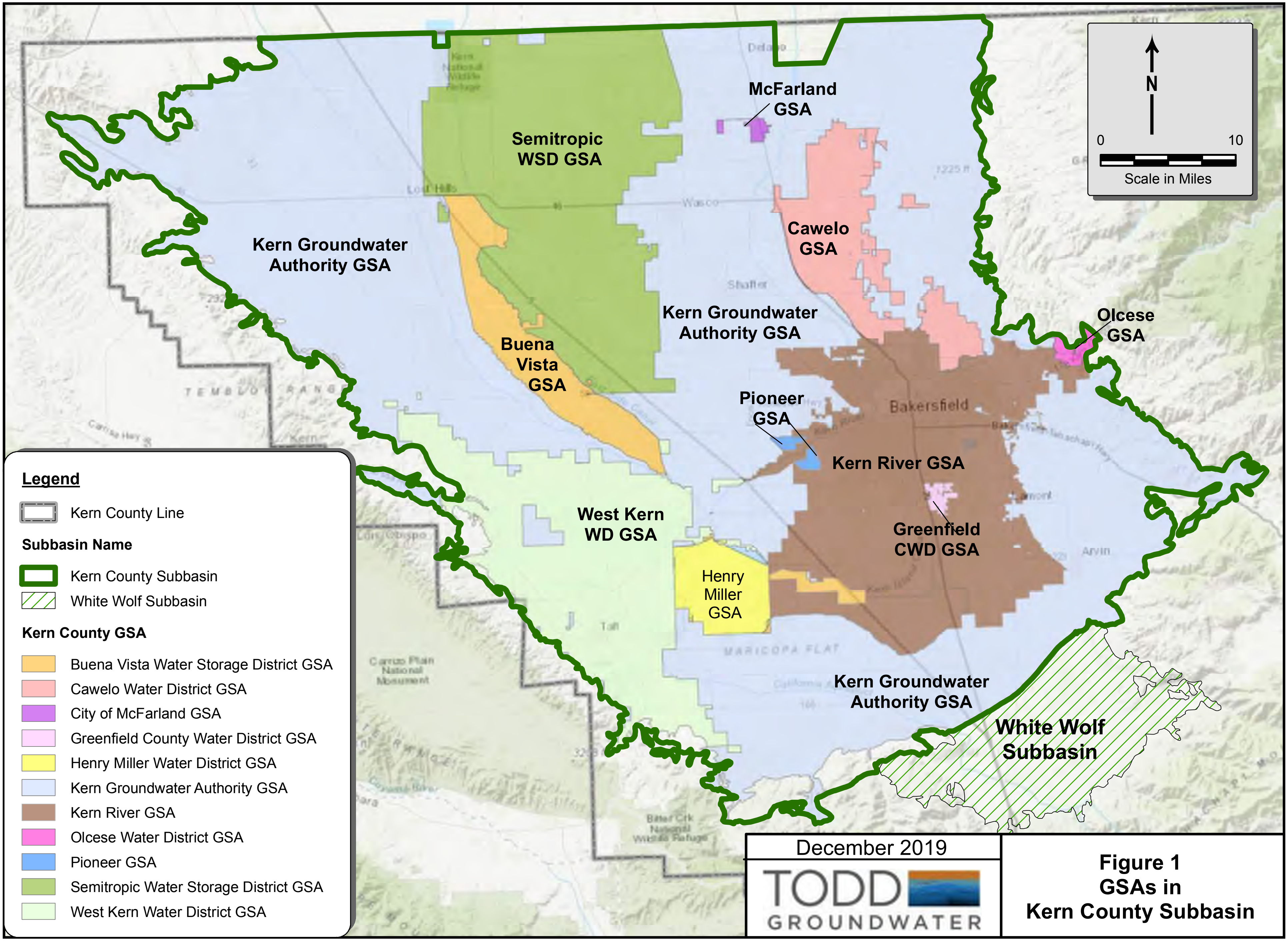


Figure 1
GSAs in Kern County Subbasin

December 2019	Figure 2 C2VSimFG Simulation Grid for Central Valley Showing Kern County Subbasin
TODD GROUNDWATER	

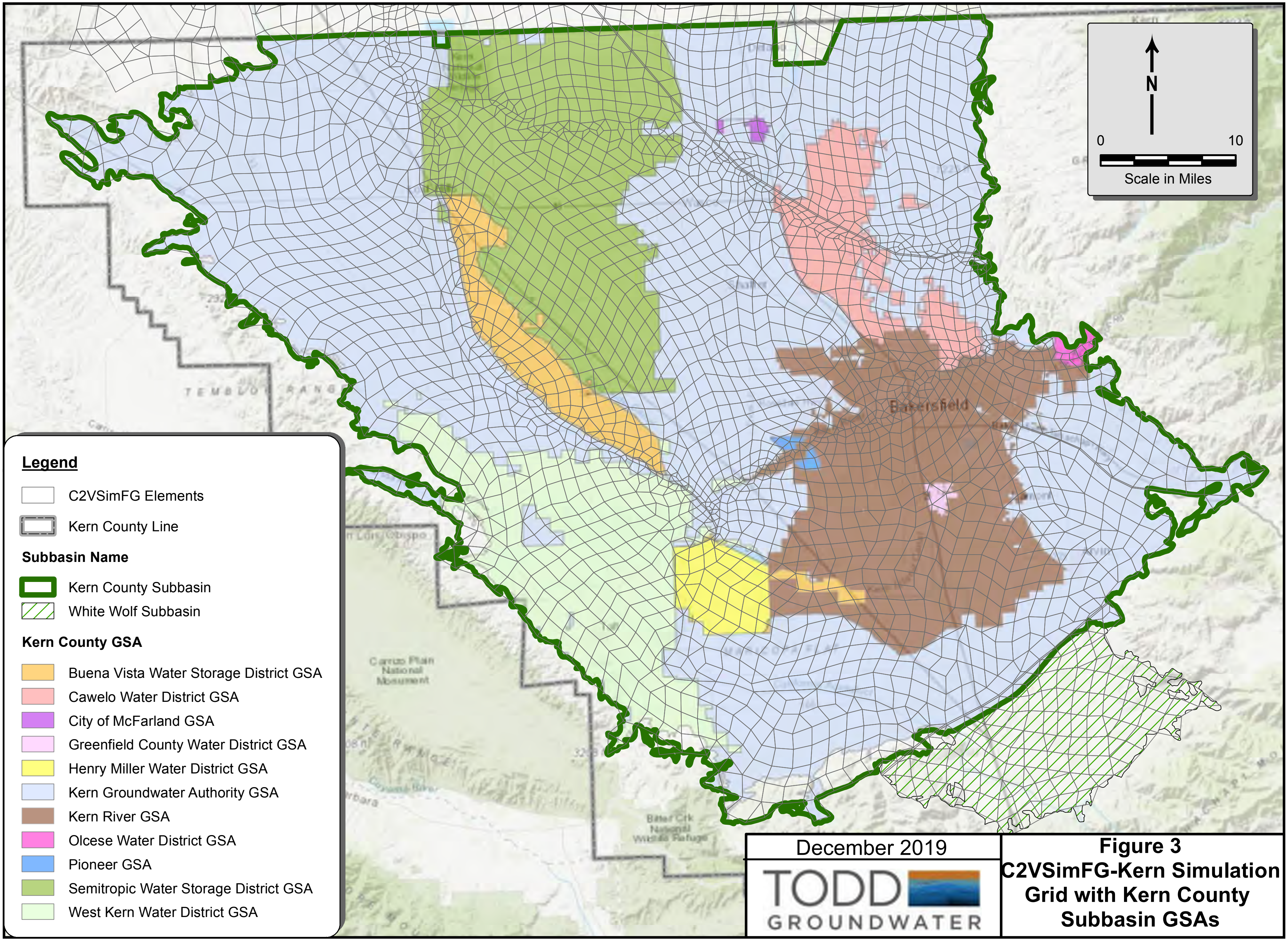
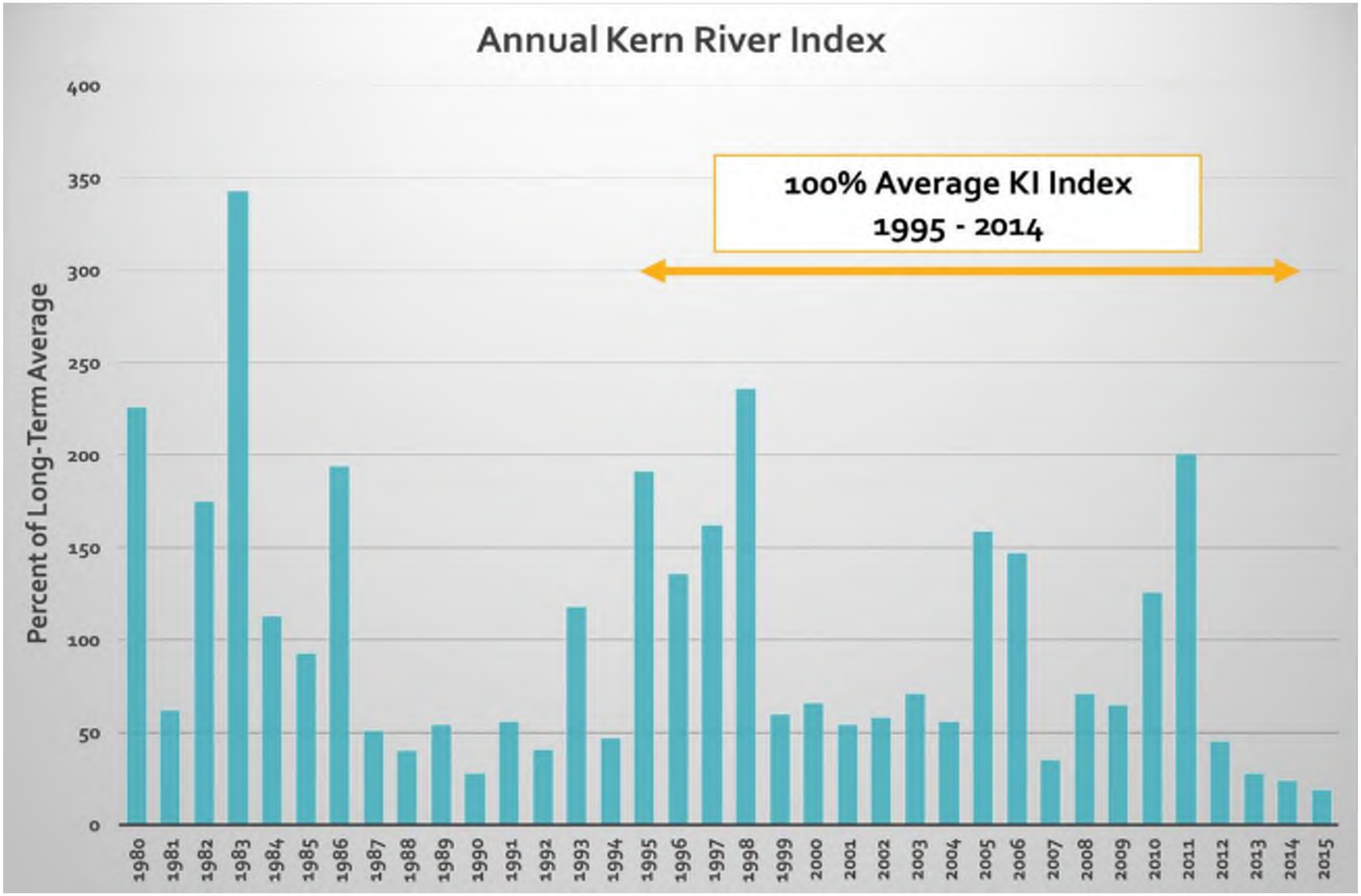


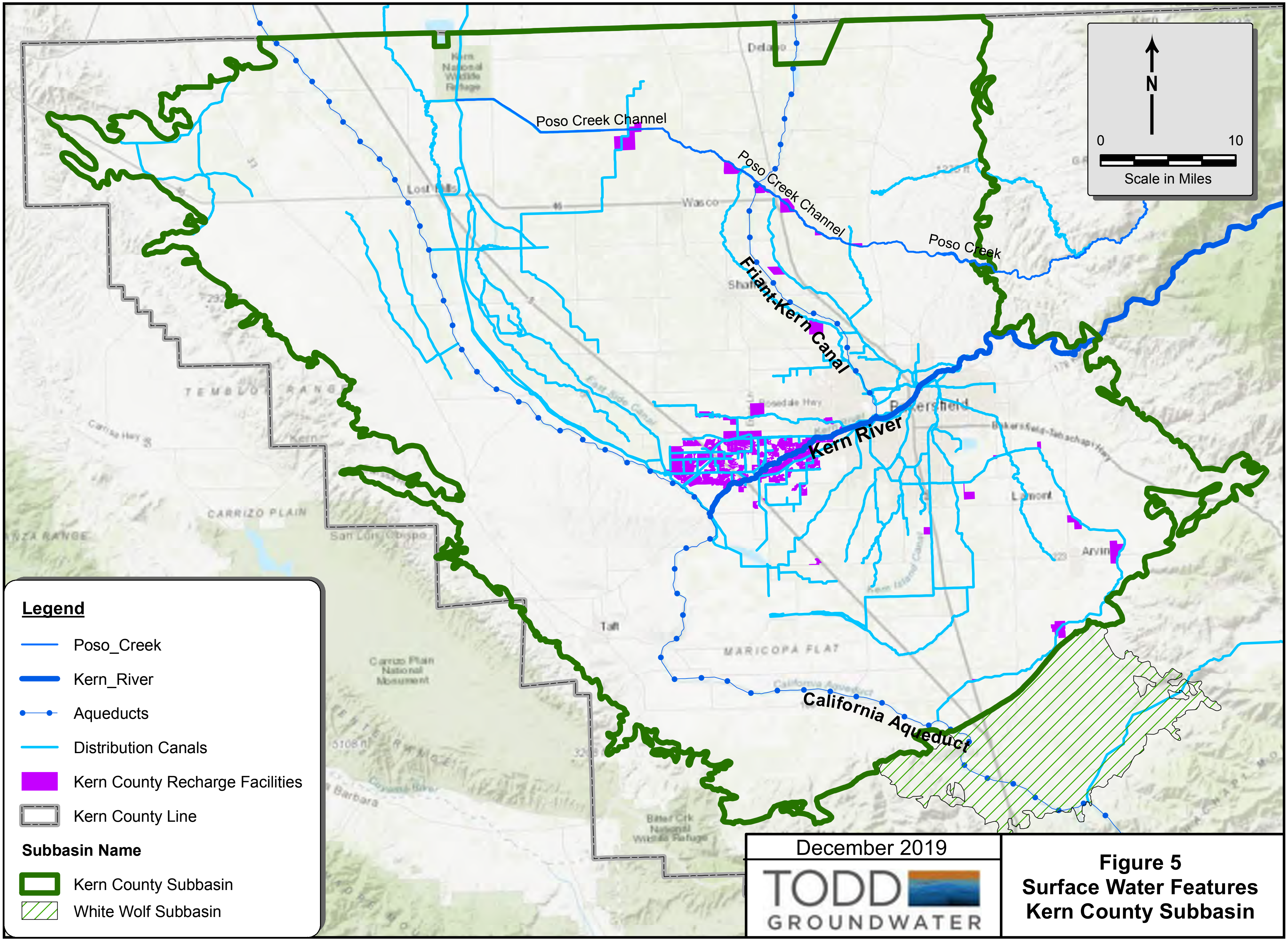
Figure 3
C2VSimFG-Kern Simulation Grid with Kern County Subbasin GSAs



December 2019

TODD GROUNDWATER

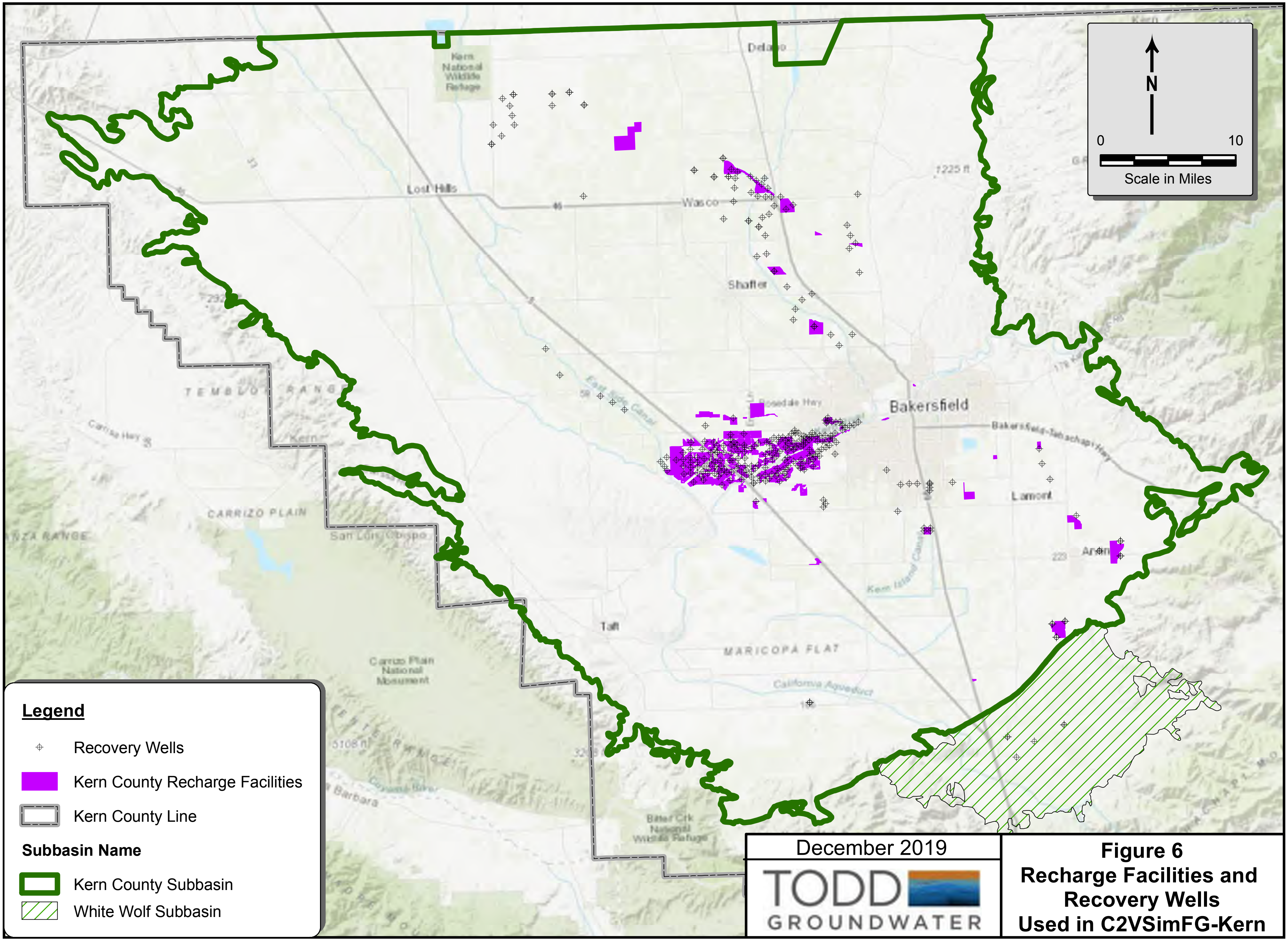
Figure 4
Annual Kern River Index used to Define 20-Year Historical Study Period



December 2019

TODD GROUNDWATER

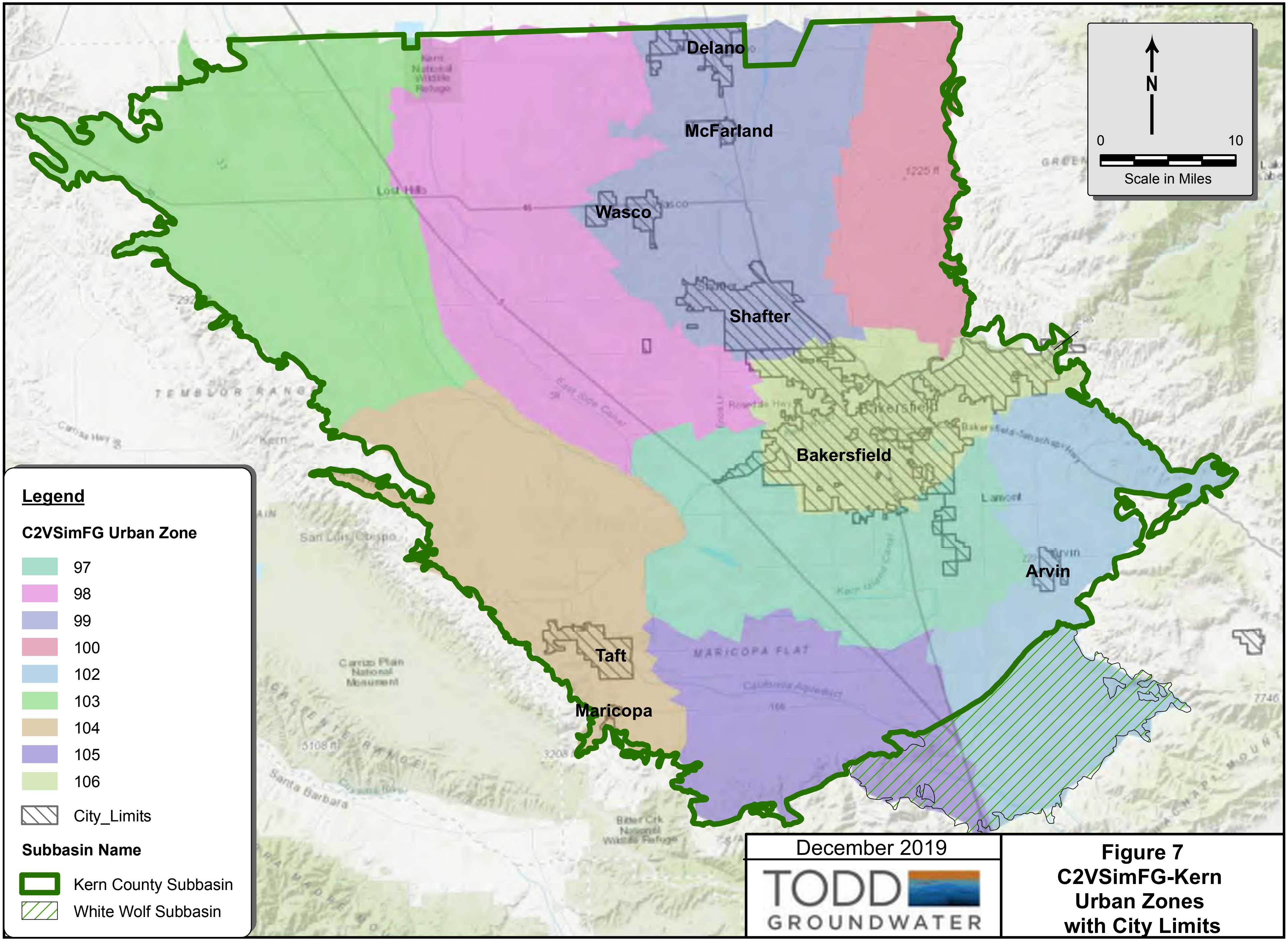
Figure 5
Surface Water Features
Kern County Subbasin



December 2019

TODD GROUNDWATER

Figure 6
Recharge Facilities and Recovery Wells Used in C2VSimFG-Kern



December 2019

TODD GROUNDWATER

Figure 7
C2VSimFG-Kern Urban Zones with City Limits

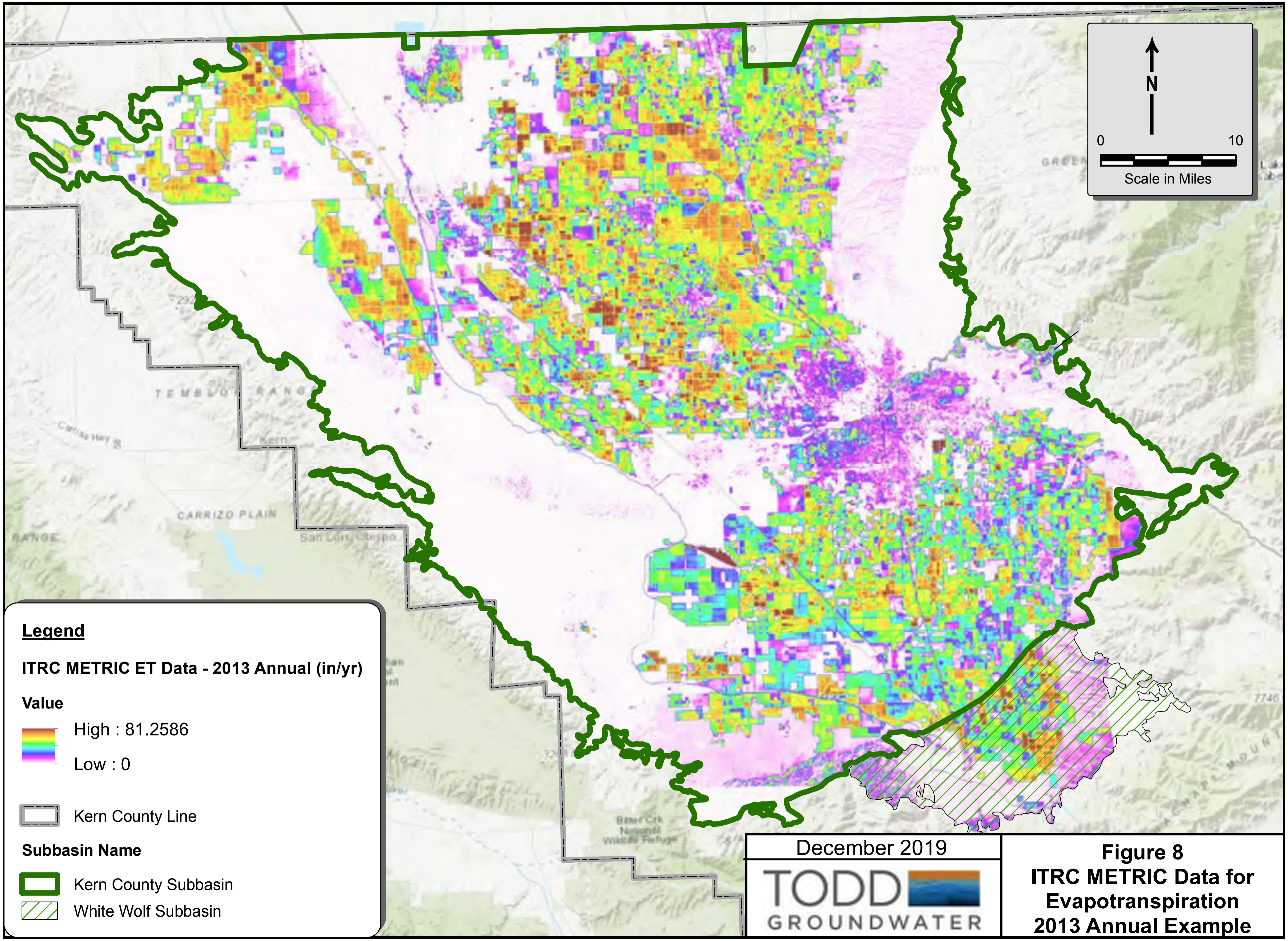
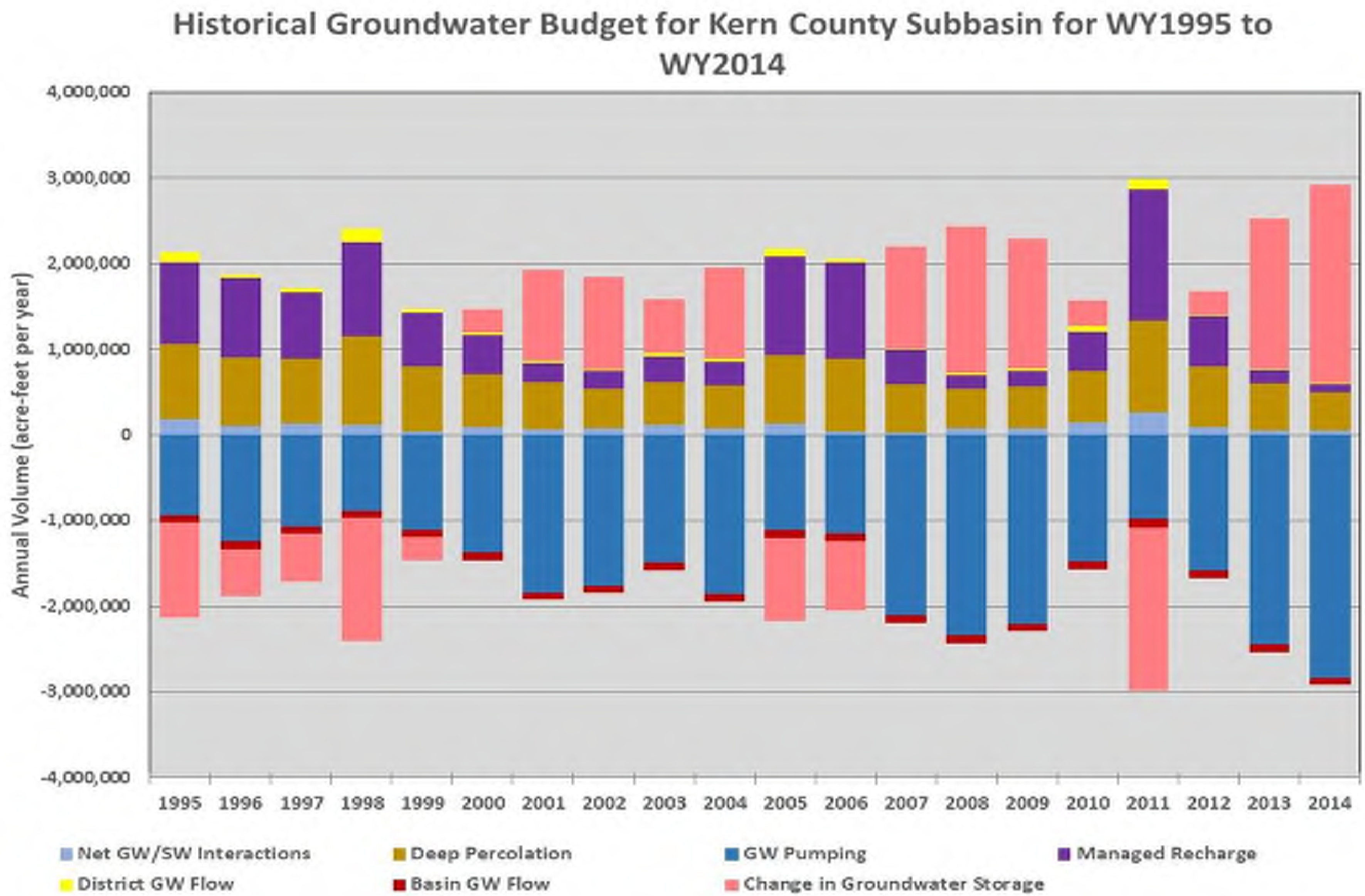
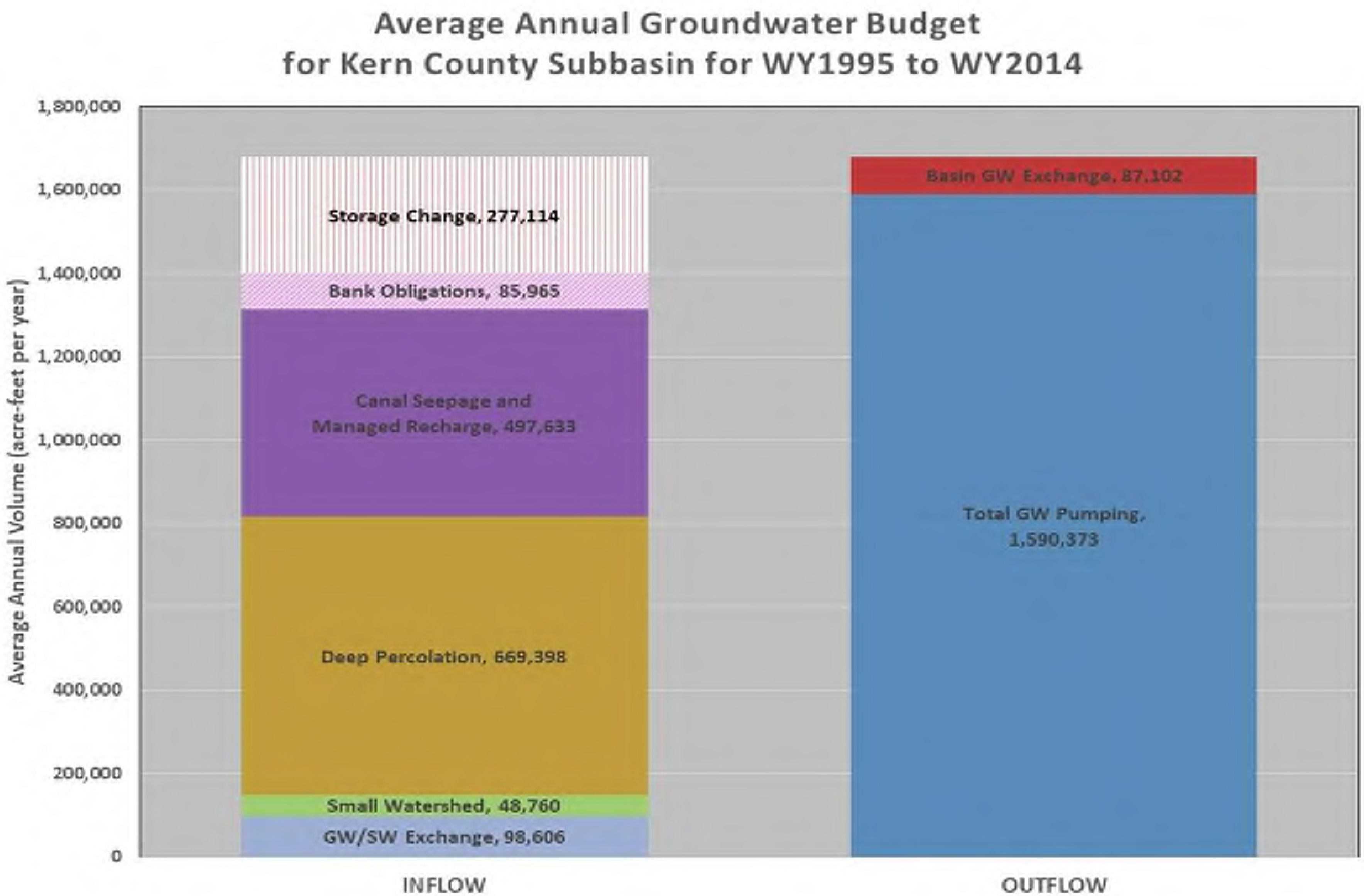


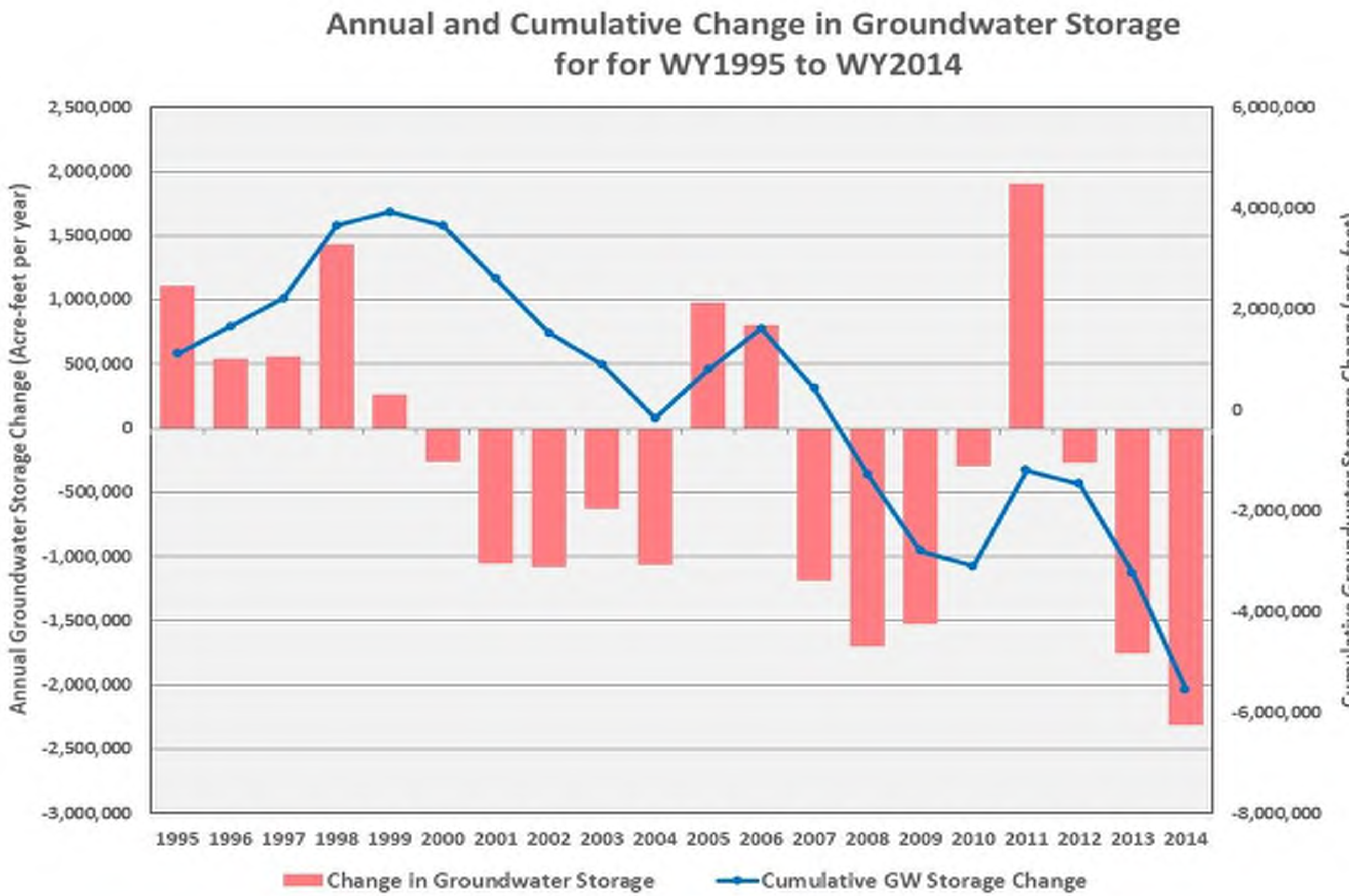
Figure 8
ITRC METRIC Data for Evapotranspiration 2013 Annual Example



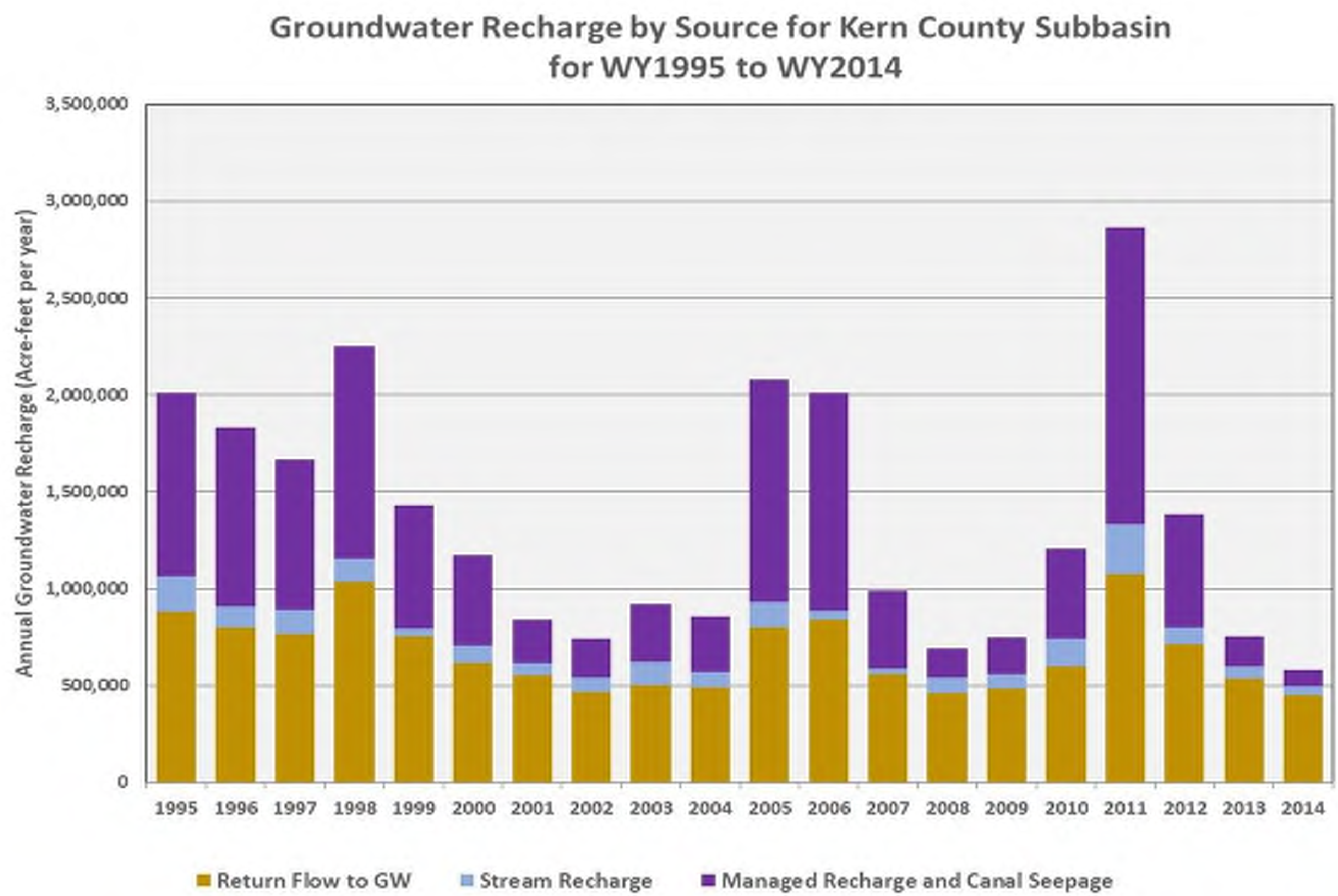
December 2019	Figure 9
TODD GROUNDWATER	C2VSimFG-Kern Historical Groundwater Budget for Kern County Subbasin



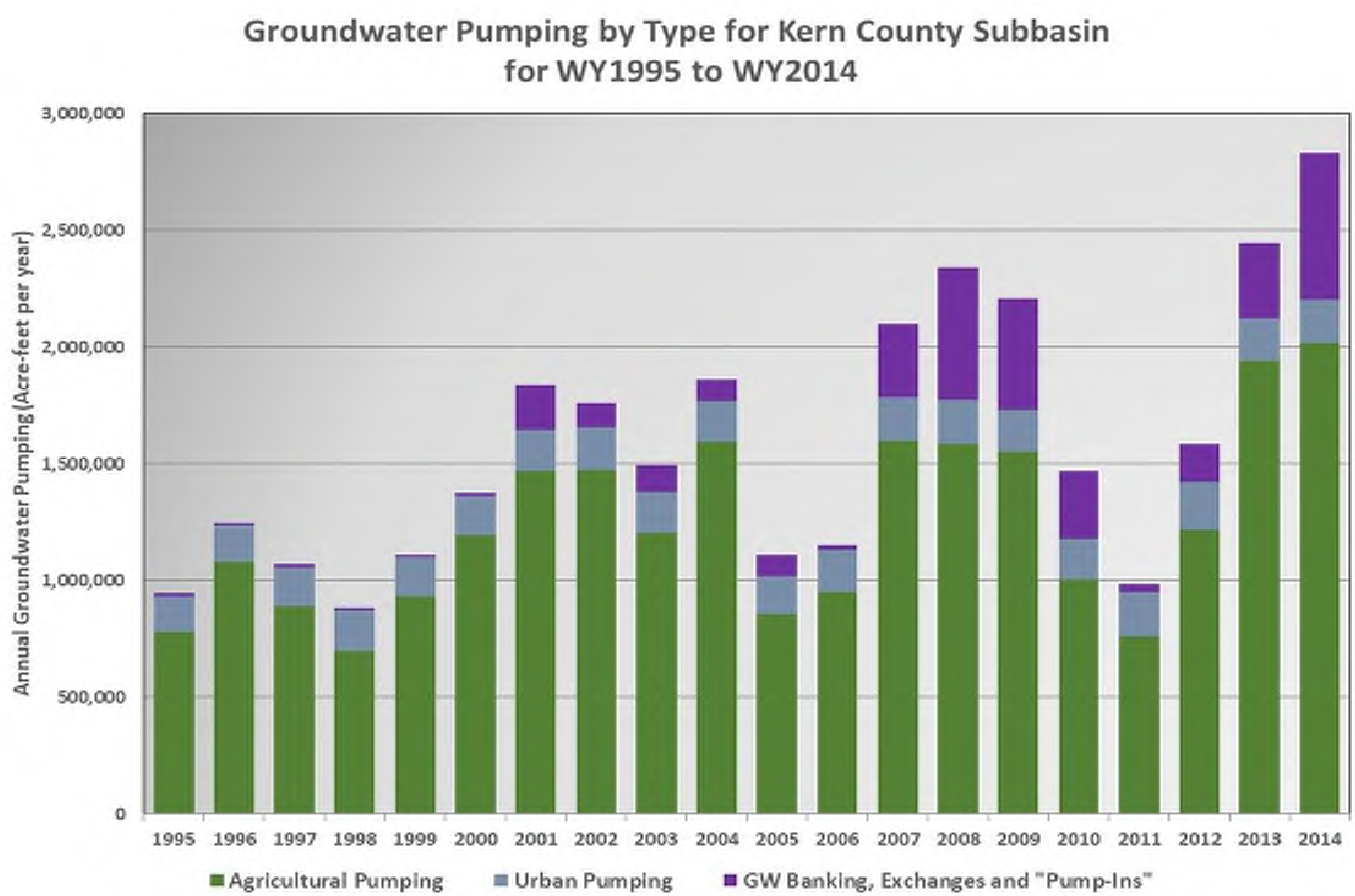
December 2019	Figure 10
TODD GROUNDWATER	C2VSimFG-Kern Average Annual Water Budget for Kern County Subbasin



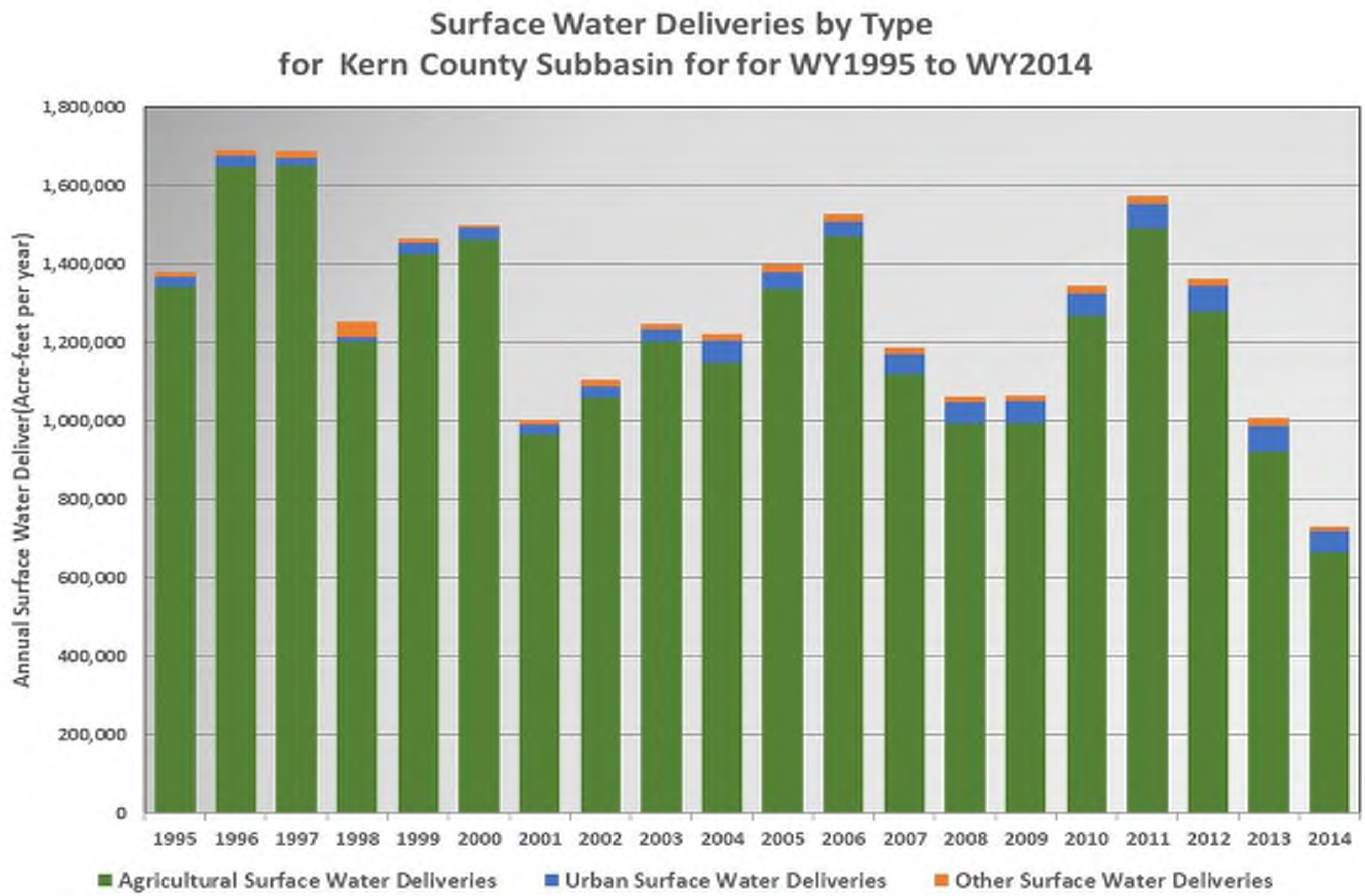
December 2019	Figure 11 Simulated Historical Change in Groundwater Storage for Kern County Subbasin
TODD GROUNDWATER	



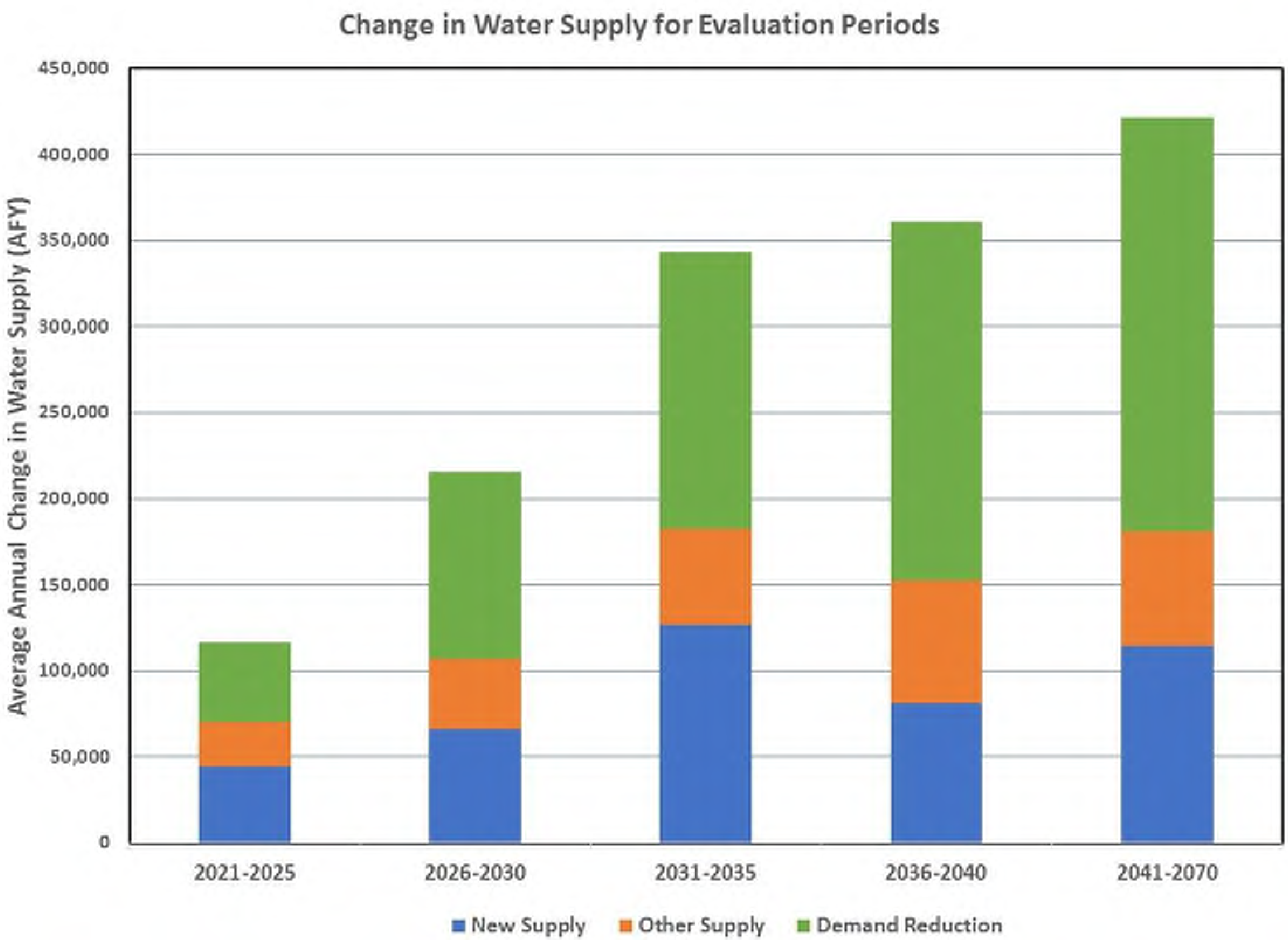
December 2019	Figure 12 Simulated Historical Recharge Operations for Kern County Subbasin
TODD GROUNDWATER	



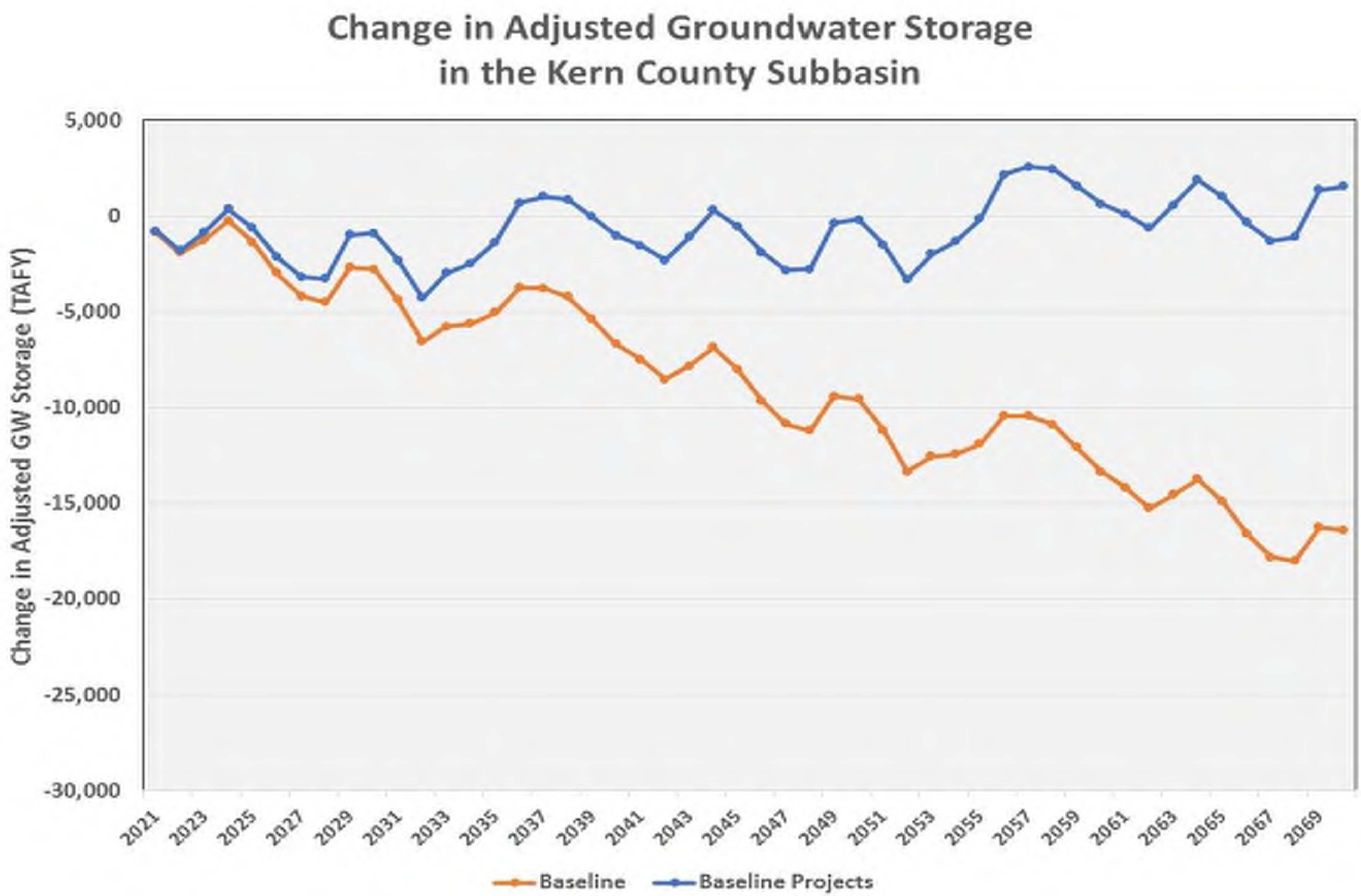
December 2019	Figure 13 Simulated Historical Groundwater Pumping for Kern County Subbasin
TODD GROUNDWATER	



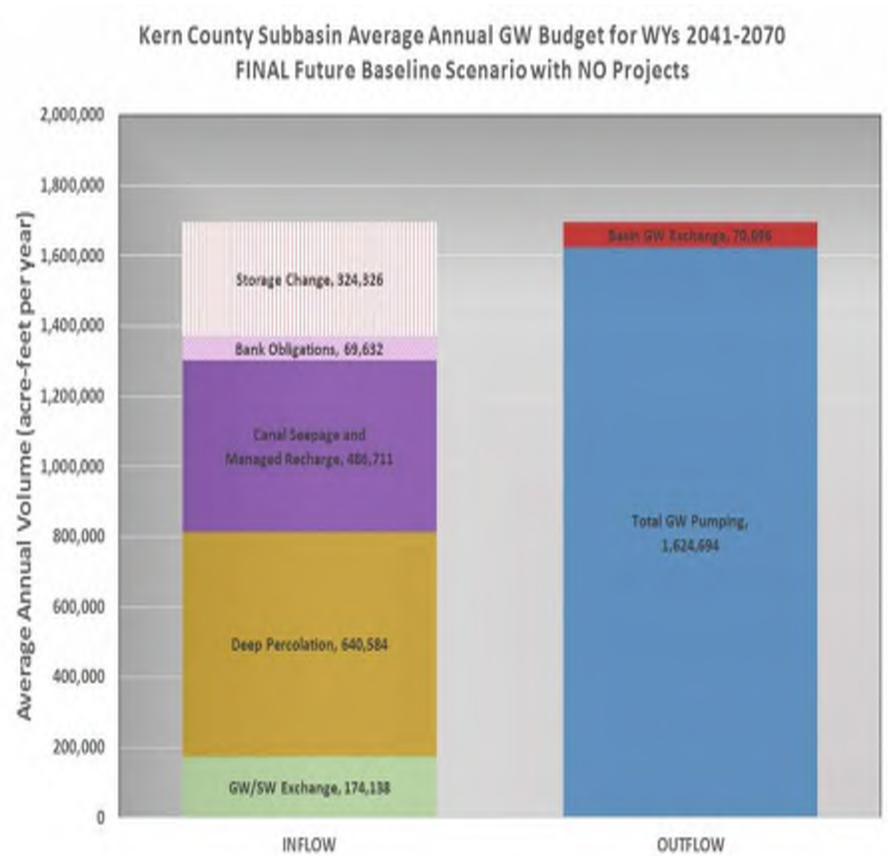
December 2019	Figure 14 Simulated Historical Surface Water Deliveries for Kern County Subbasin
TODD GROUNDWATER	

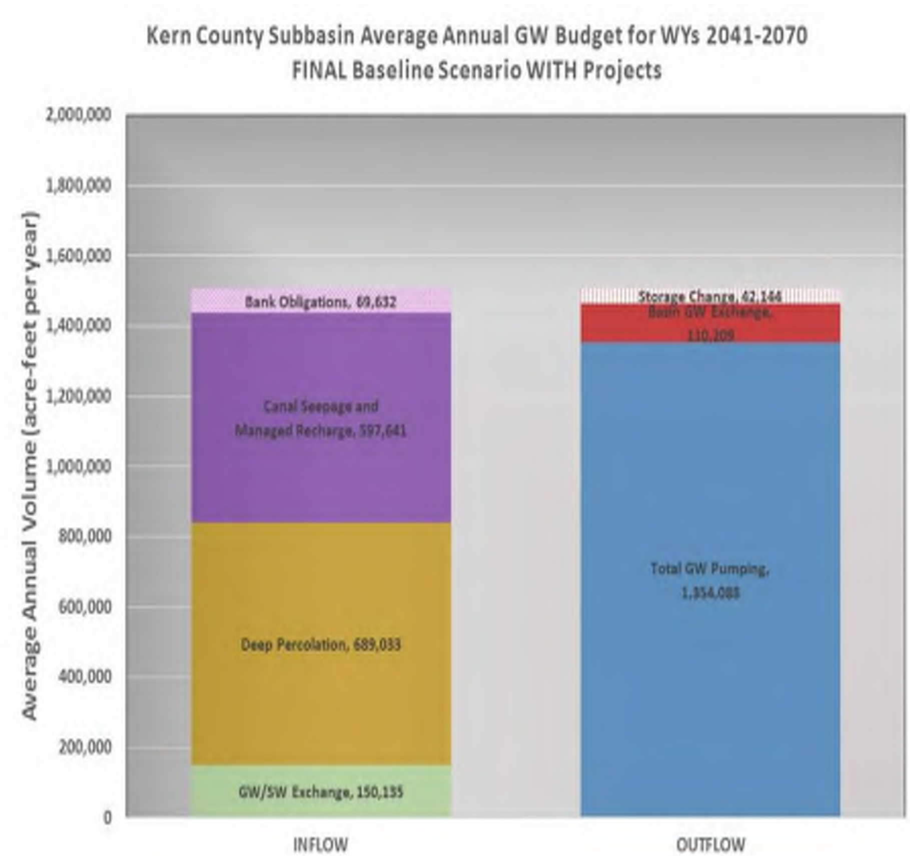


December 2019	Figure 15
TODD GROUNDWATER	Average Annual Benefit of Proposed SGMA Projects and Management Actions

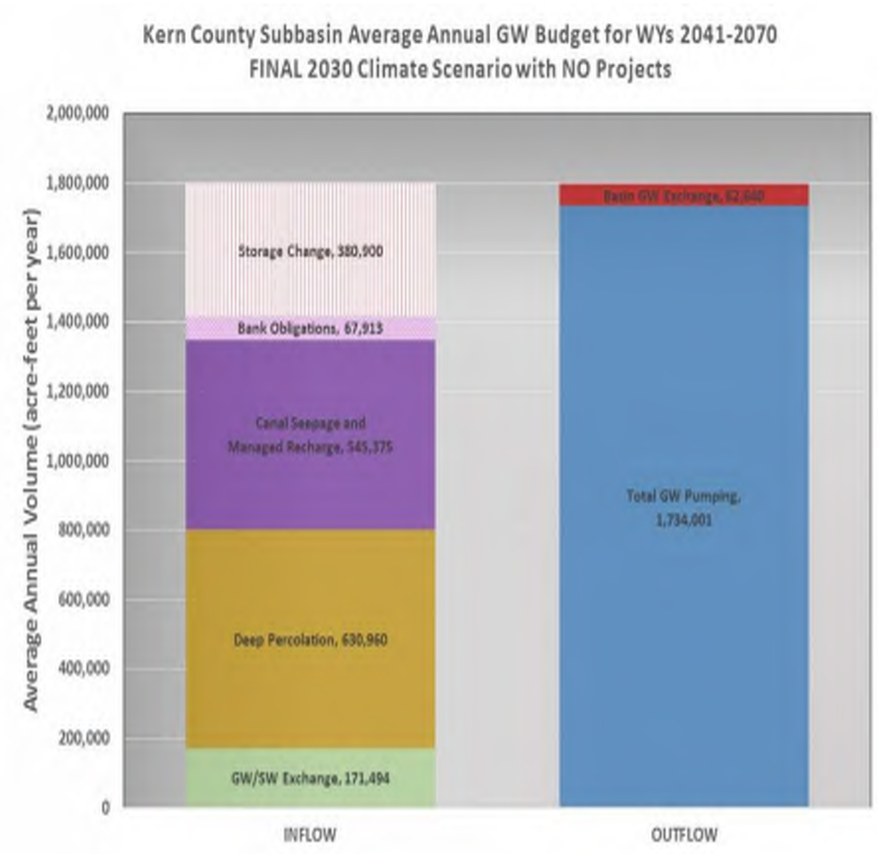


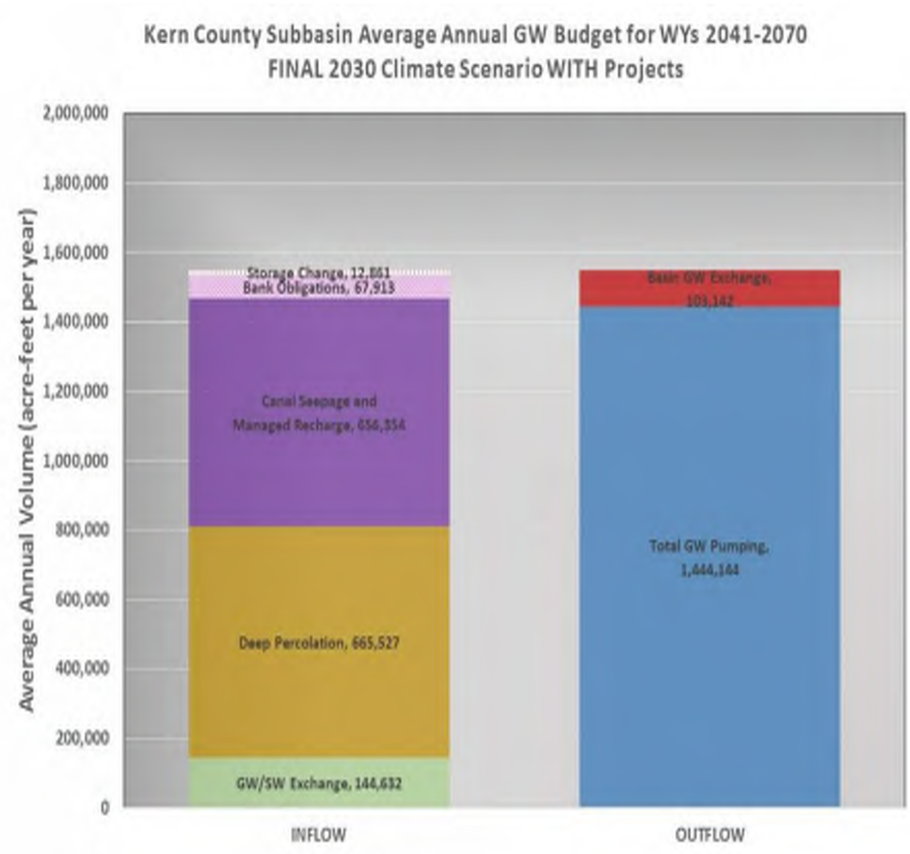
December 2019	Figure 16
TODD GROUNDWATER	**Projected Future Change in Groundwater Storage for Baseline Conditions**



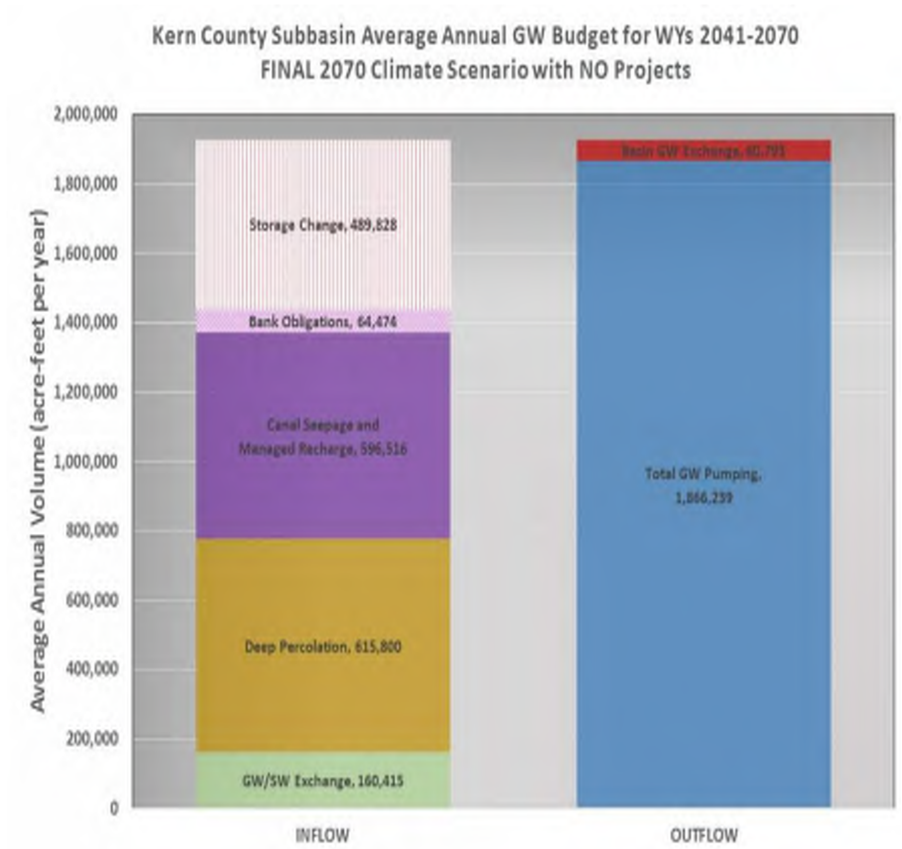


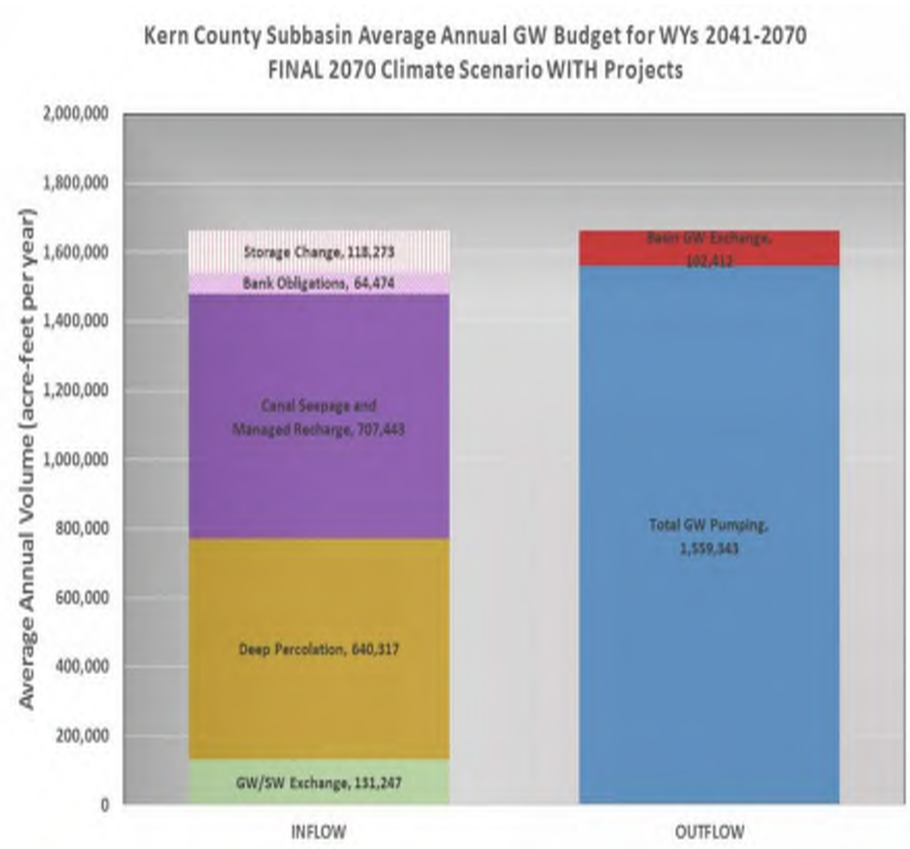
December 2019	Figure 17
TODD GROUNDWATER	Baseline Projected Future Average Annual Groundwater Budget for WY2041-2070



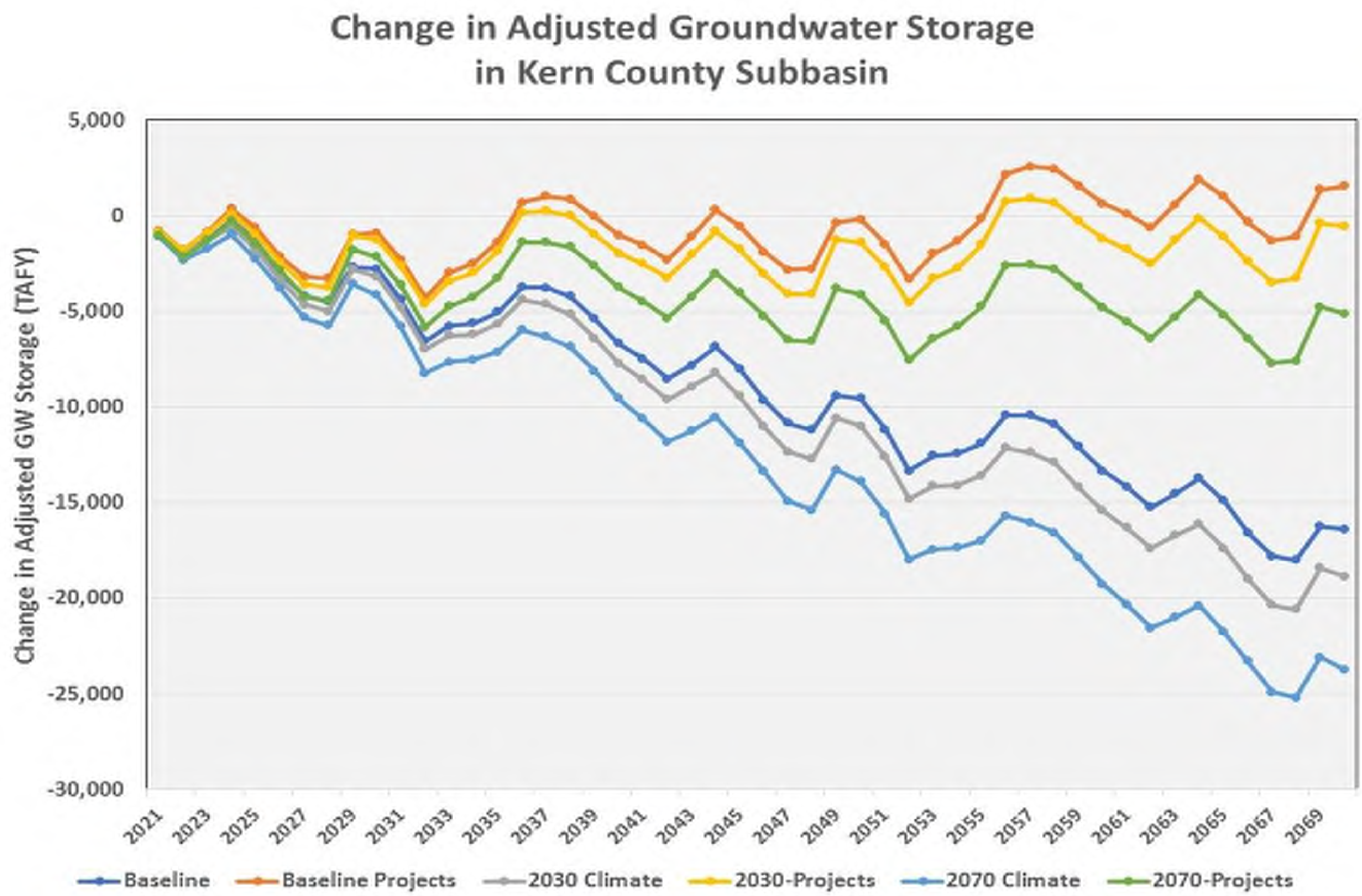


December 2019	Figure 18 2030 Climate Projected Future Average Annual Groundwater Budget for WY2041-2070
TODD GROUNDWATER	

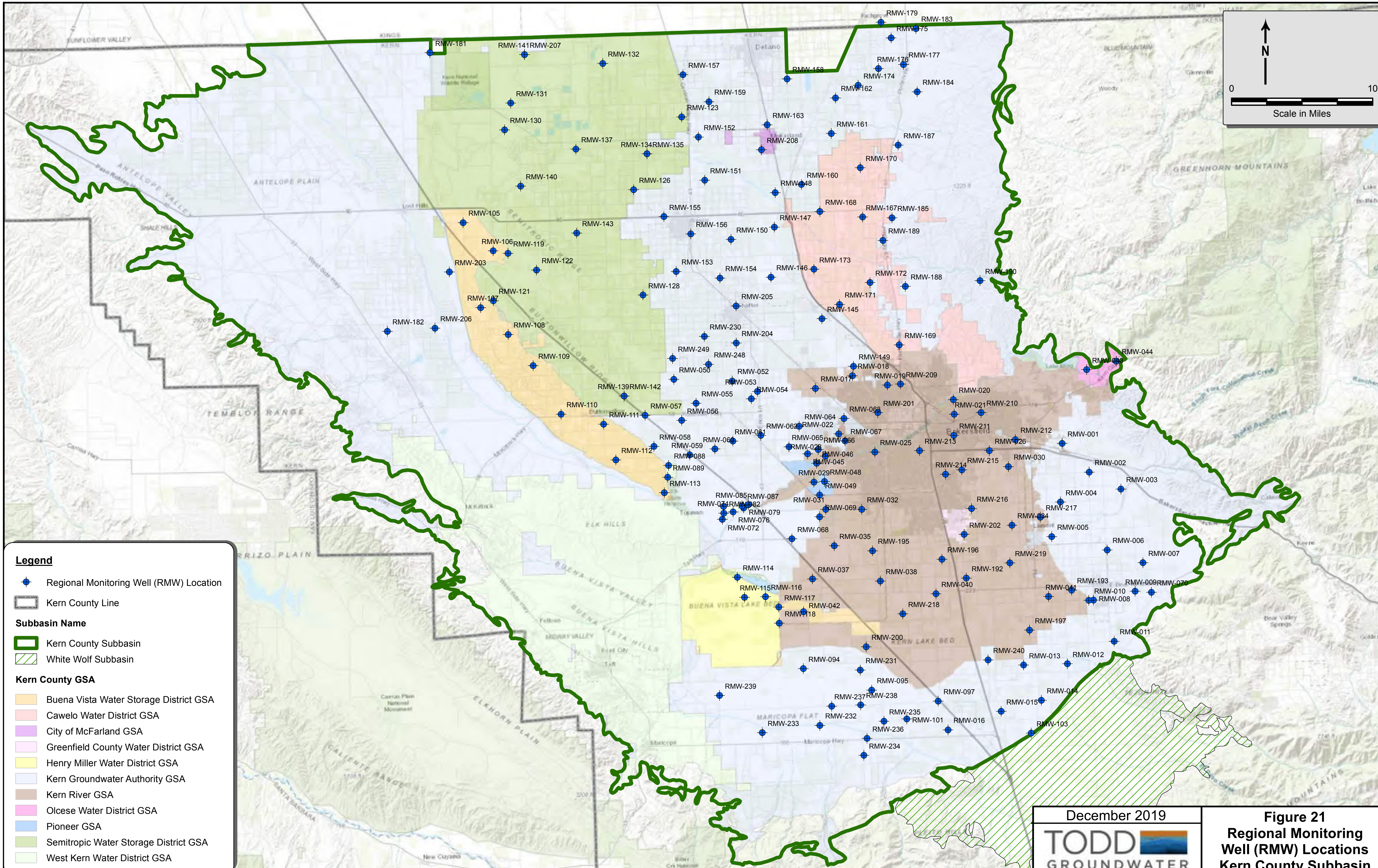




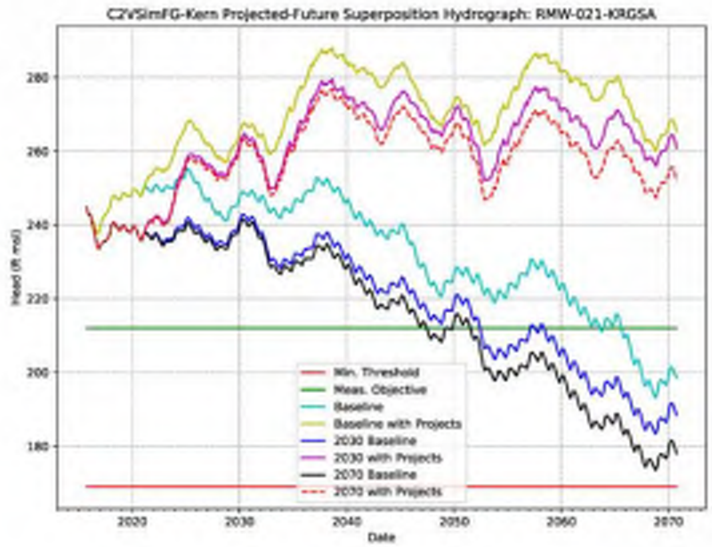
December 2019	**Figure 19**
TODD GROUNDWATER	**2070 Climate Projected Future Average Annual Groundwater Budget for WY2041-2070**

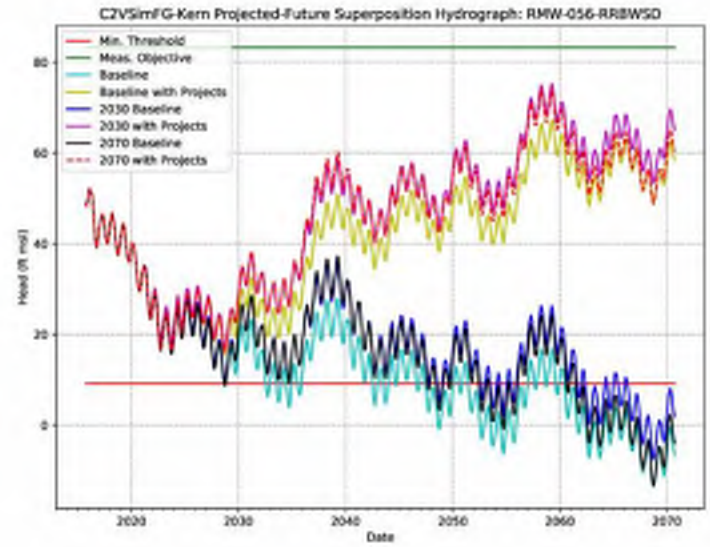


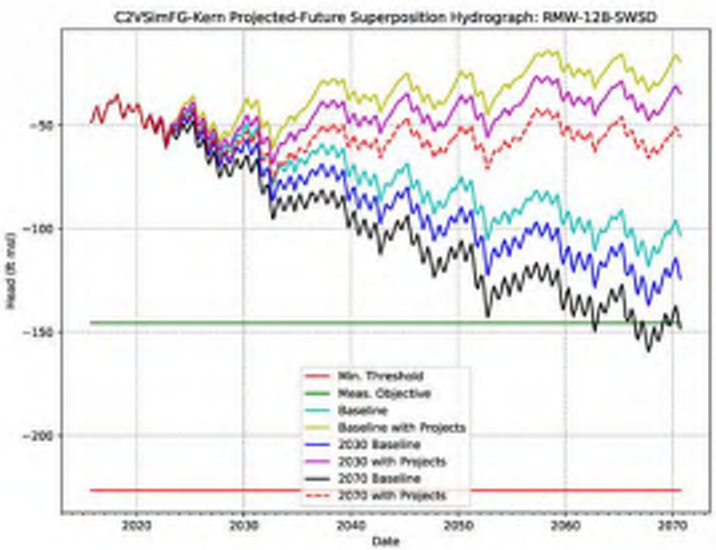
December 2019	Figure 20 Projected Future Change in Groundwater Storage for All Conditions
TODD GROUNDWATER	

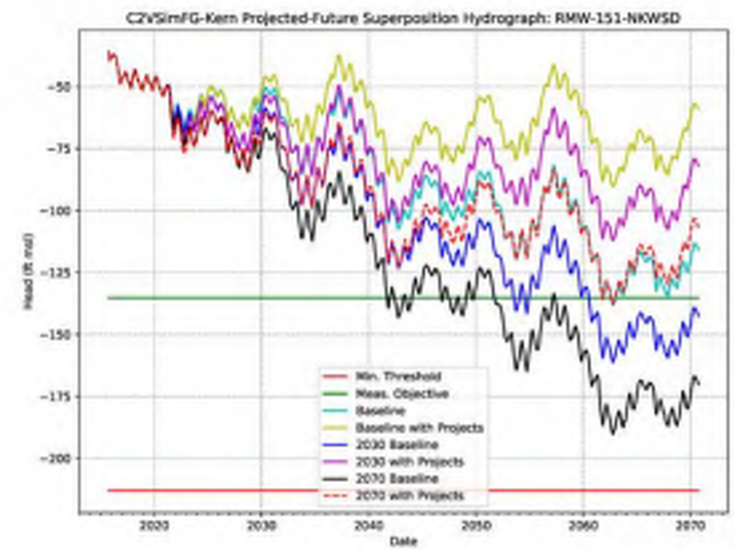


N
0
10
Scale in Miles
Legend
Regional Monitoring Well (RMW) Location
Kern County Line
Subbasin Name
Kern County Subbasin
White Wolf Subbasin
Kern County GSA
Buena Vista Water Storage District GSA
Cawelo Water District GSA
City of McFarland GSA
Greenfield County Water District GSA
Henry Miller Water District GSA
Kern Groundwater Authority GSA
Kern River GSA
Olcese Water District GSA
Pioneer GSA
Semitropic Water Storage District GSA
West Kern Water District GSA
December 2019
TODD GROUNDWATER
Figure 21
Regional Monitoring Well (RMW) Locations
Kern County Subbasin

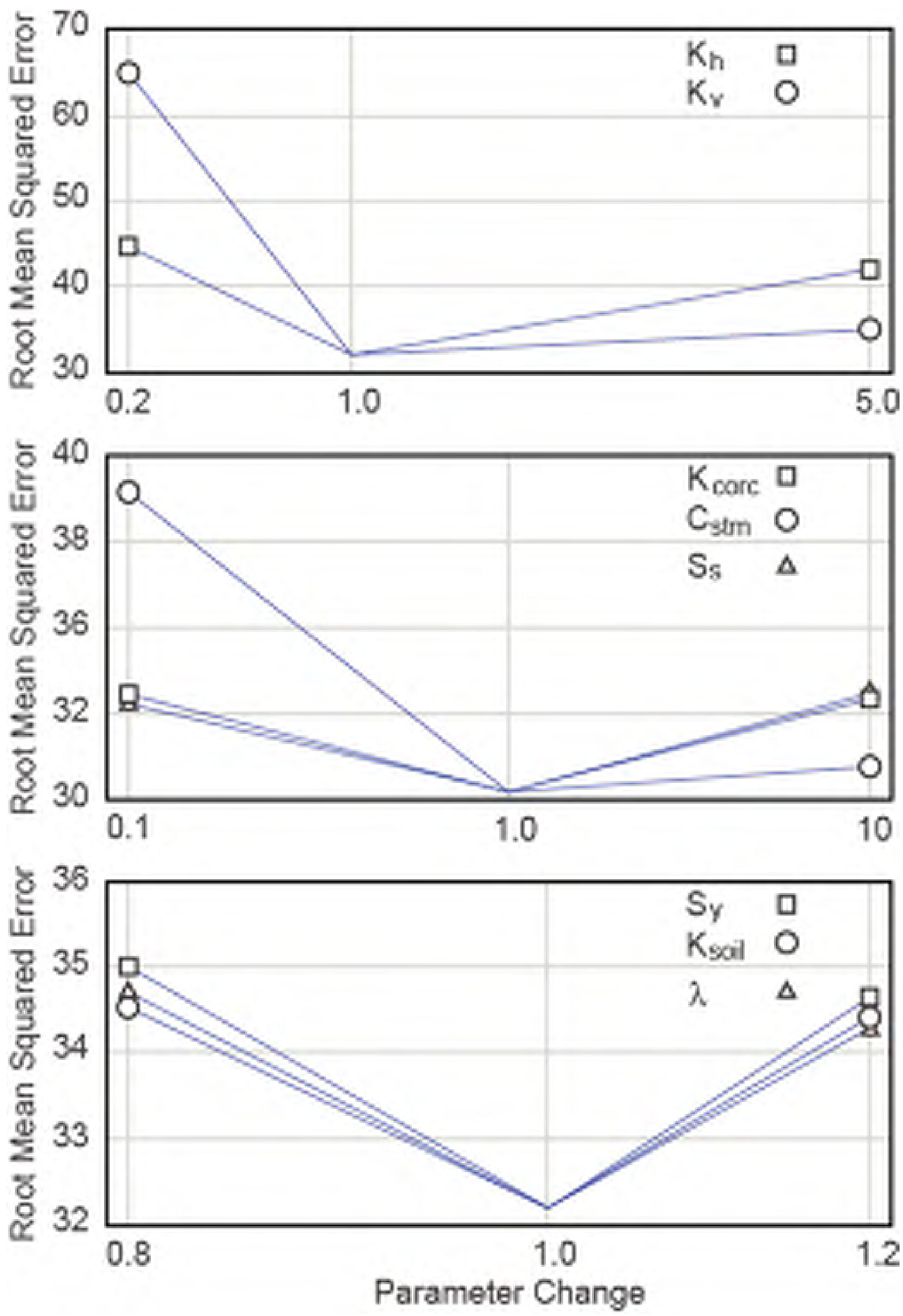








December 2019	Figure 22 Hydrographs for all Projected Future Conditions with SGMA Sustainability Criteria
TODD GROUNDWATER	



Notes:
Sensitivity parameters modified and evaluated for Kern County Subbasin
Kh – horizontal hydraulic conductivity of aquifer
Kv – vertical hydraulic conductivity of aquifer

Kcorc - horizontal hydraulic conductivity of Corcoran Clay aquitard or equivalent
Cstm – streambed conductance of Kern River and Poso Creek
Ss – specific storage of aquifer

Sy – specific yield of aquifer
Ksoil –soil hydraulic conductivity in root zone
Λ –soil pore size distribution index in root zone

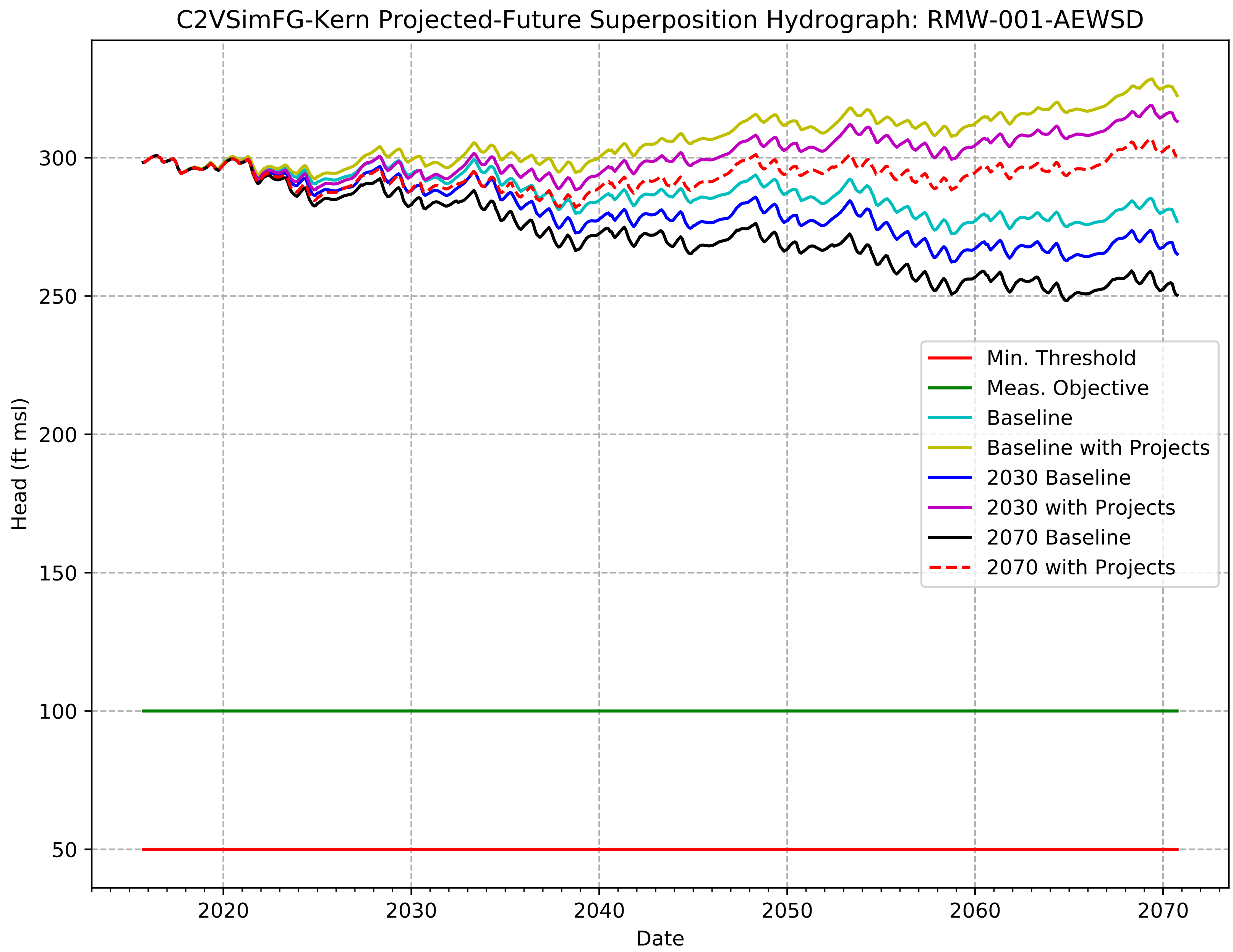
December 2019

TODD GROUNDWATER

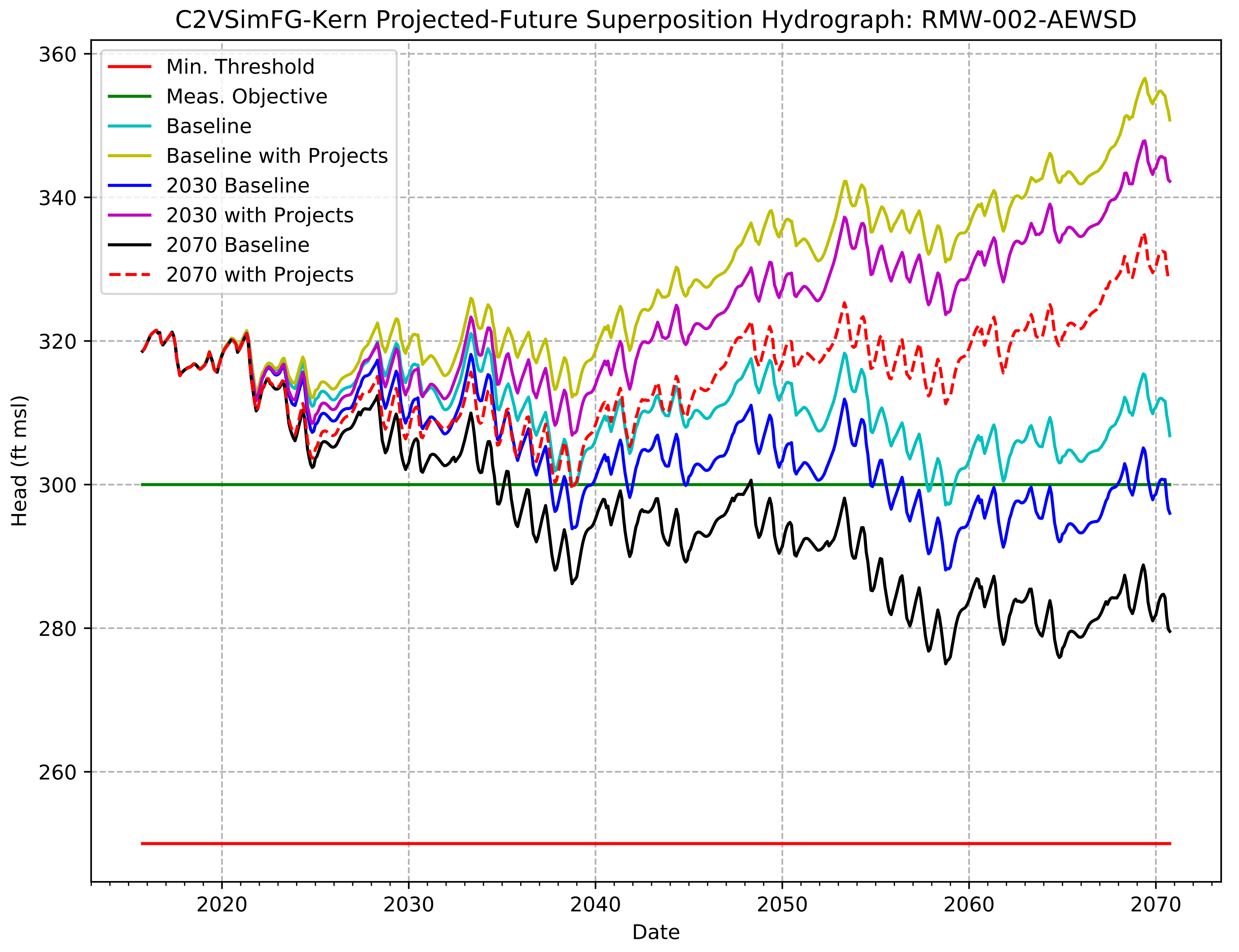
Figure 23
C2VSimFG-Kern Sensitivity Analysis Results

ATTACHMENT

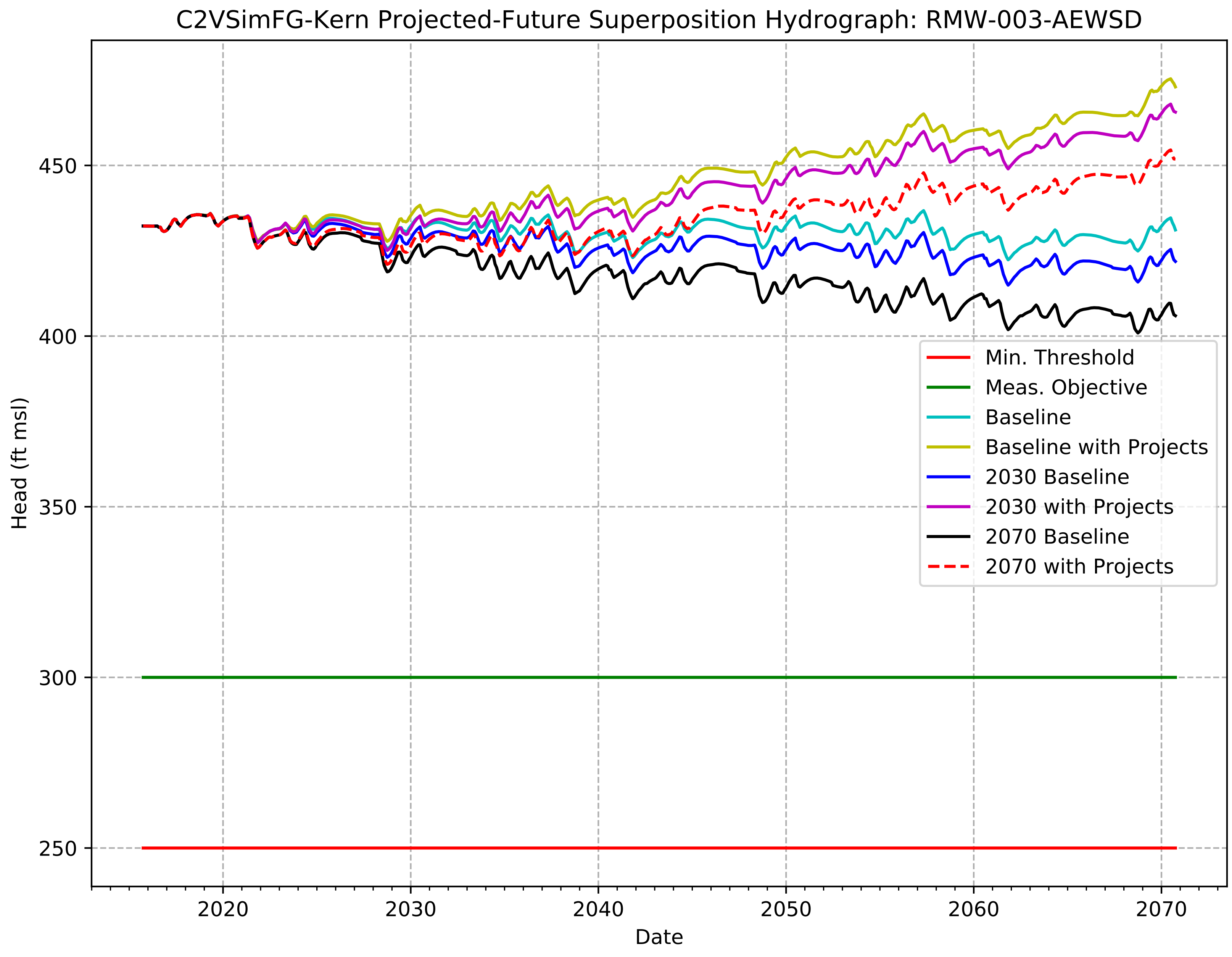
C2VSimFG-Kern Hydrographs at Regional Monitoring Wells in Kern County Subbasin for Projected Future Water Budget Simulations



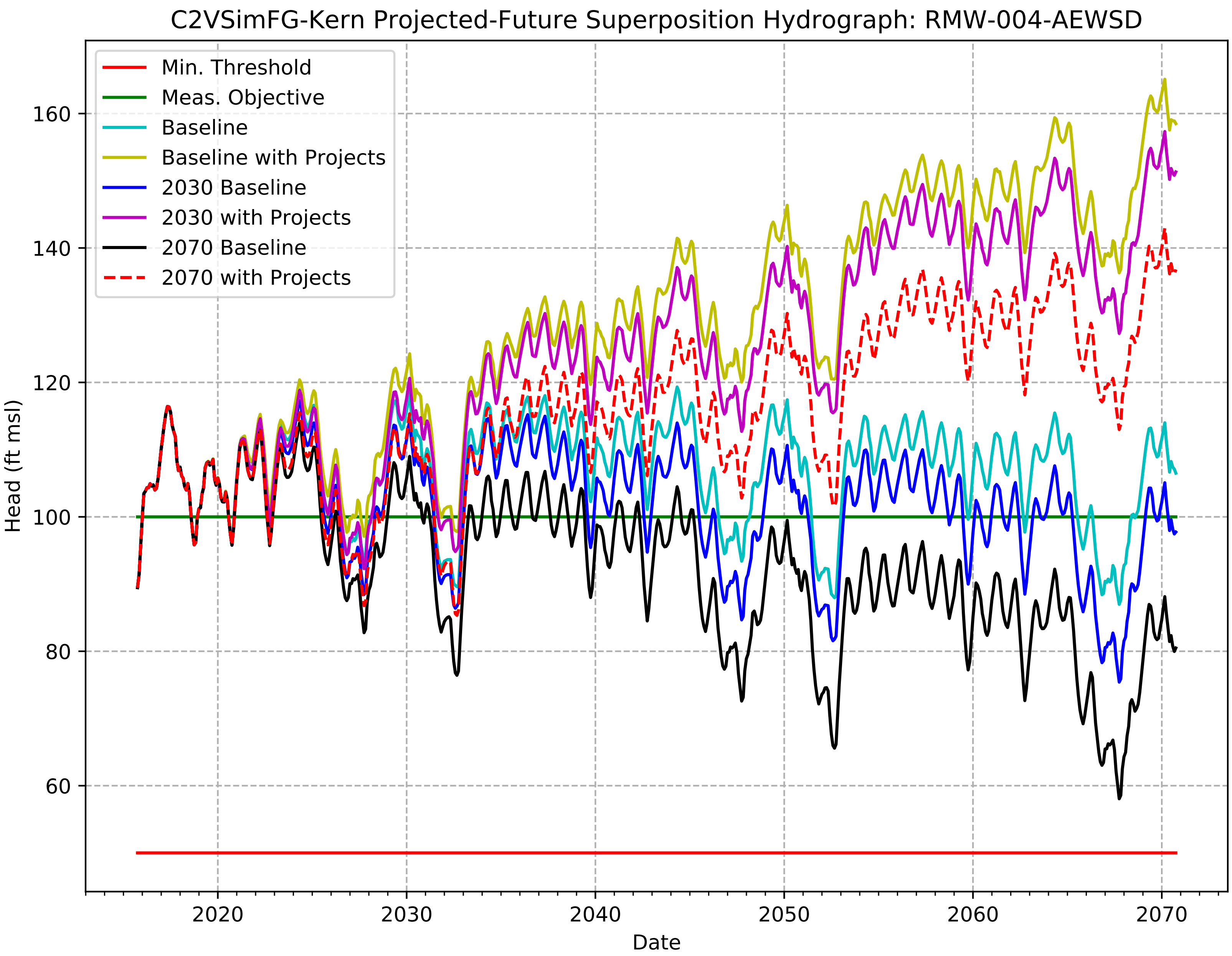
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-001-AEWSD
Head (ft msl)
300
250
200
150
100
50
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



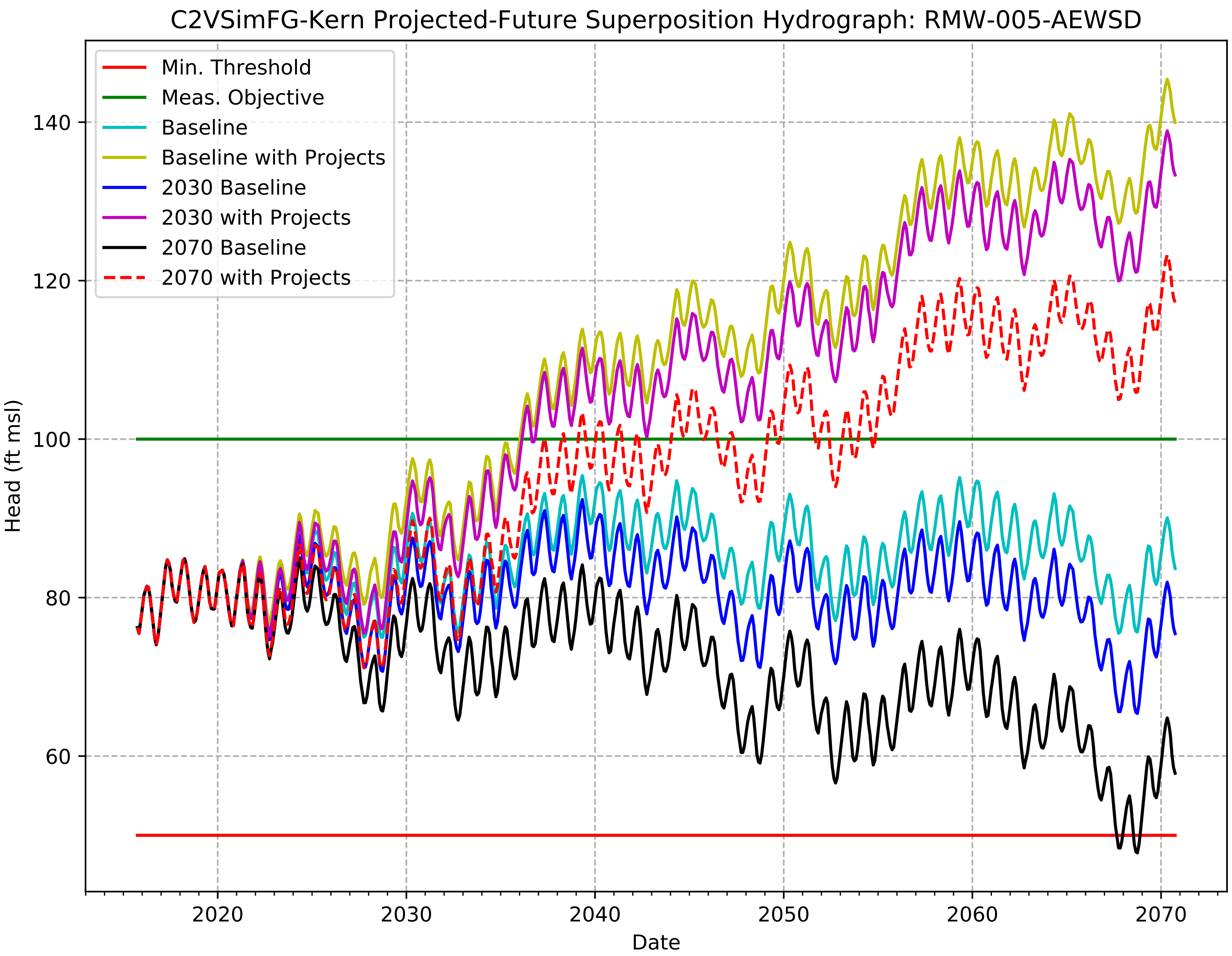
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-002-AEWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
360
340
320
300
280
260
2020
2030
2040
2050
2060
2070
Date



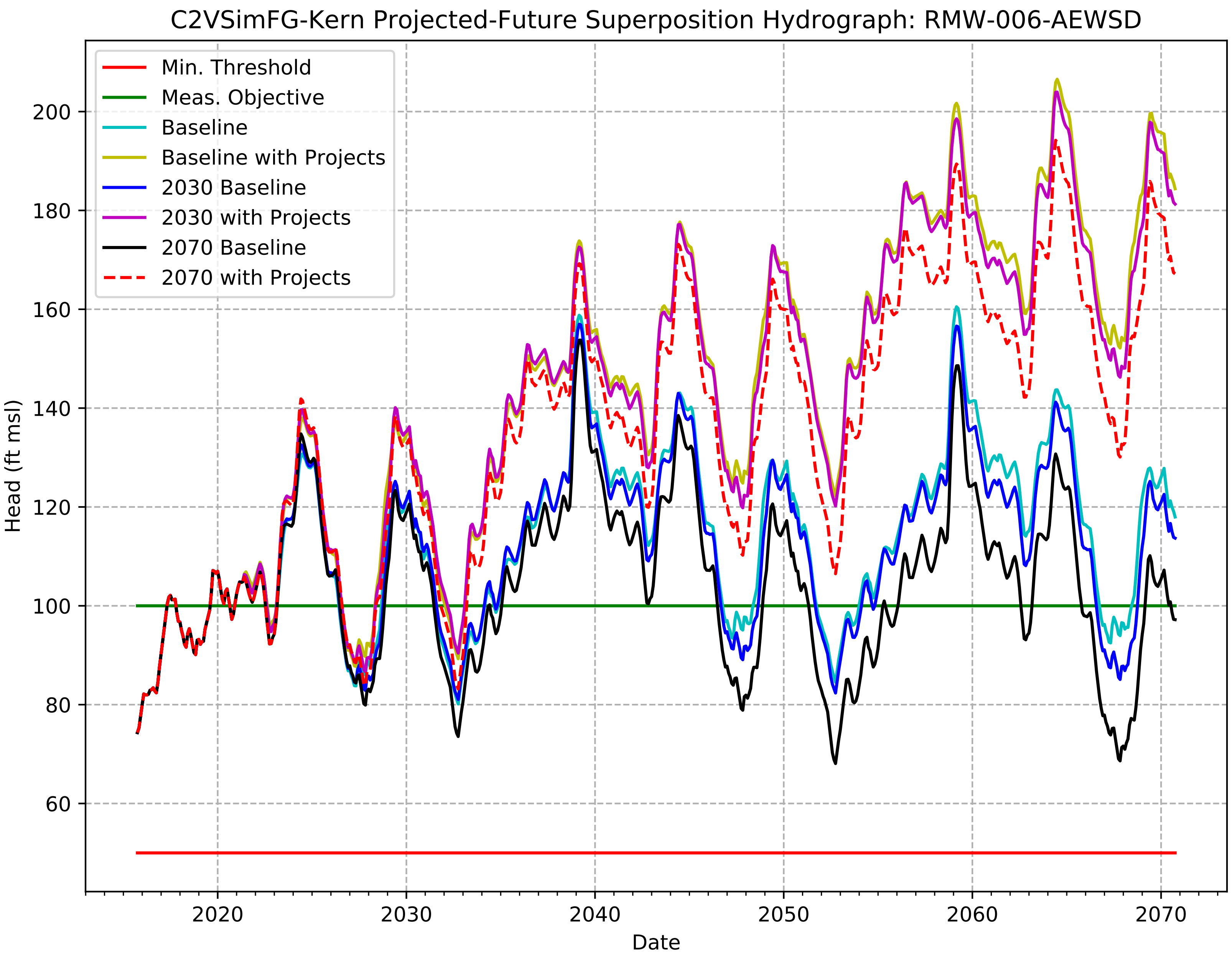
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-003-AEWSD
Head (ft msl)
Date
450
400
350
300
250
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

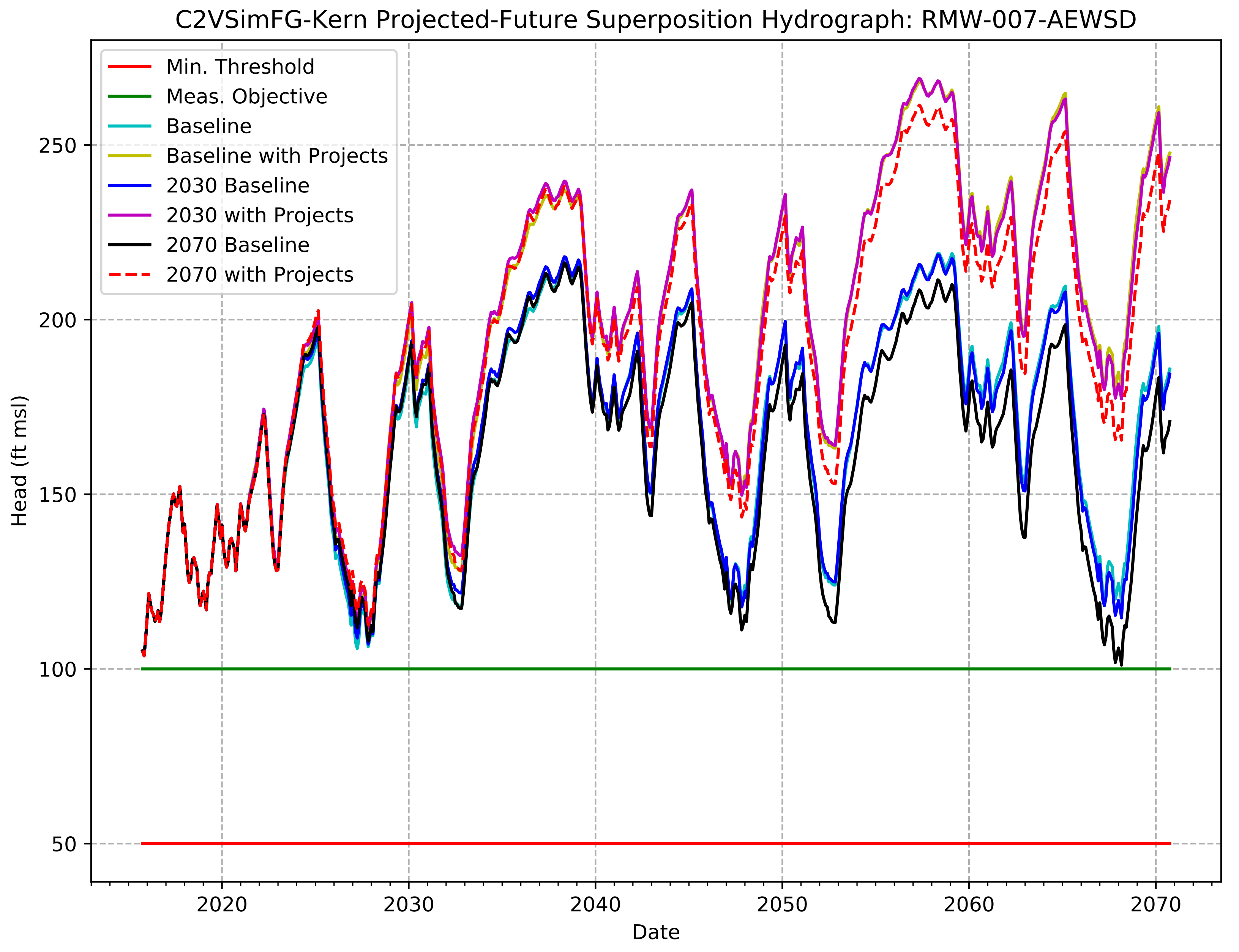


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-004-AEWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
160
140
120
100
80
60
2020
2030
2040
2050
2060
2070
Date

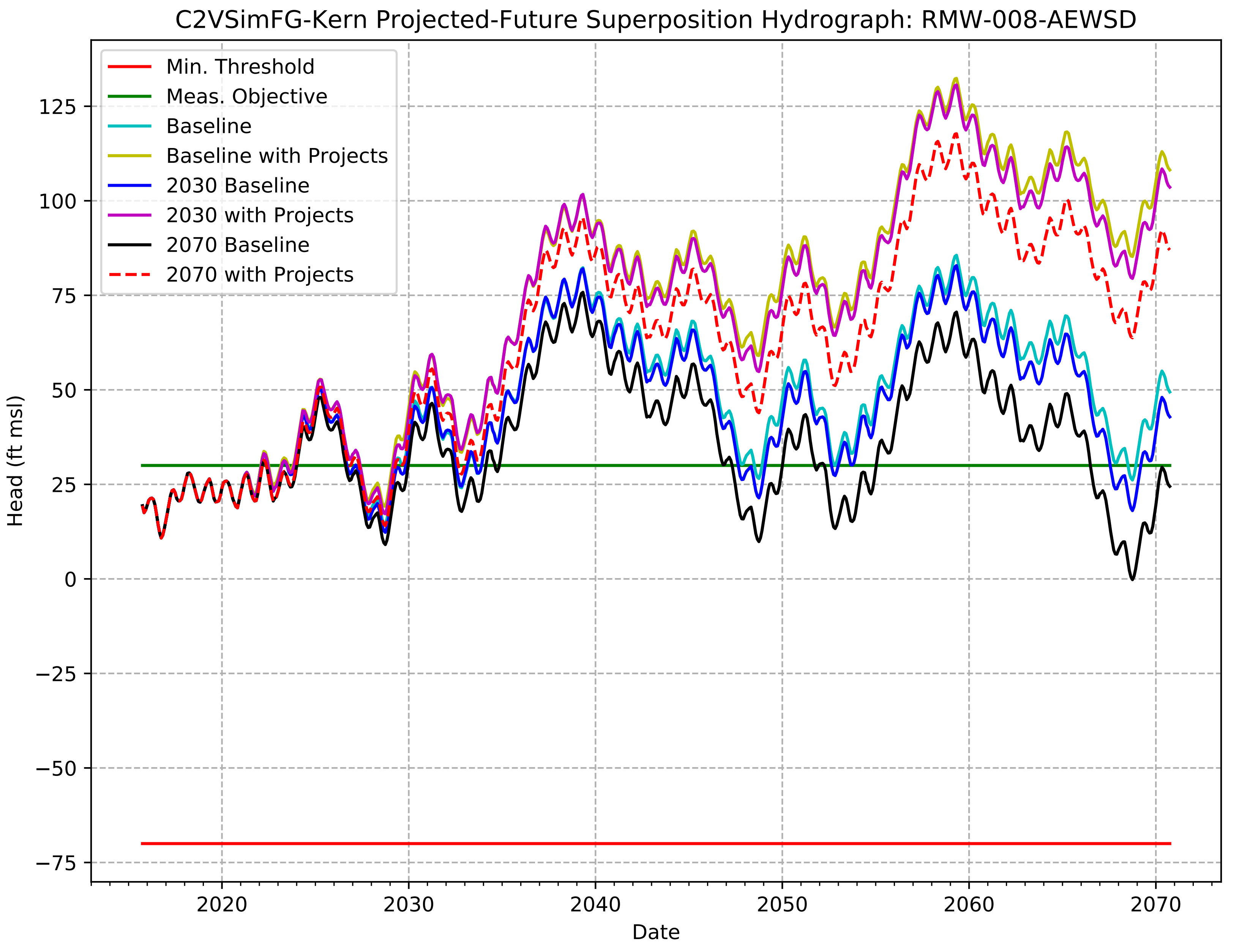


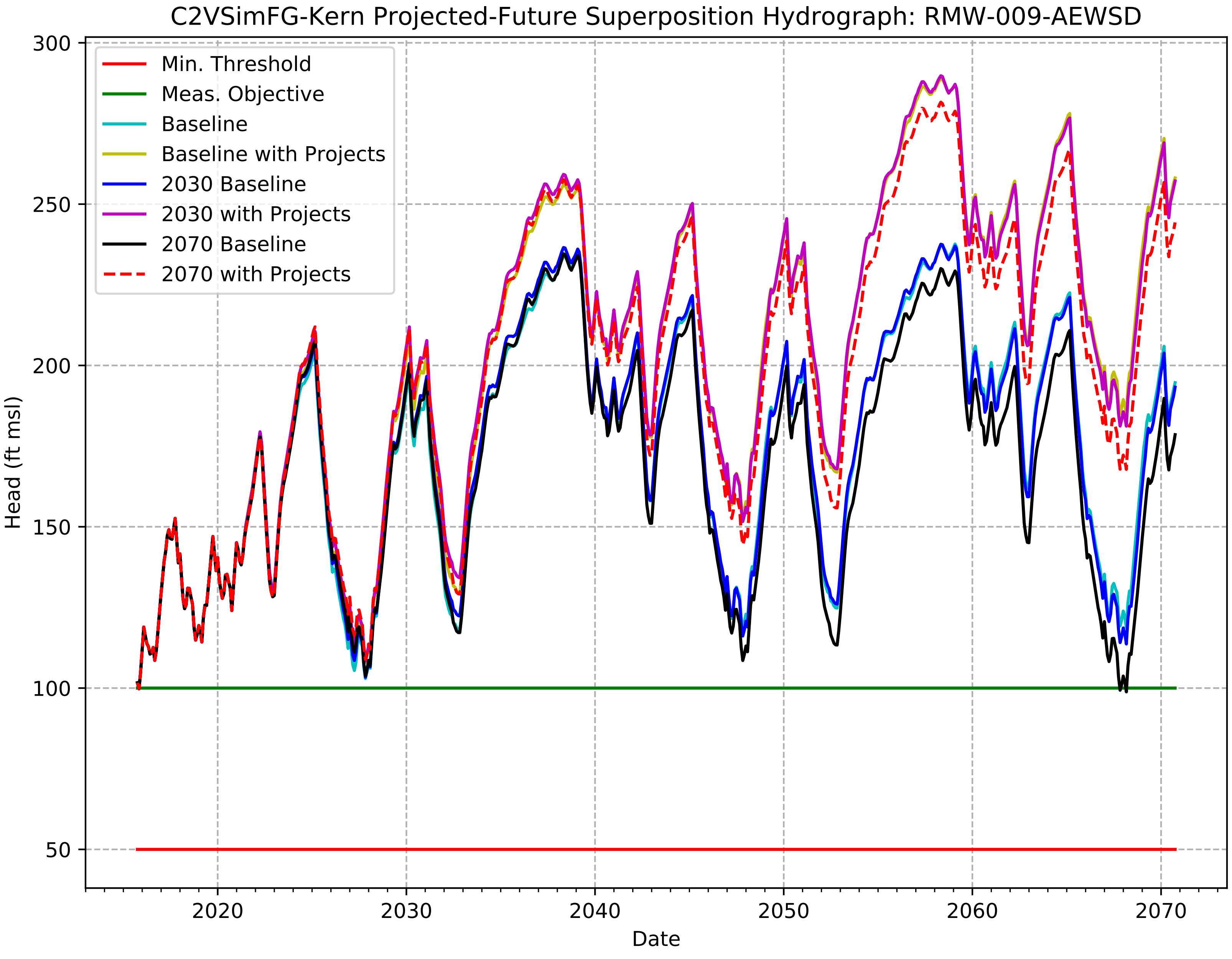
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-005-AEWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
140
120
100
80
60
2020
2030
2040
2050
2060
2070
Date


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-006-AEWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
200
180
160
140
120
100
80
60
2020
2030
2040
2050
2060
2070
Date

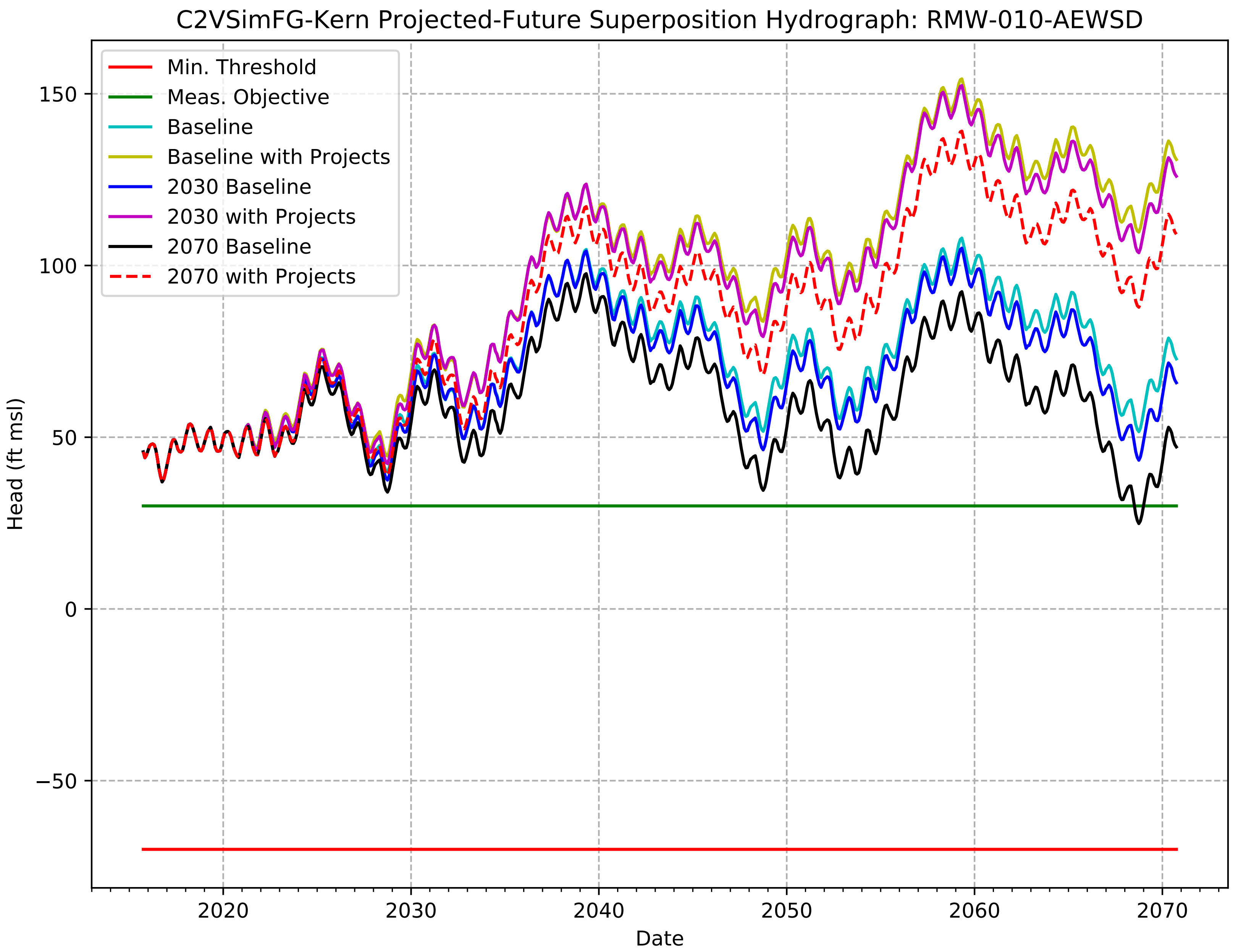


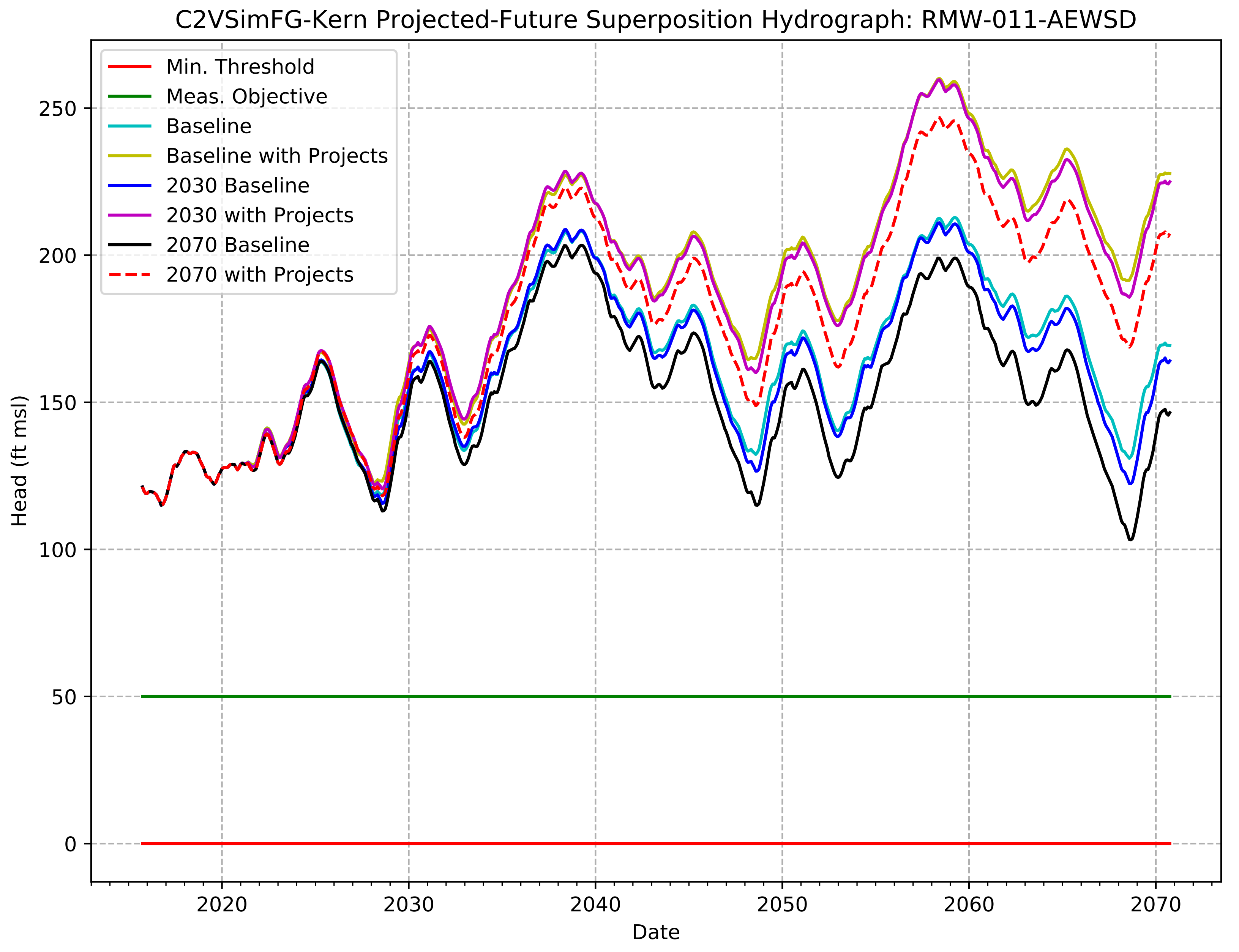
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-007-AEWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
250
200
150
100
50
2020
2030
2040
2050
2060
2070
Date


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-008-AEWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
125
100
75
50
25
0
−25
−50
−75
2020
2030
2040
2050
2060
2070
Date

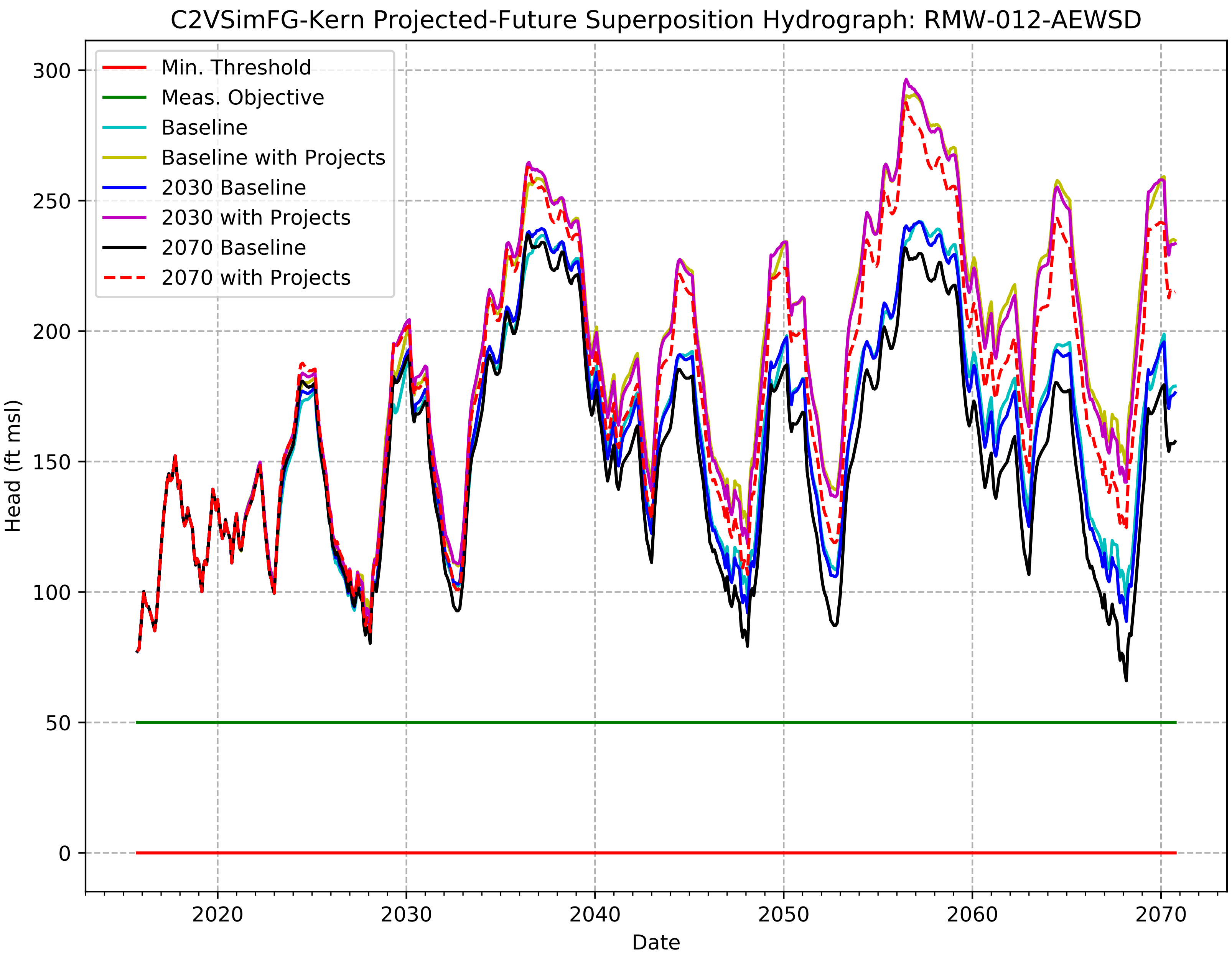


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-009-AEWSD
Head (ft msl)
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
300
250
200
150
100
50
2020
2030
2040
2050
2060
2070

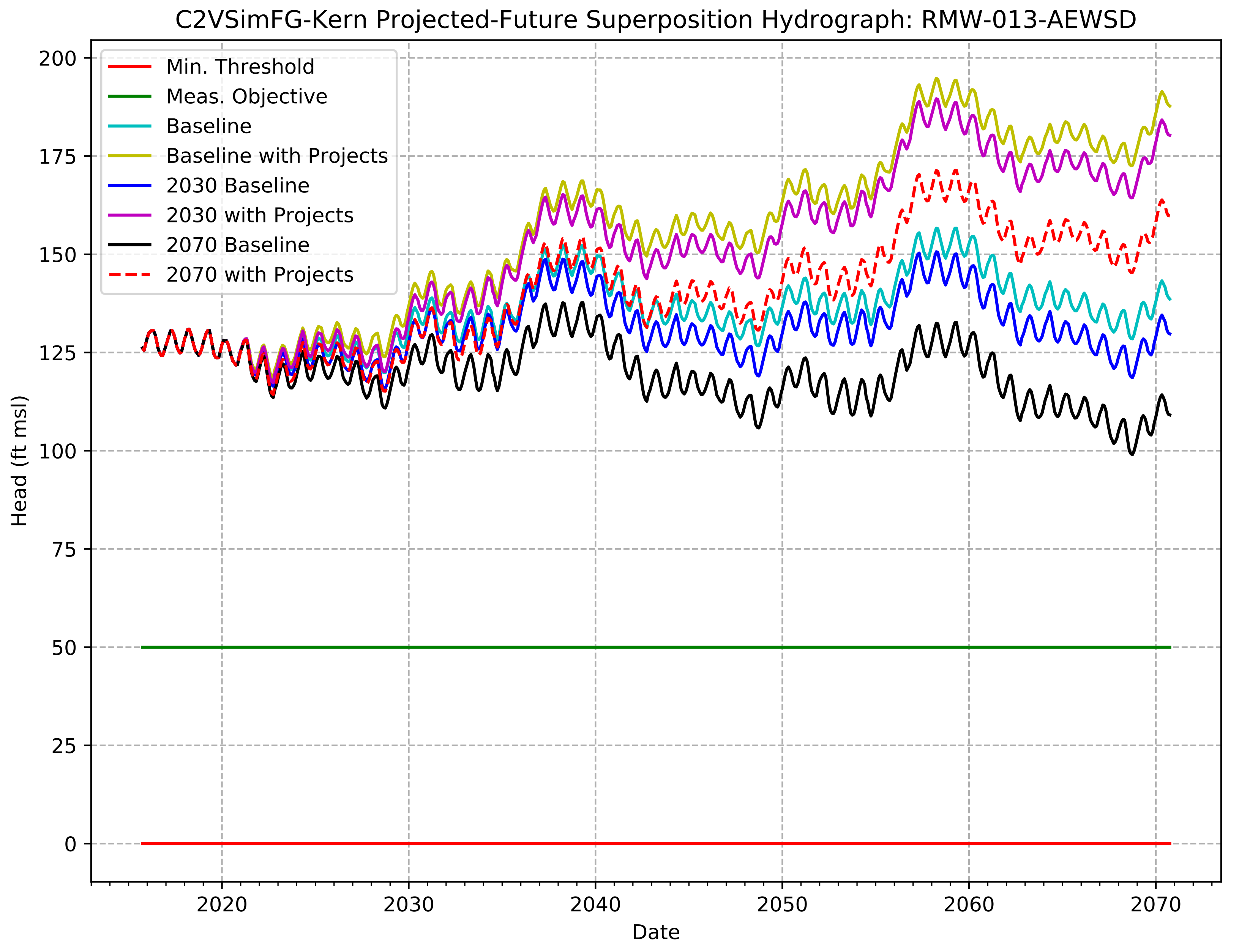

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-010-AEWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
150
100
50
0
−50
Head (ft msl)
2020
2030
2040
2050
2060
2070
Date

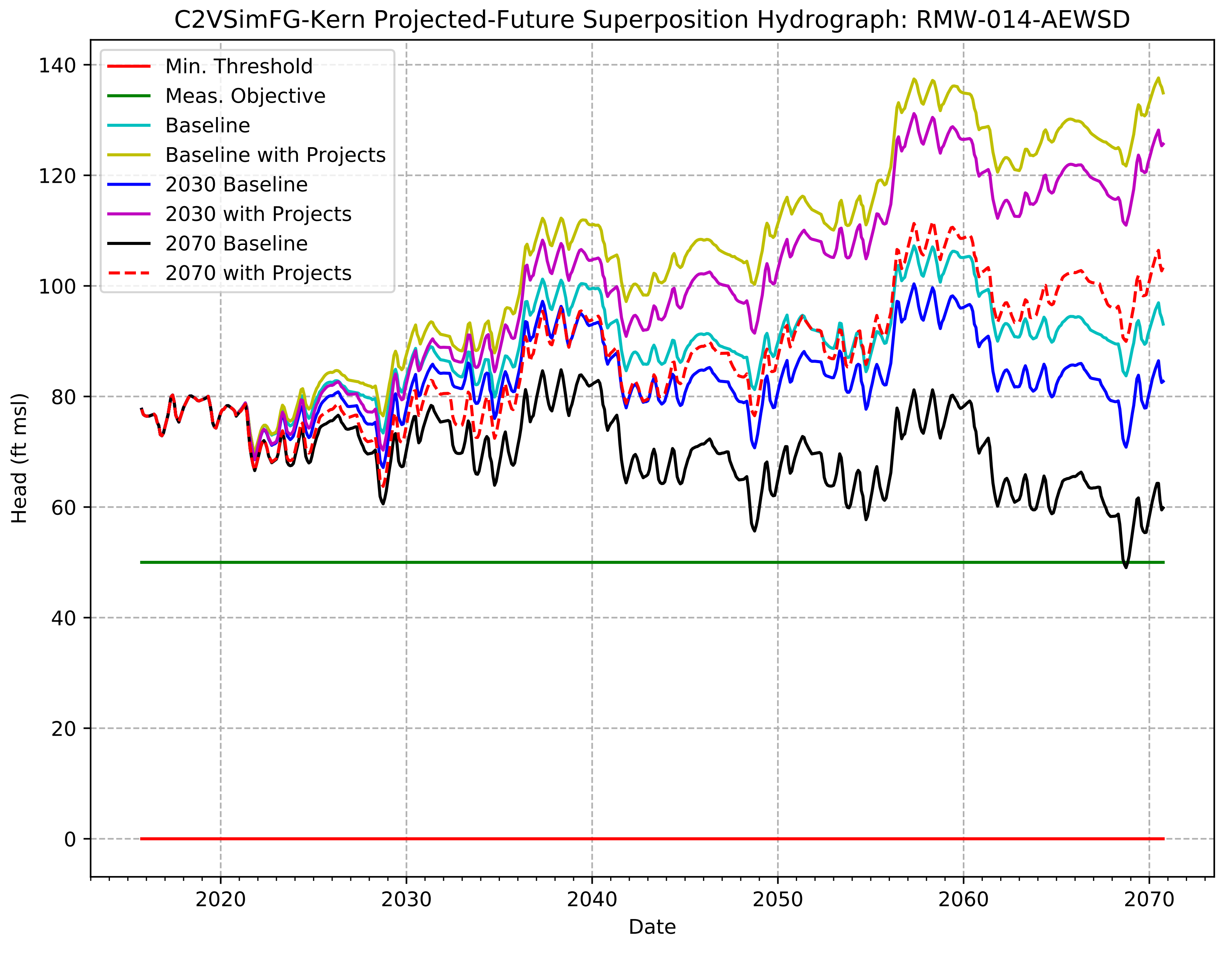


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-011-AEWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
0
50
100
150
200
250
2020
2030
2040
2050
2060
2070
Date



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-012-AEWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
300
250
200
150
100
50
0
2020
2030
2040
2050
2060
2070


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-013-AEWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
0
25
50
75
100
125
150
175
200
2020
2030
2040
2050
2060
2070


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-014-AEWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
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20
40
60
80
100
120
140
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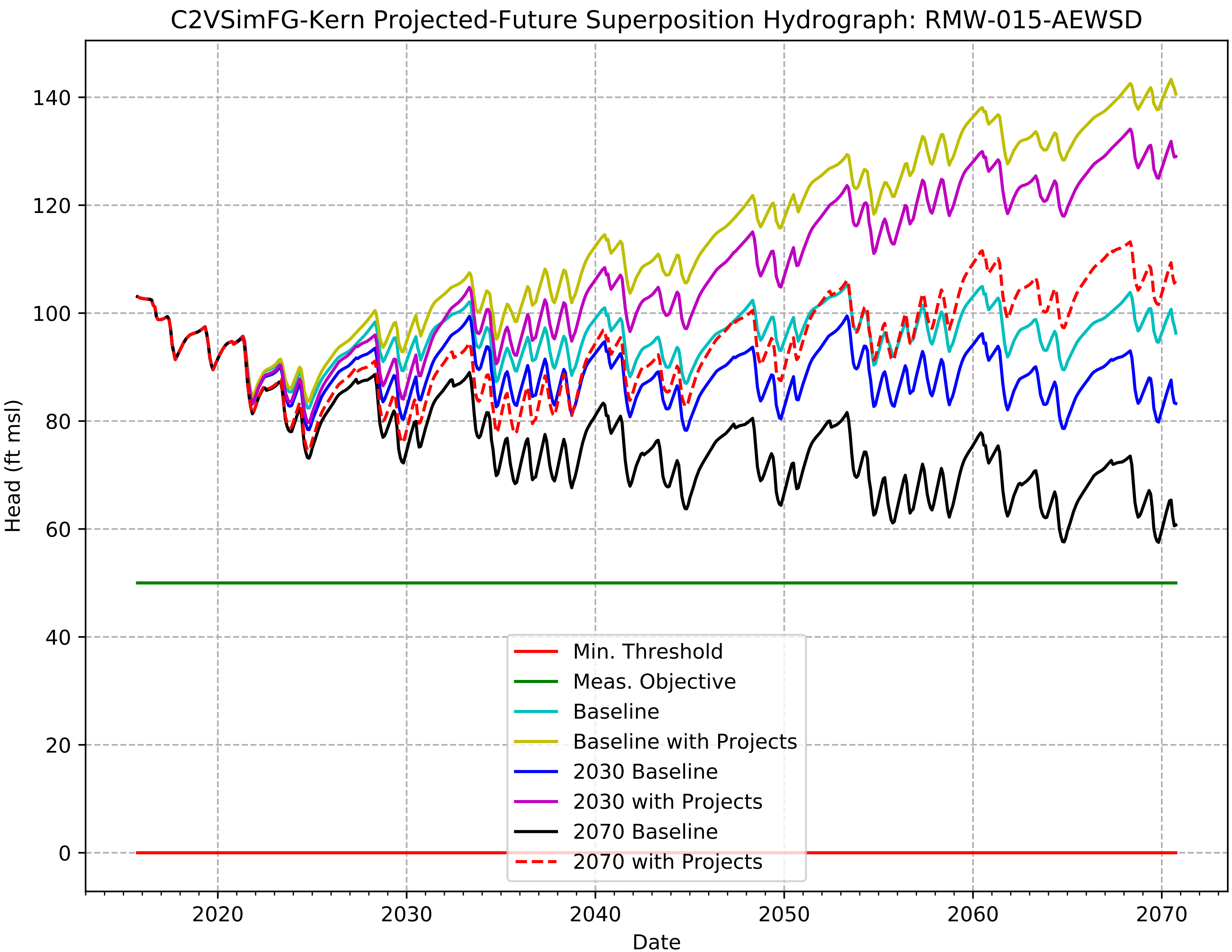
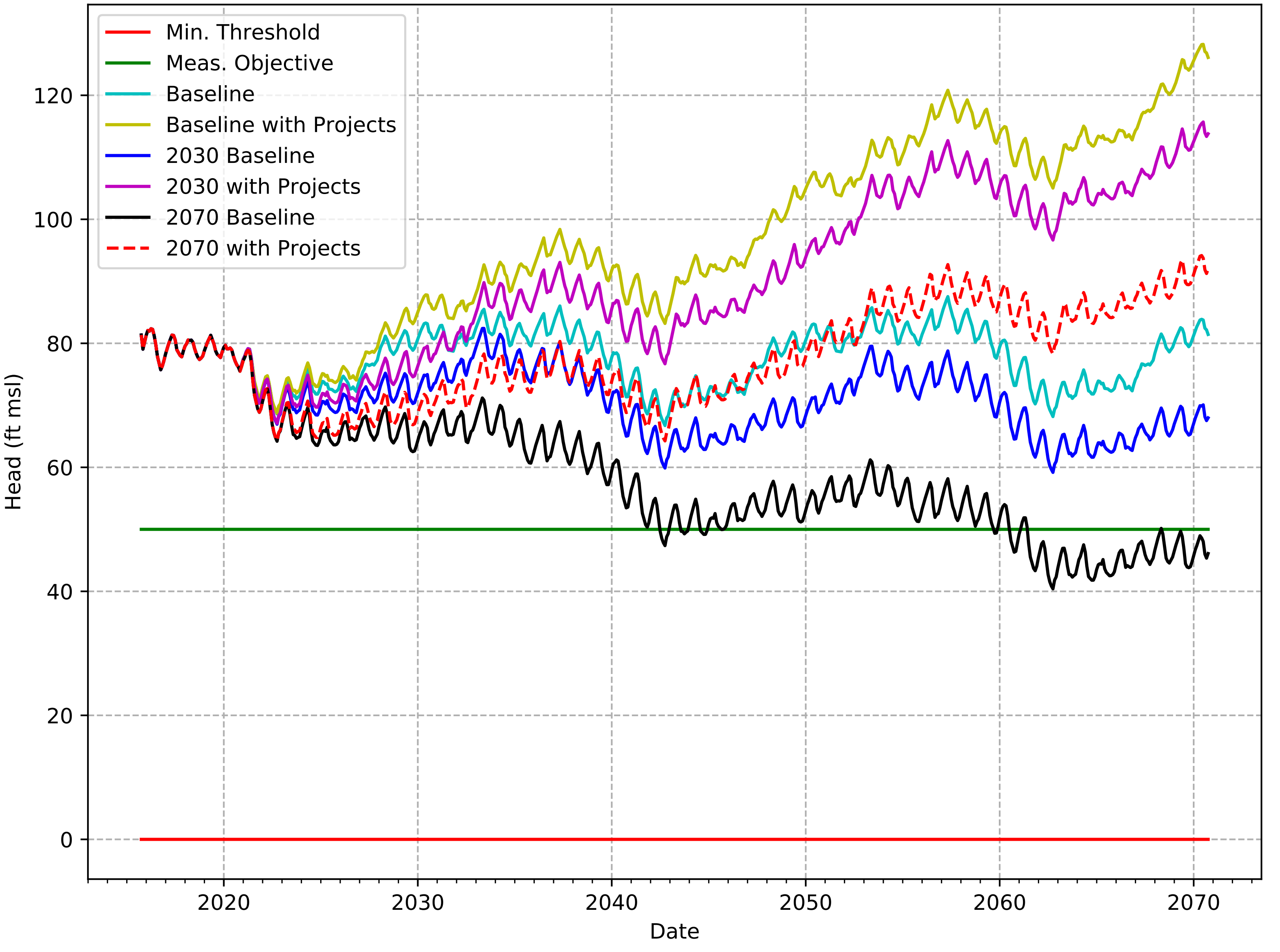
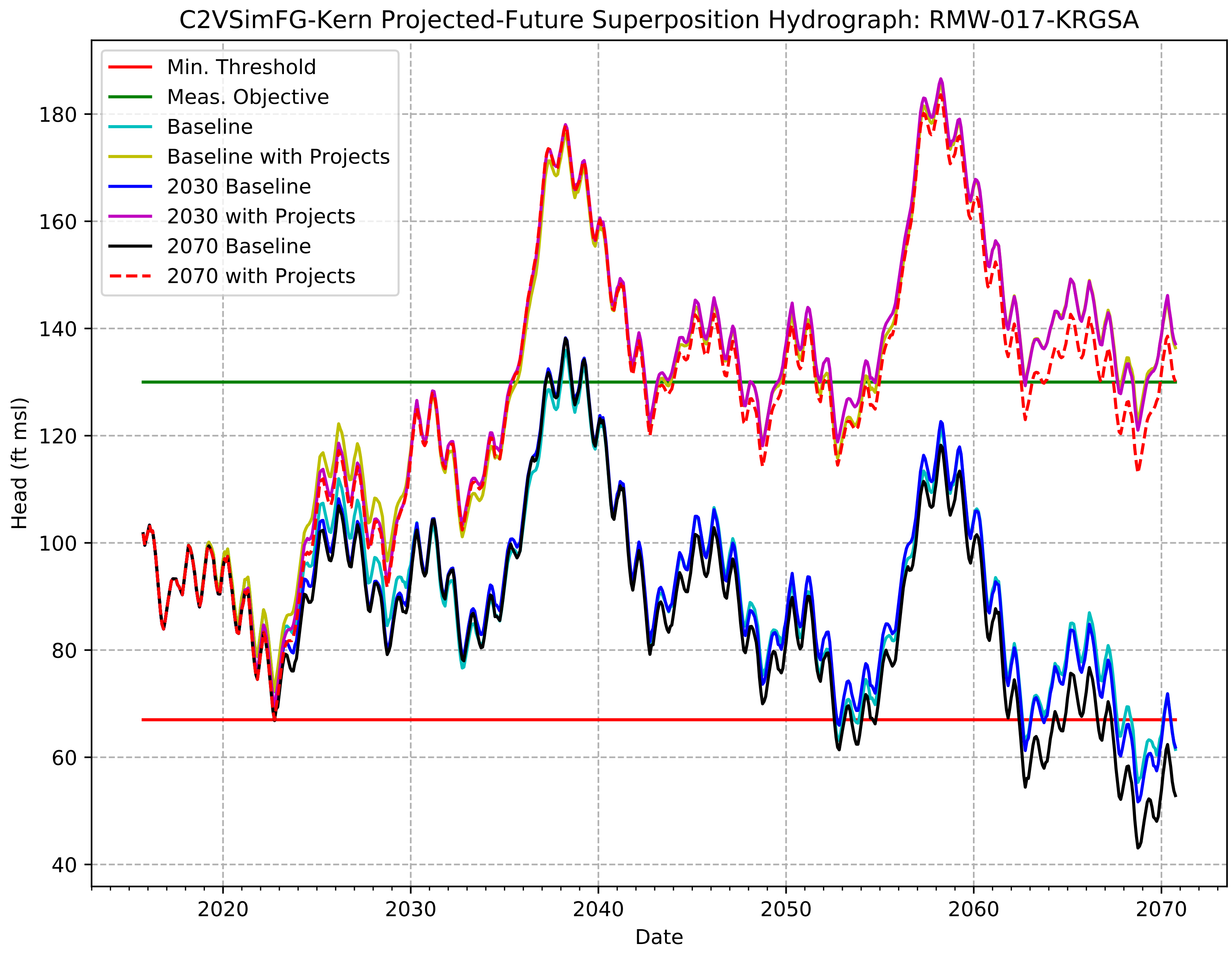
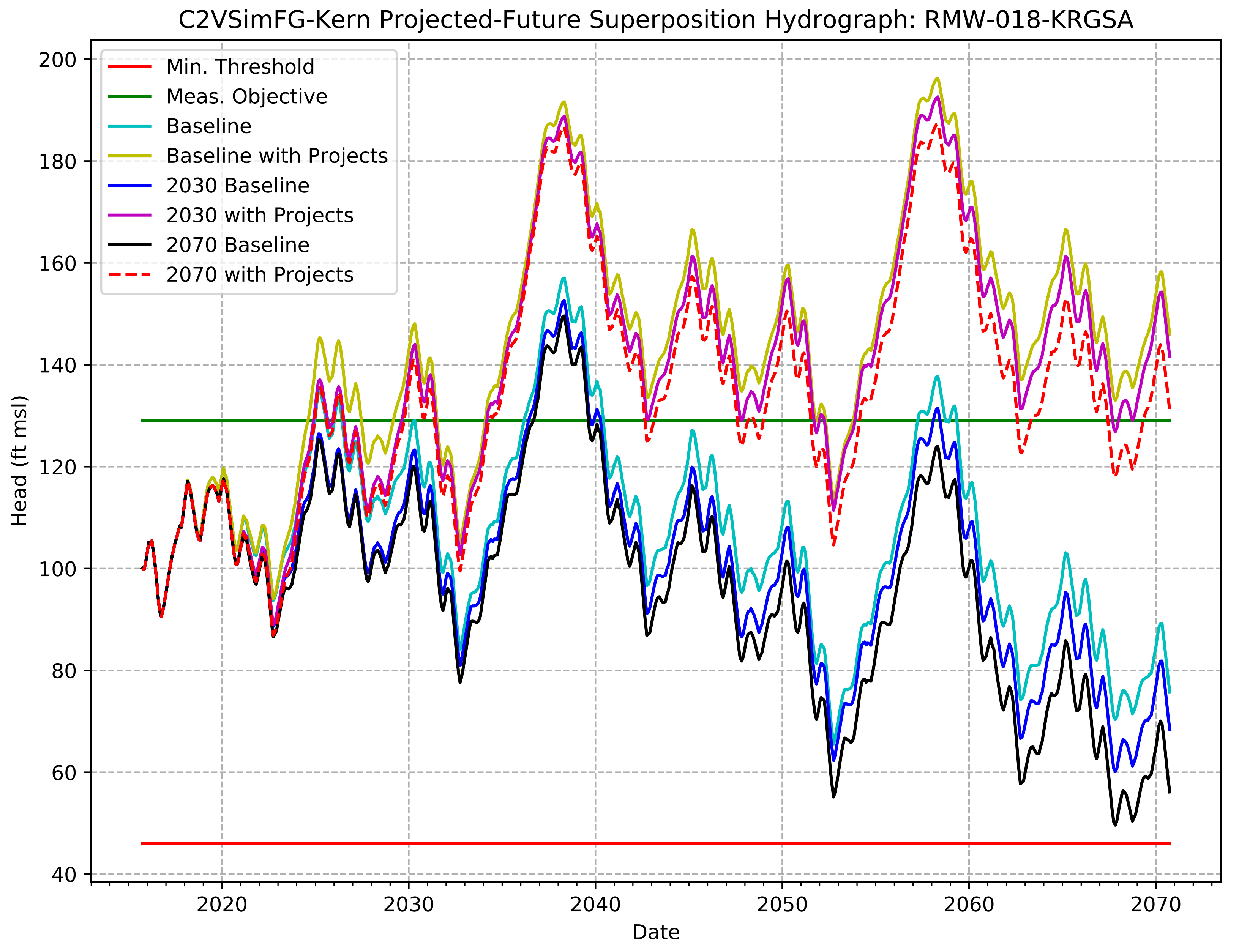
2050
2060
2070
Date

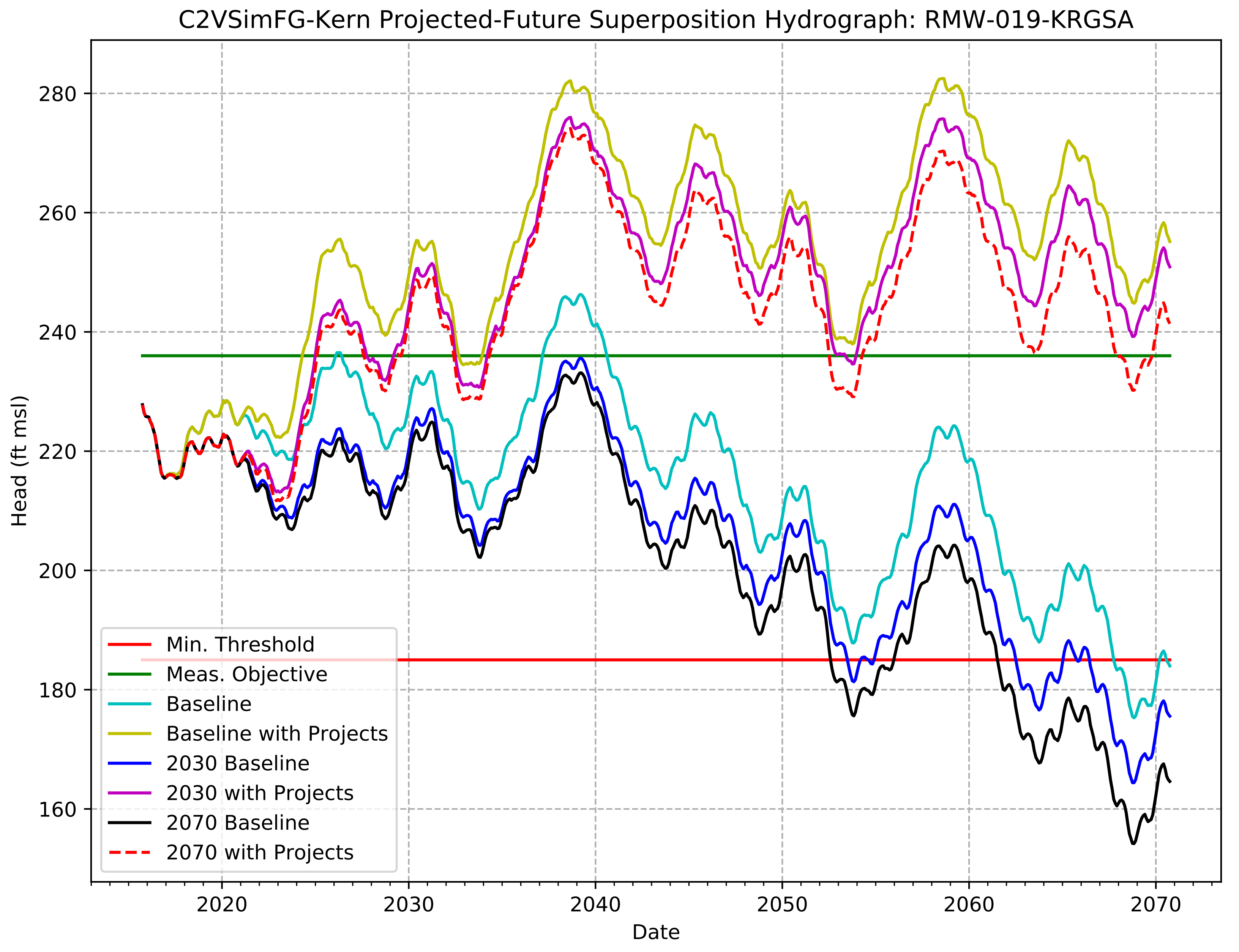

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-015-AEWSD
Head (ft msl)
Date
0
20
40
60
80
100
120
140
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

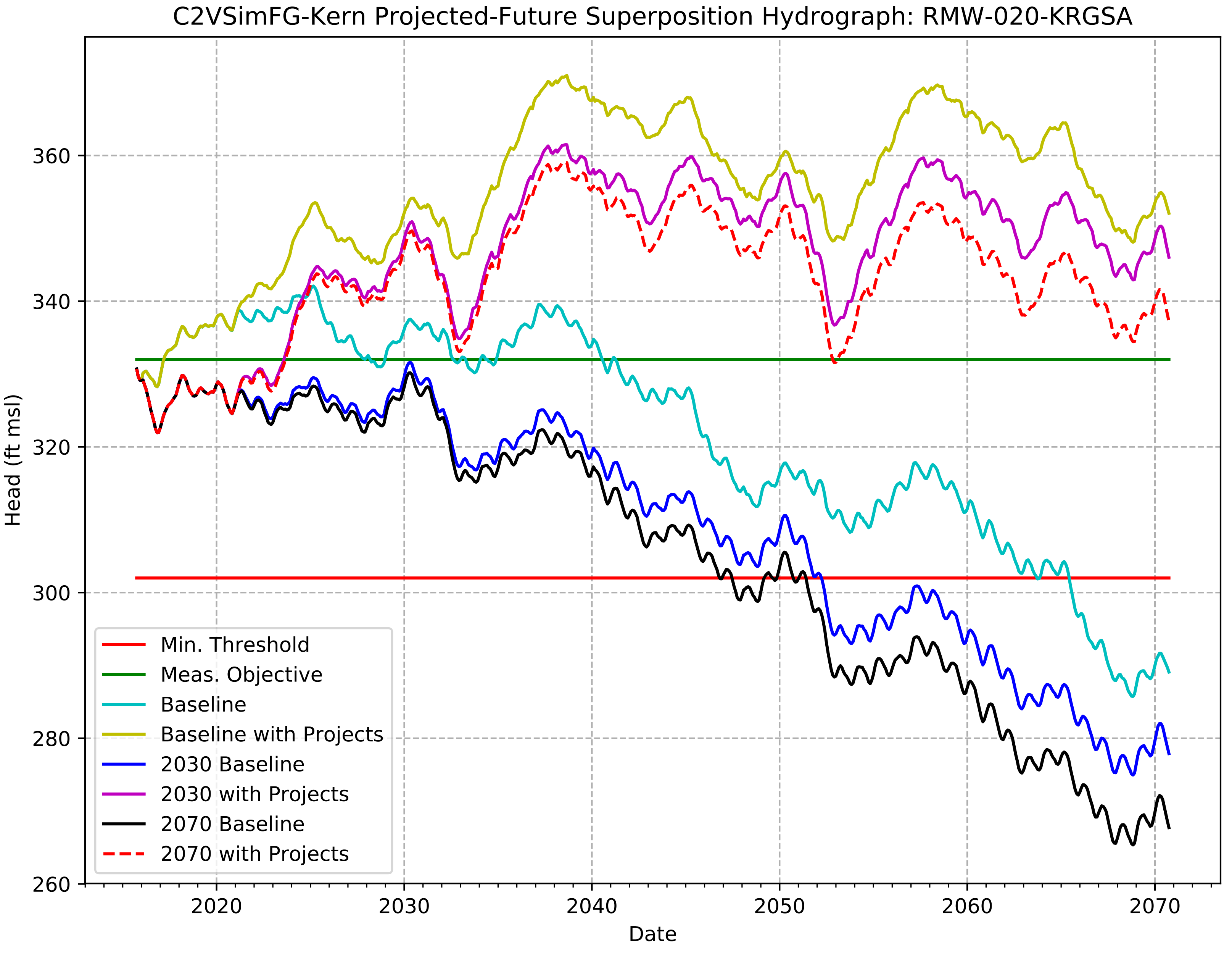
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-016-AEWSD



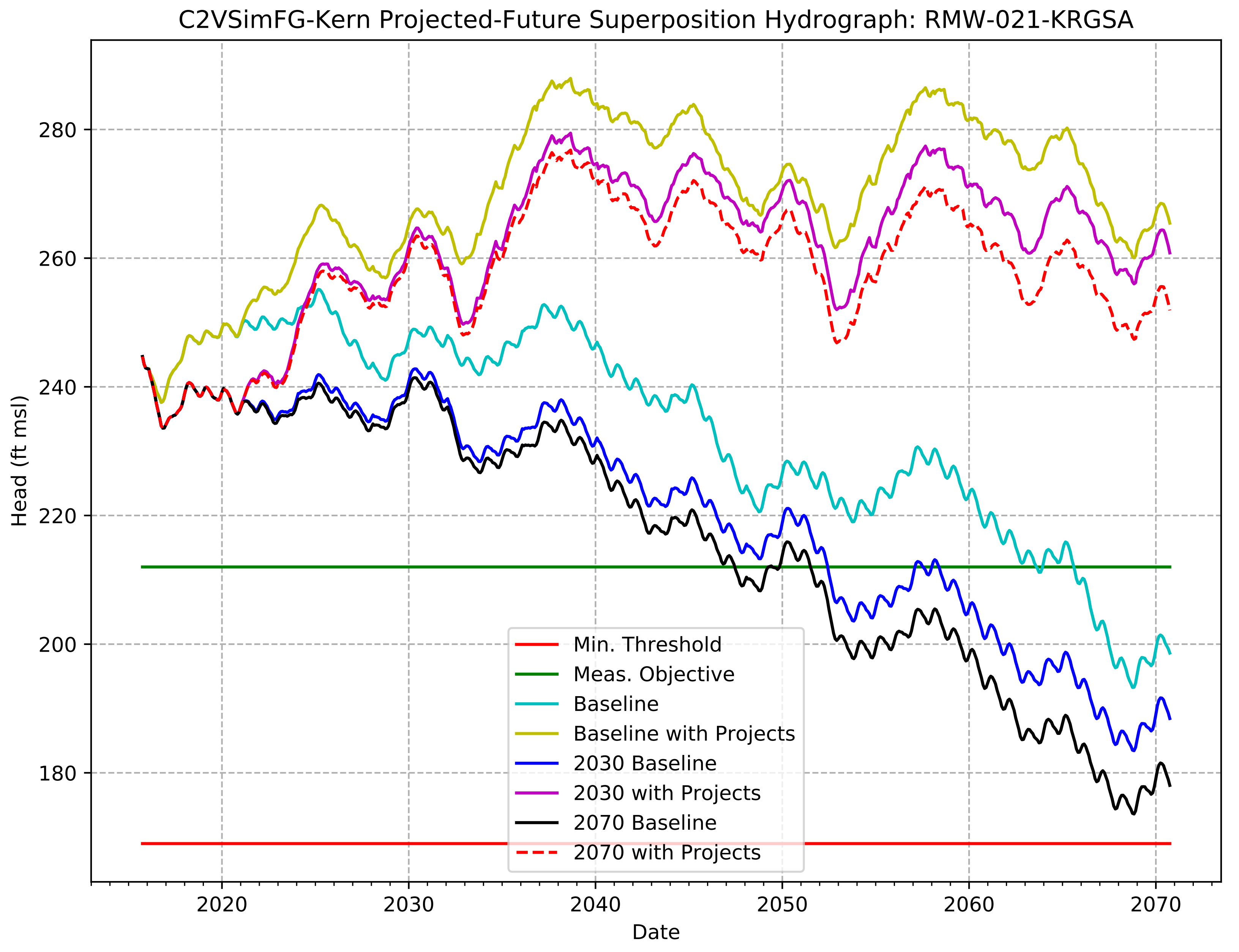

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-017-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
40
60
80
100
120
140
160
180
2020
2030
2040
2050
2060
2070


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-018-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
200
180
160
140
120
100
80
60
40
2020
2030
2040
2050
2060
2070

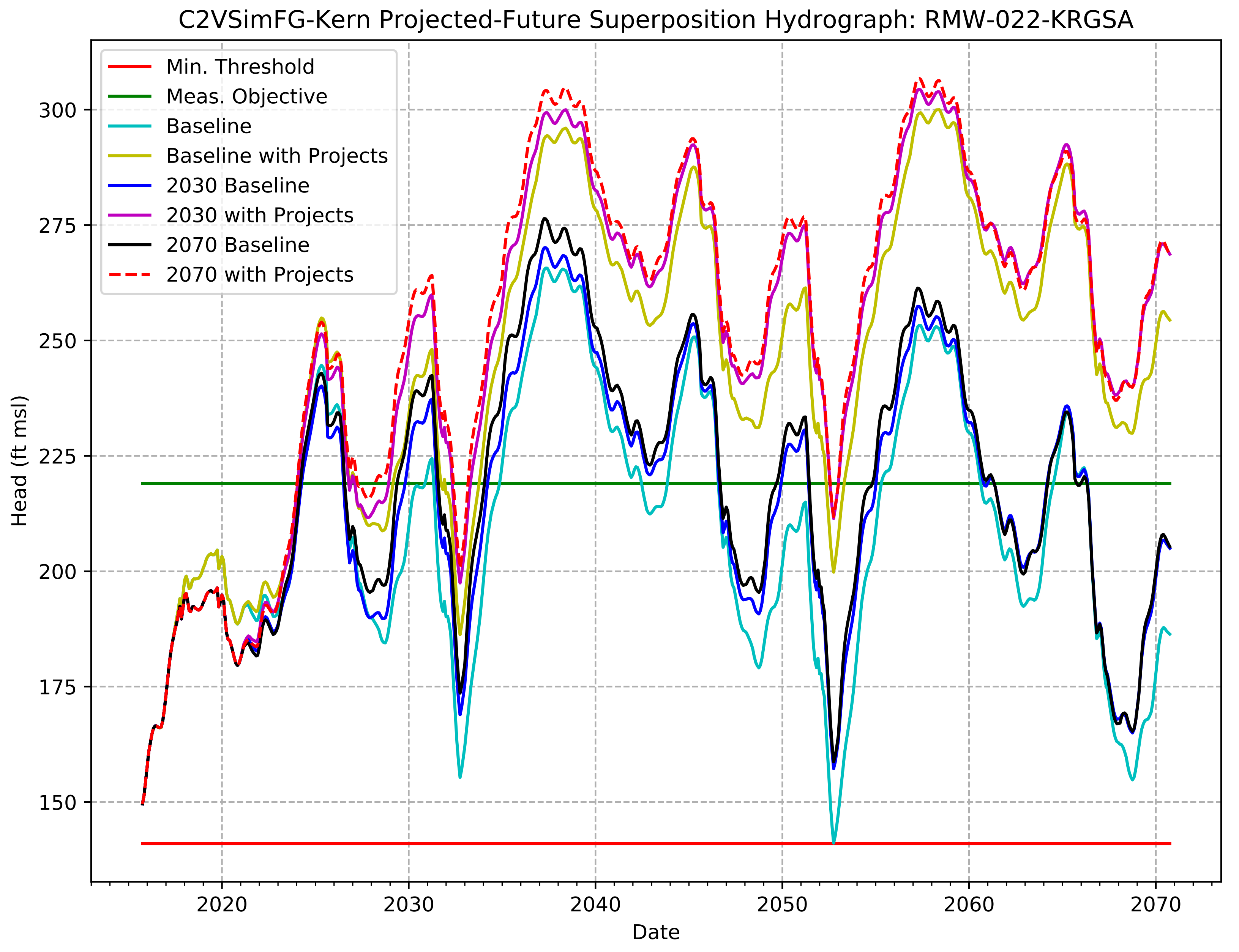

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-019-KRGSA
Head (ft msl)
Date
280
260
240
220
200
180
160
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



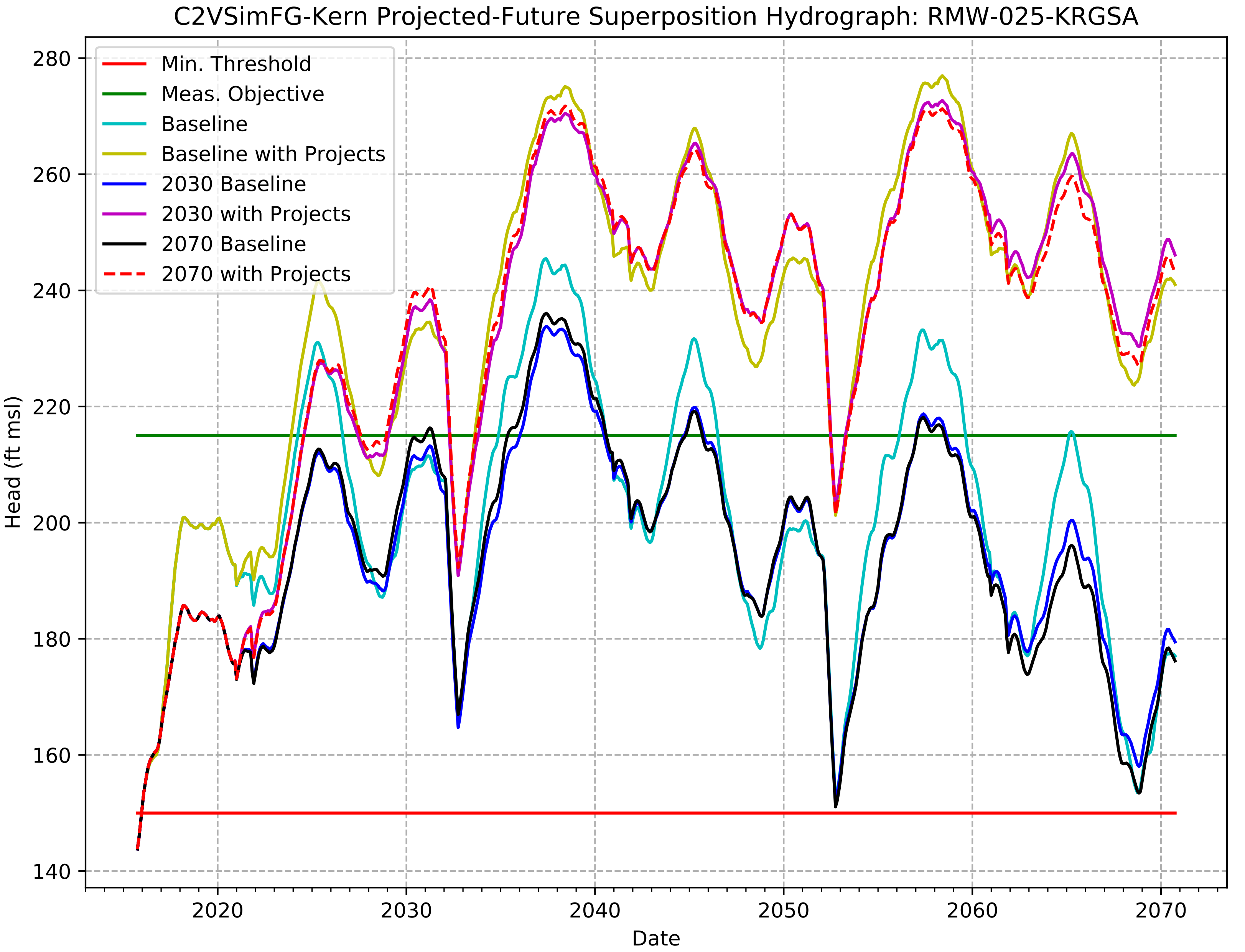
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-020-KRGSA
Head (ft msl)
360
340
320
300
280
260
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

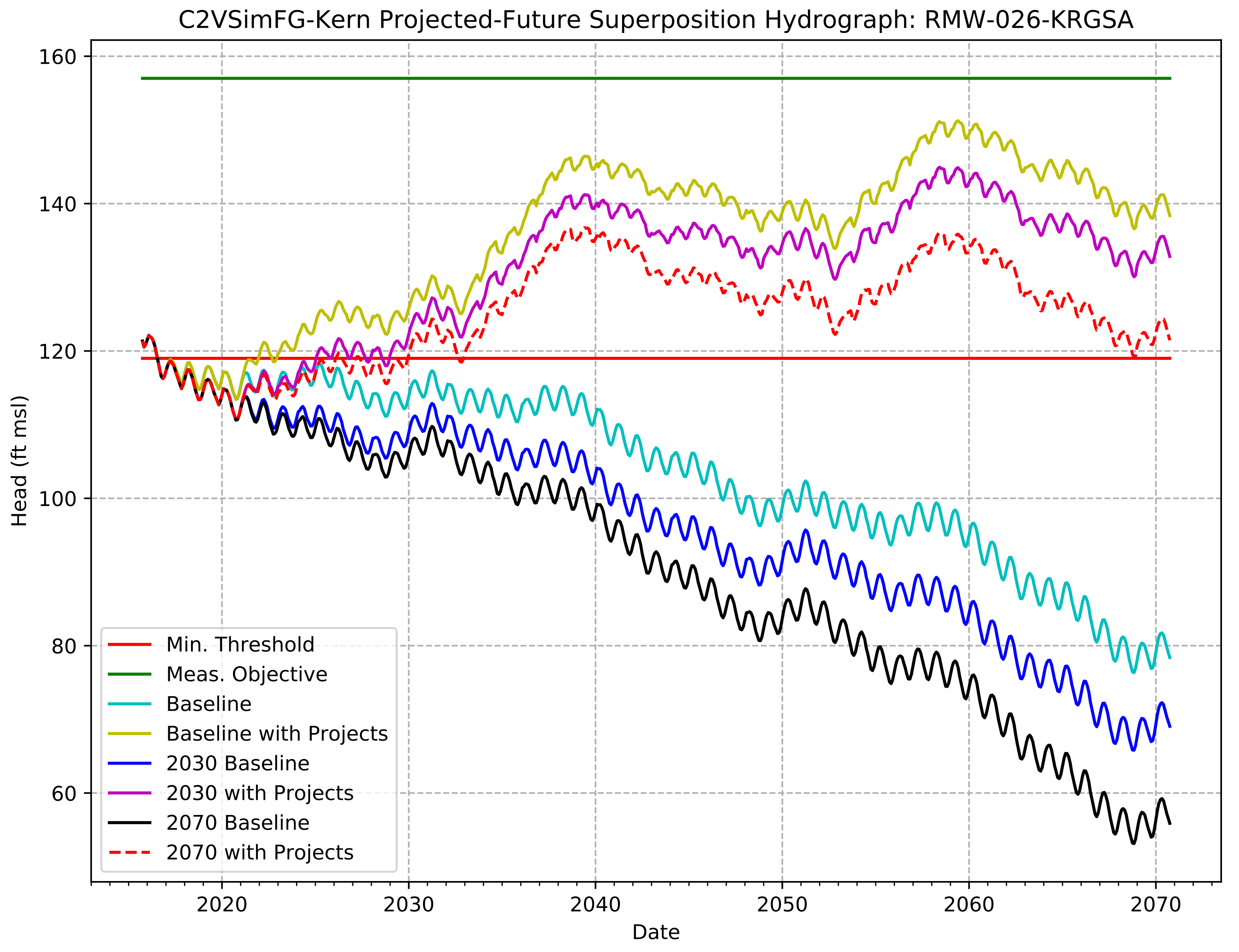


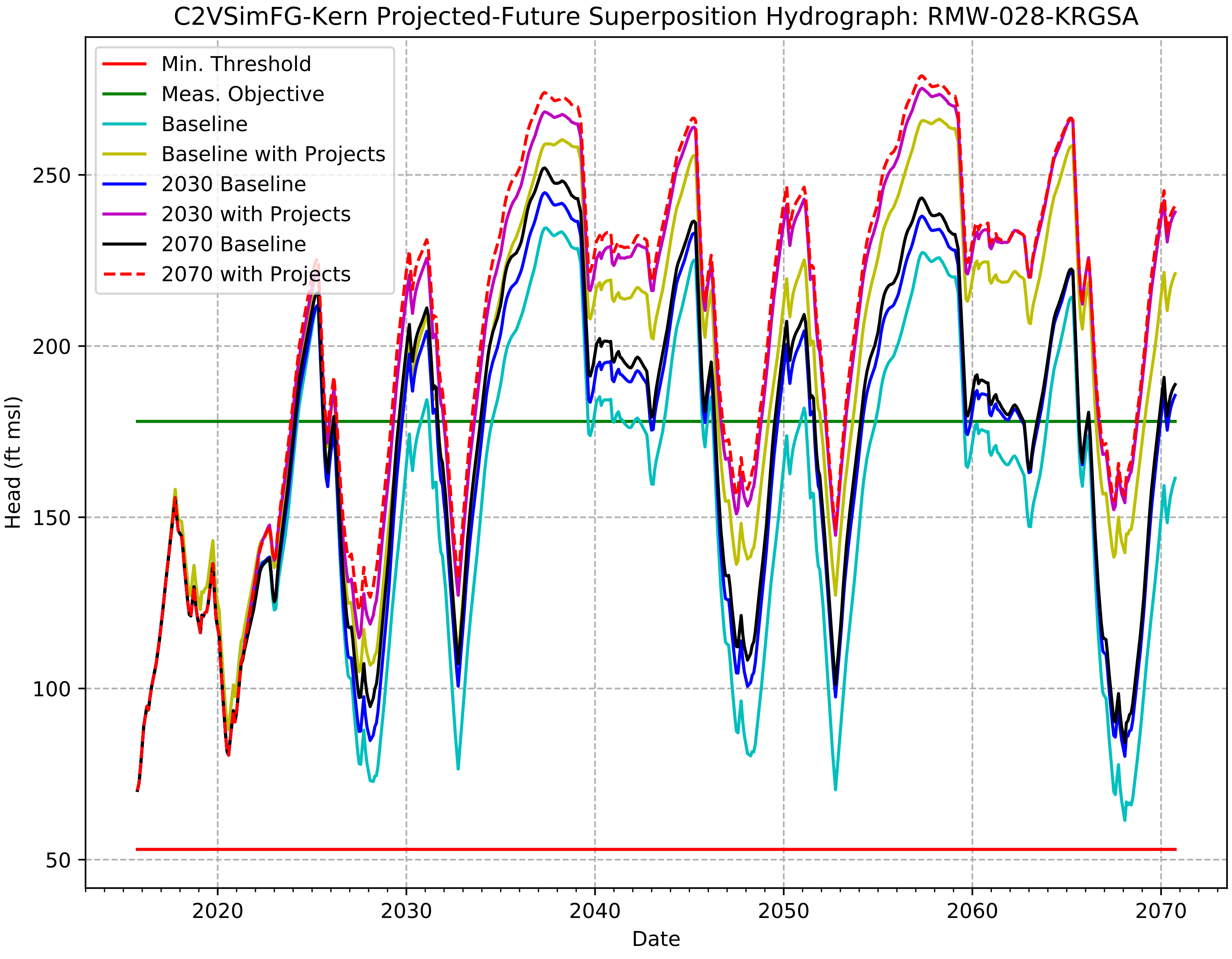
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-021-KRGSA
Head (ft msl)
Date
180
200
220
240
260
280
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



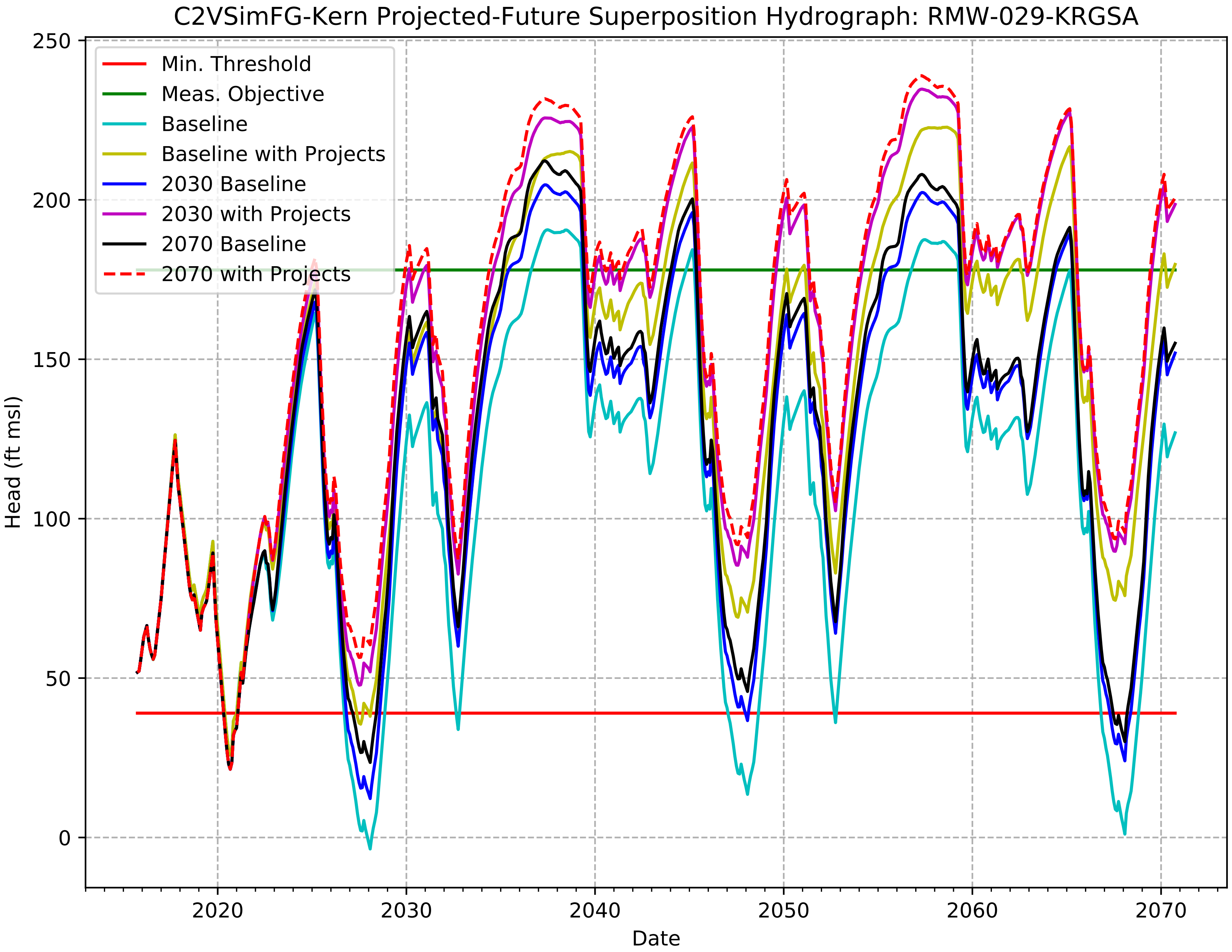
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-022-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
300
275
250
225
200
175
150
2020
2030
2040
2050
2060
2070
Date

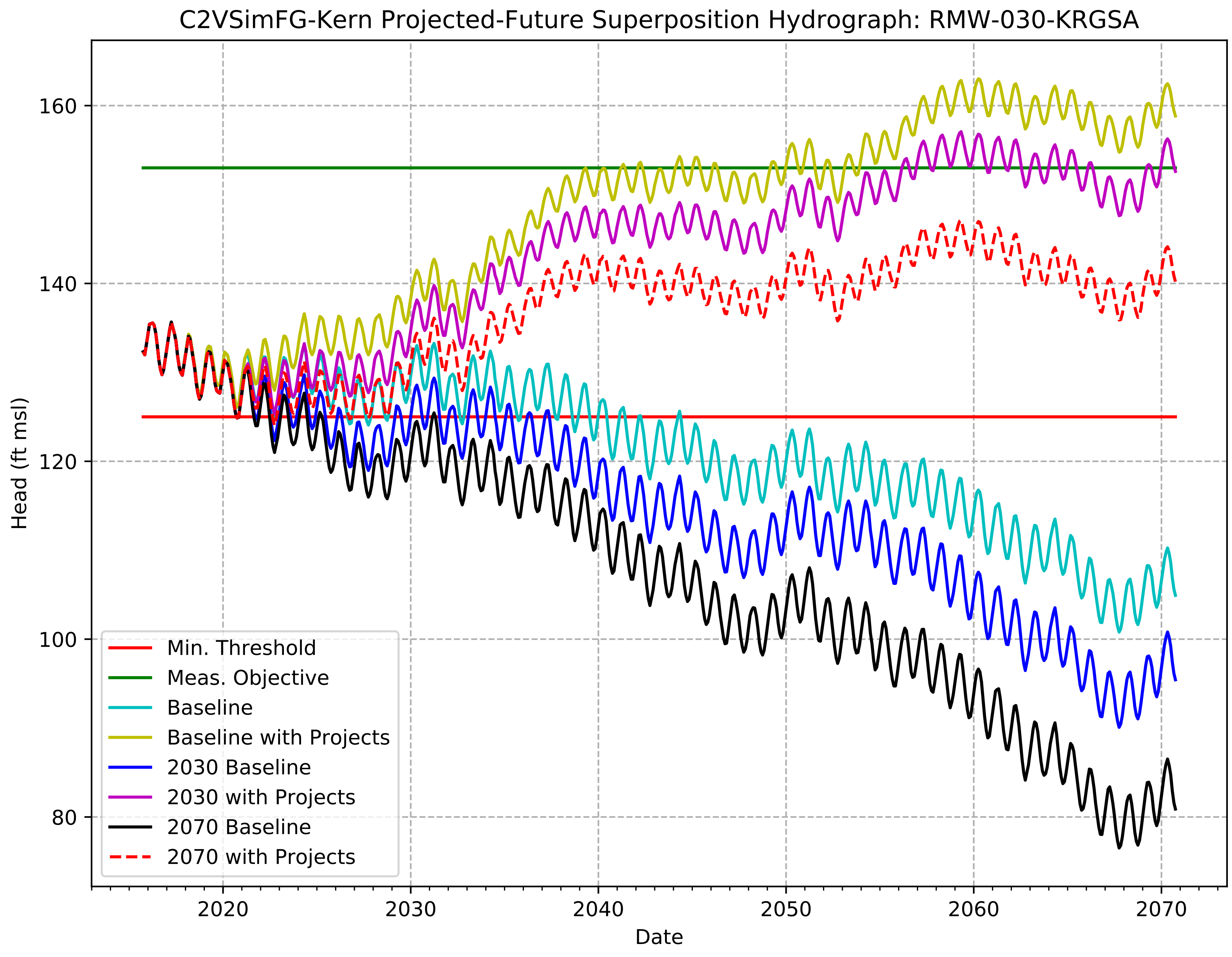

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-025-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
280
260
240
220
200
180
160
140
2020
2030
2040
2050
2060
2070
Date


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-026-KRGSA
Head (ft msl)
Date
160
140
120
100
80
60
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

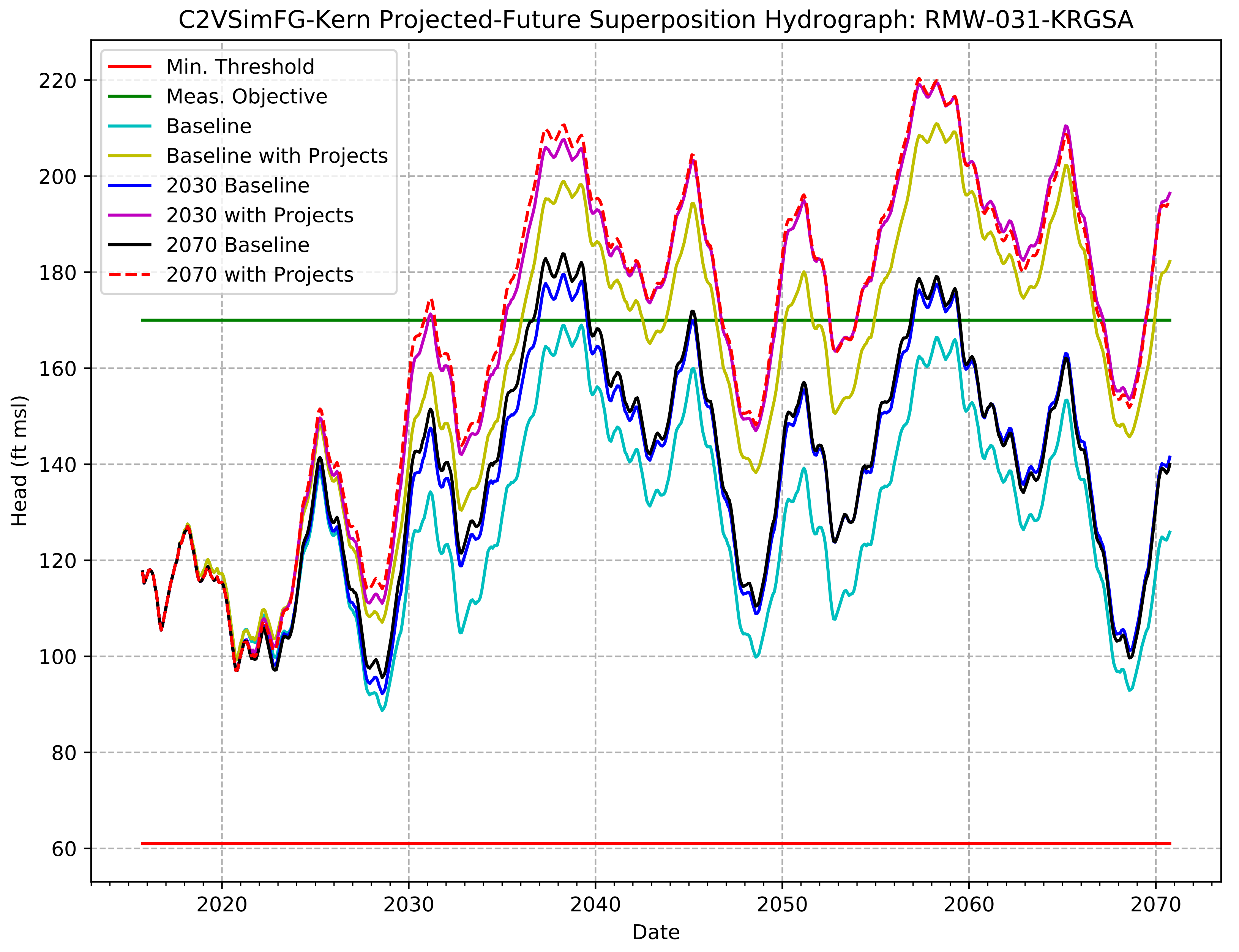


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-028-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
50
100
150
200
250
Date
2020
2030
2040
2050
2060
2070

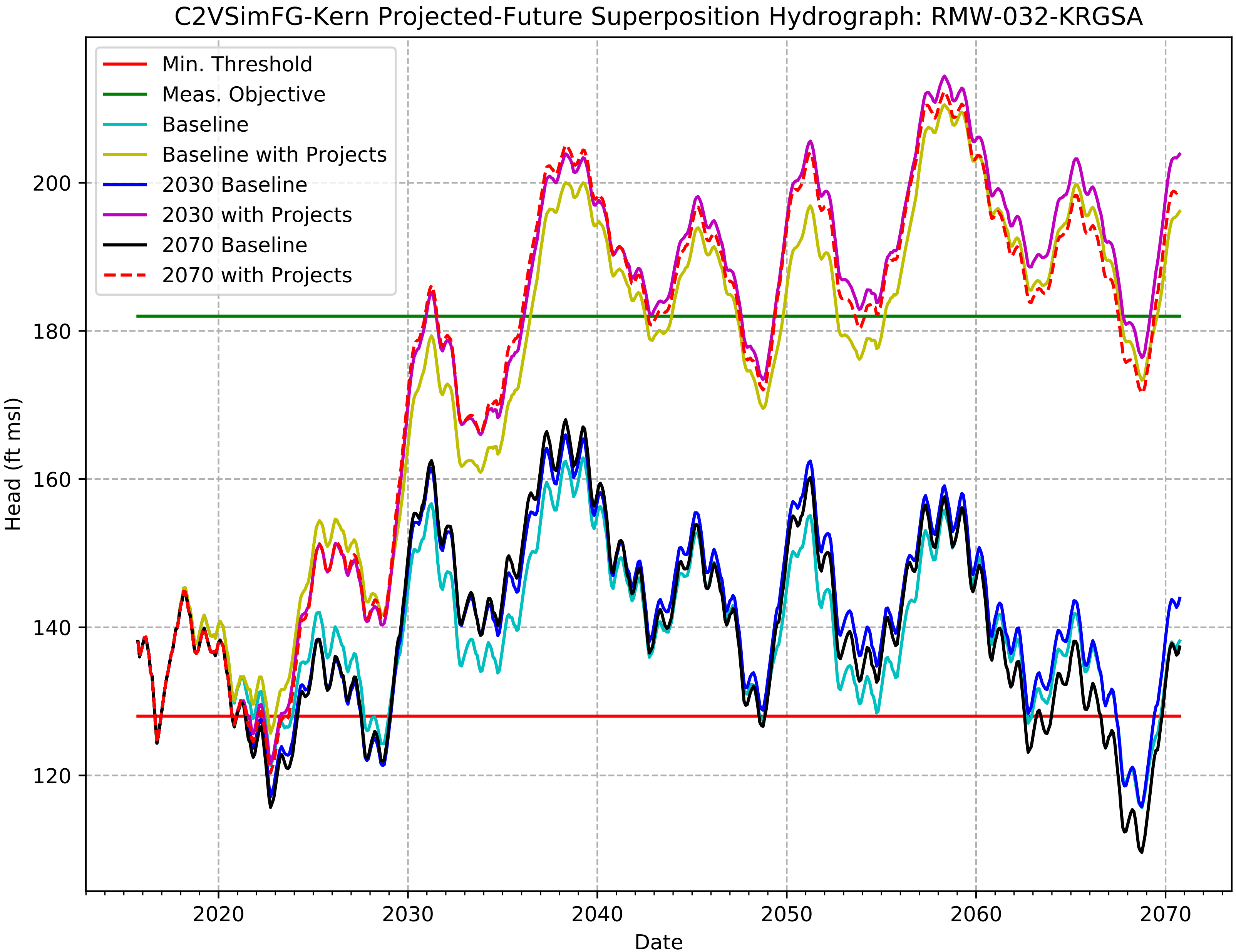

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-029-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
0
50
100
150
200
250
2020
2030
2040
2050
2060
2070

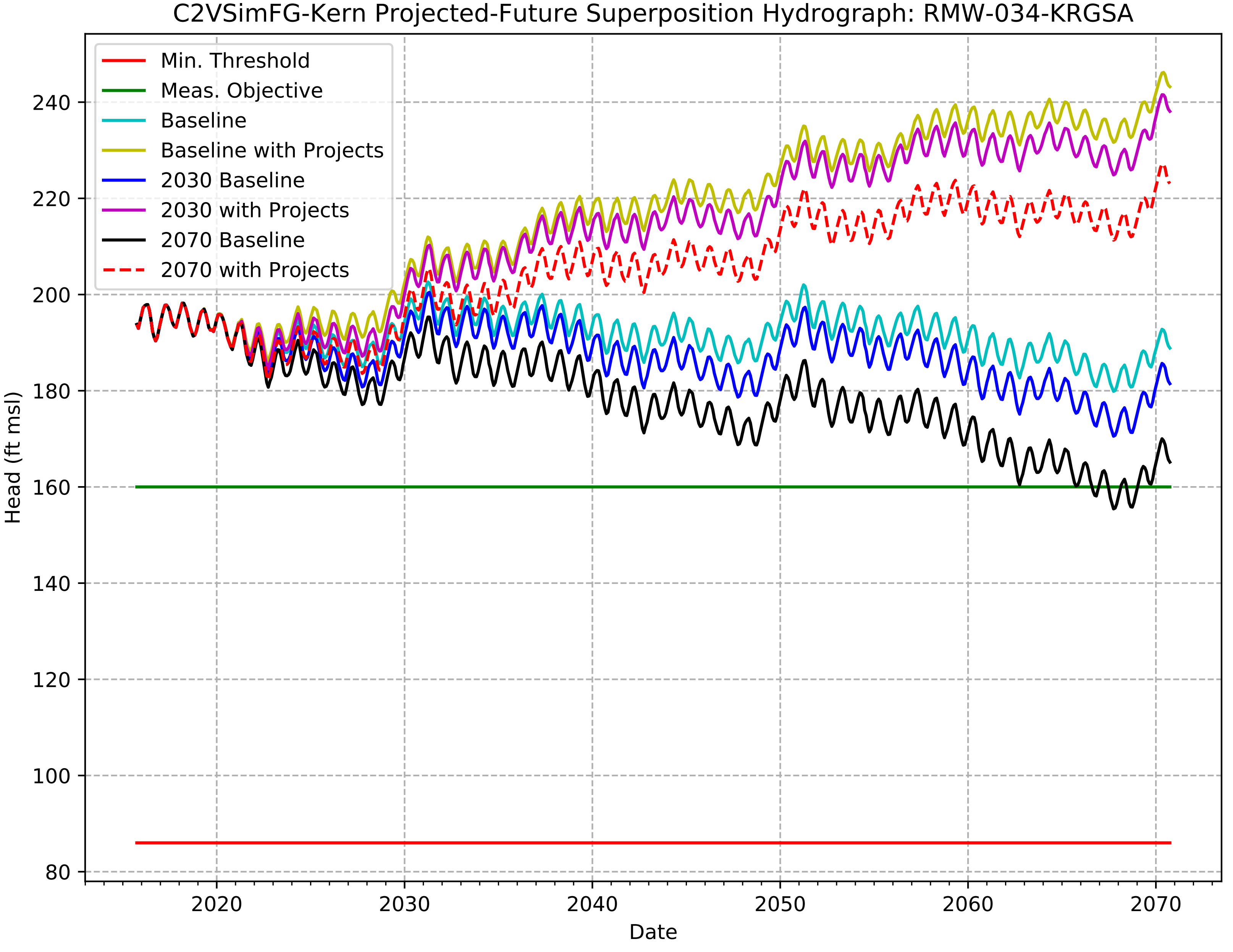


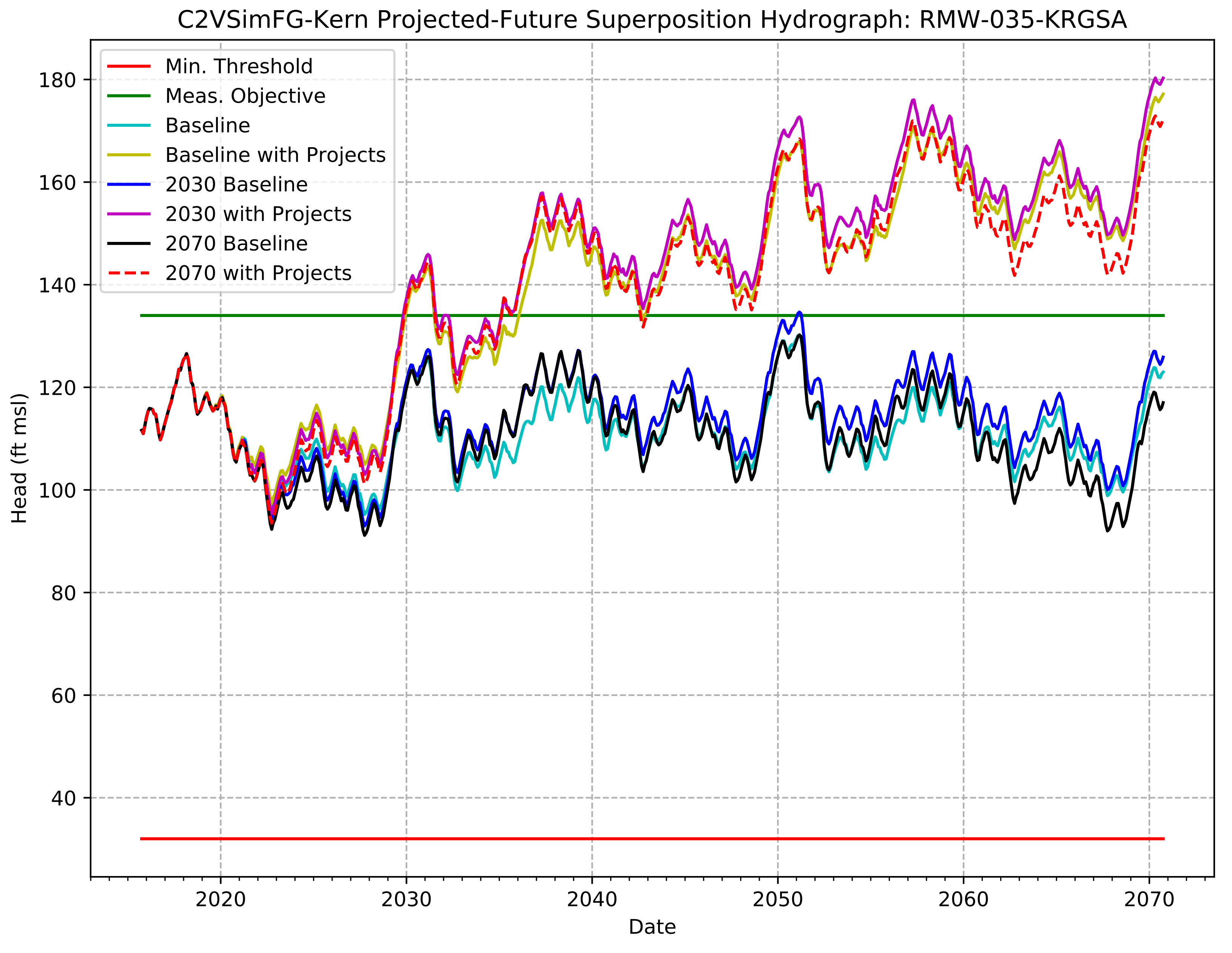
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-030-KRGSA
Head (ft msl)
160
140
120
100
80
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

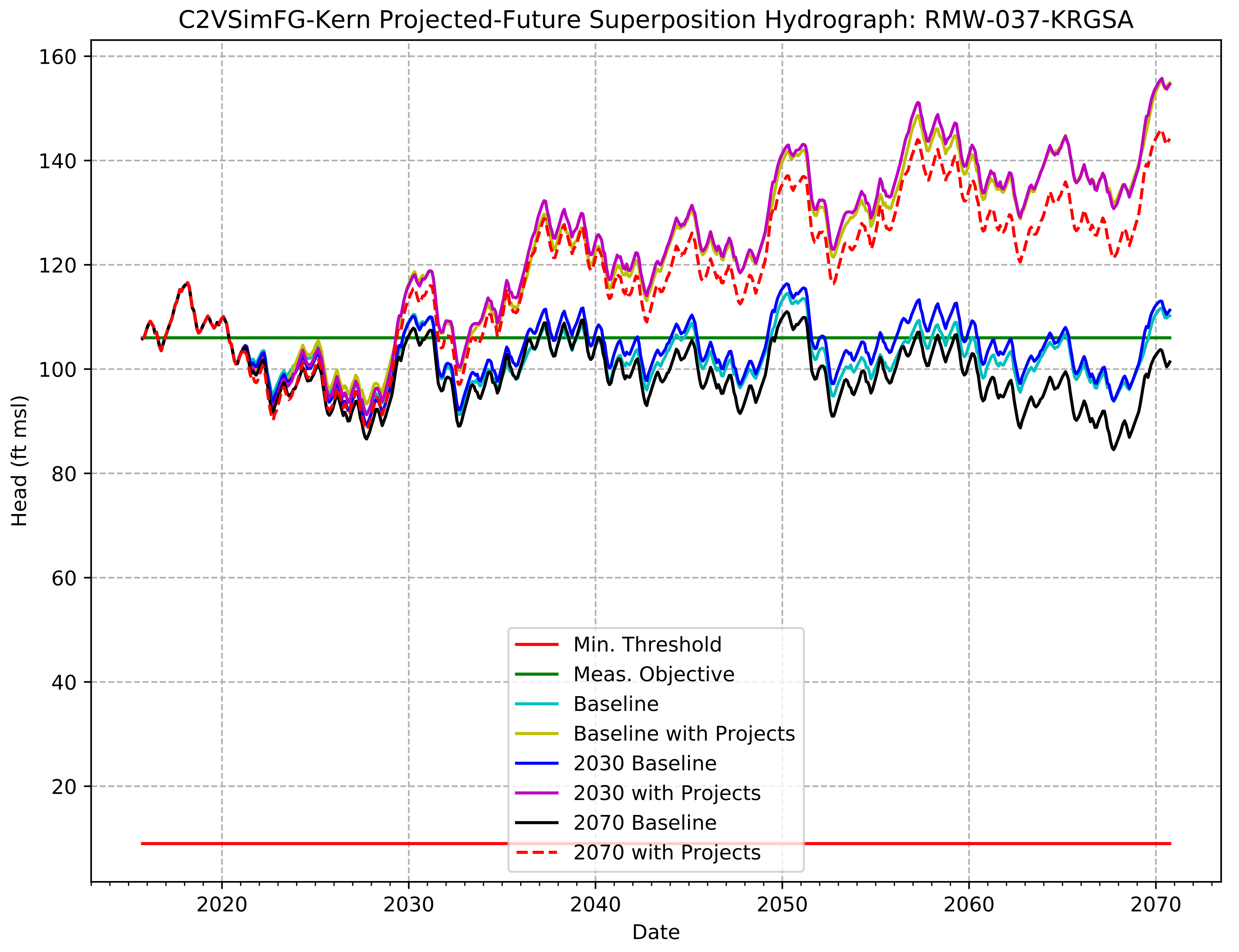


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-031-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
220
200
180
160
140
120
100
80
60
2020
2030
2040
2050
2060
2070
Date

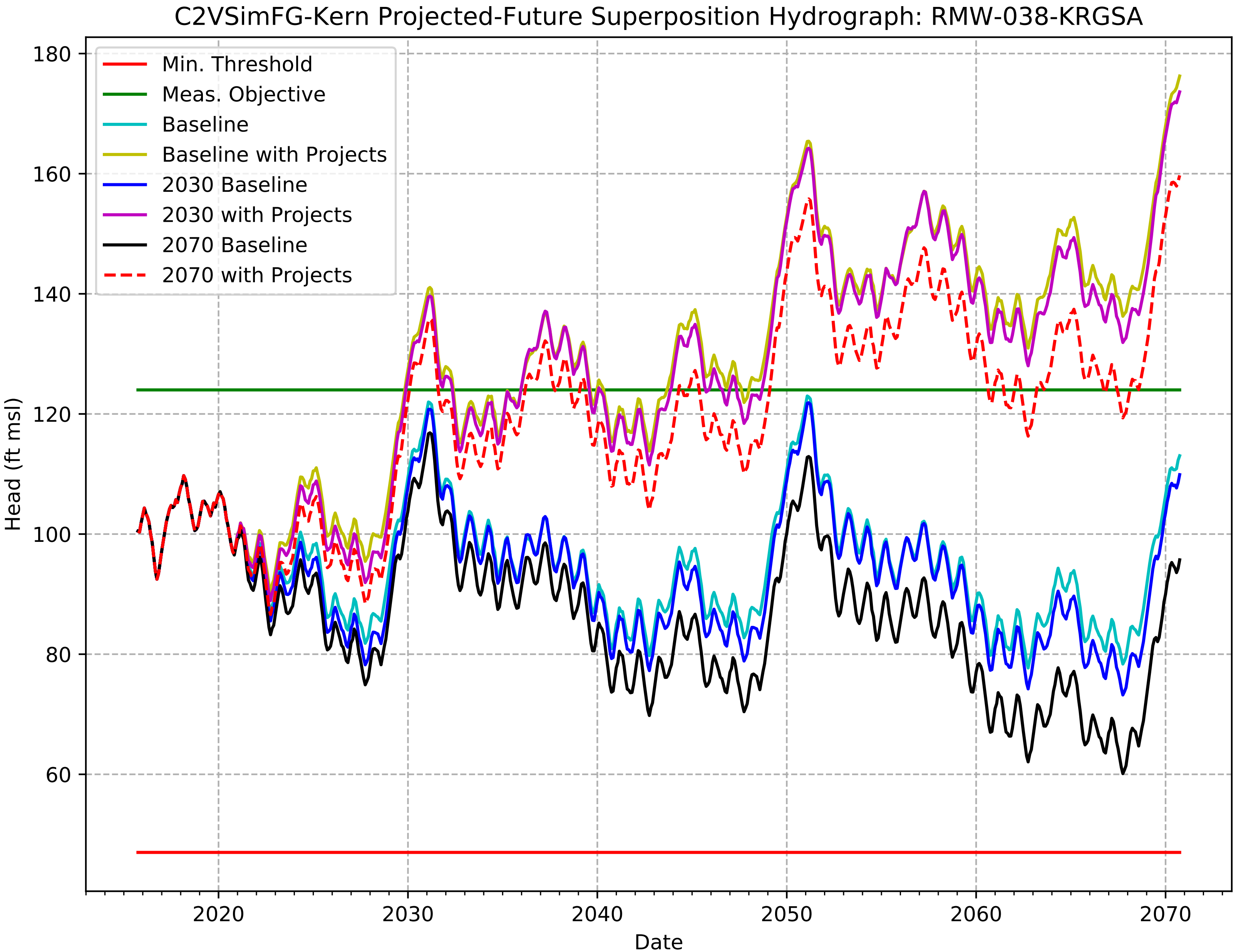

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-032-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
120
140
160
180
200
2020
2030
2040
2050
2060
2070
Date

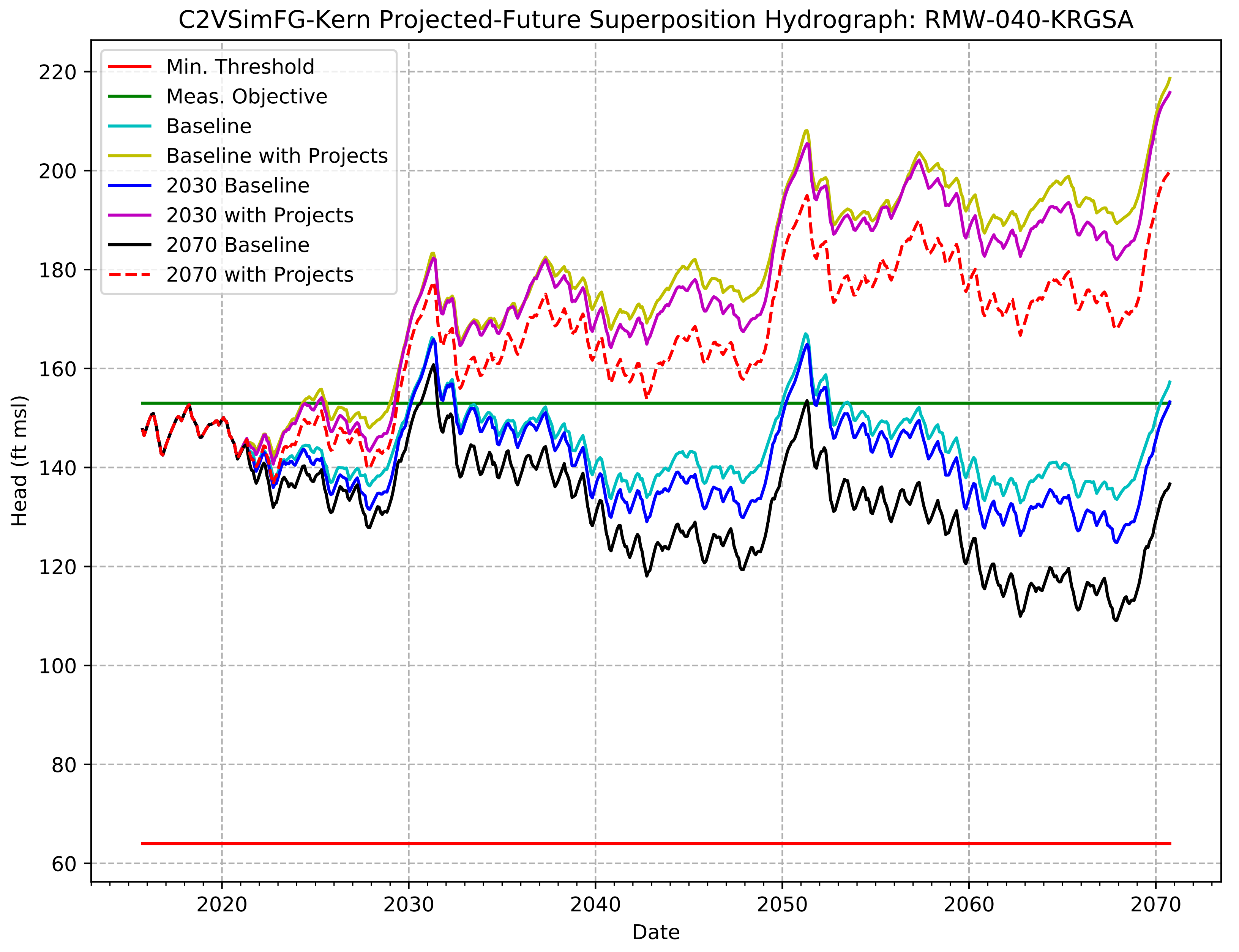

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-034-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
240
220
200
180
160
140
120
100
80
2020
2030
2040
2050
2060
2070
Date

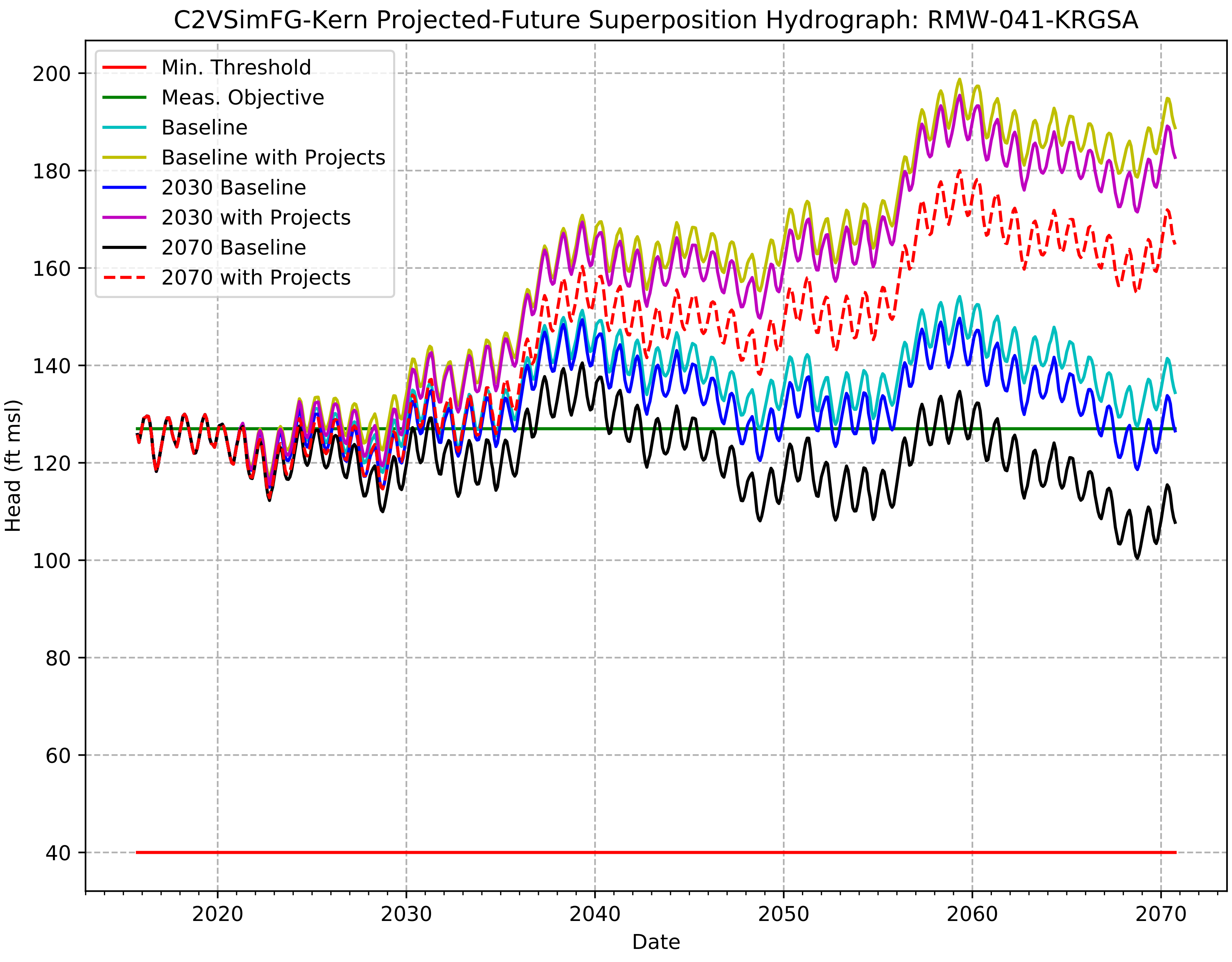

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-035-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
180
160
140
120
100
80
60
40
2020
2030
2040
2050
2060
2070



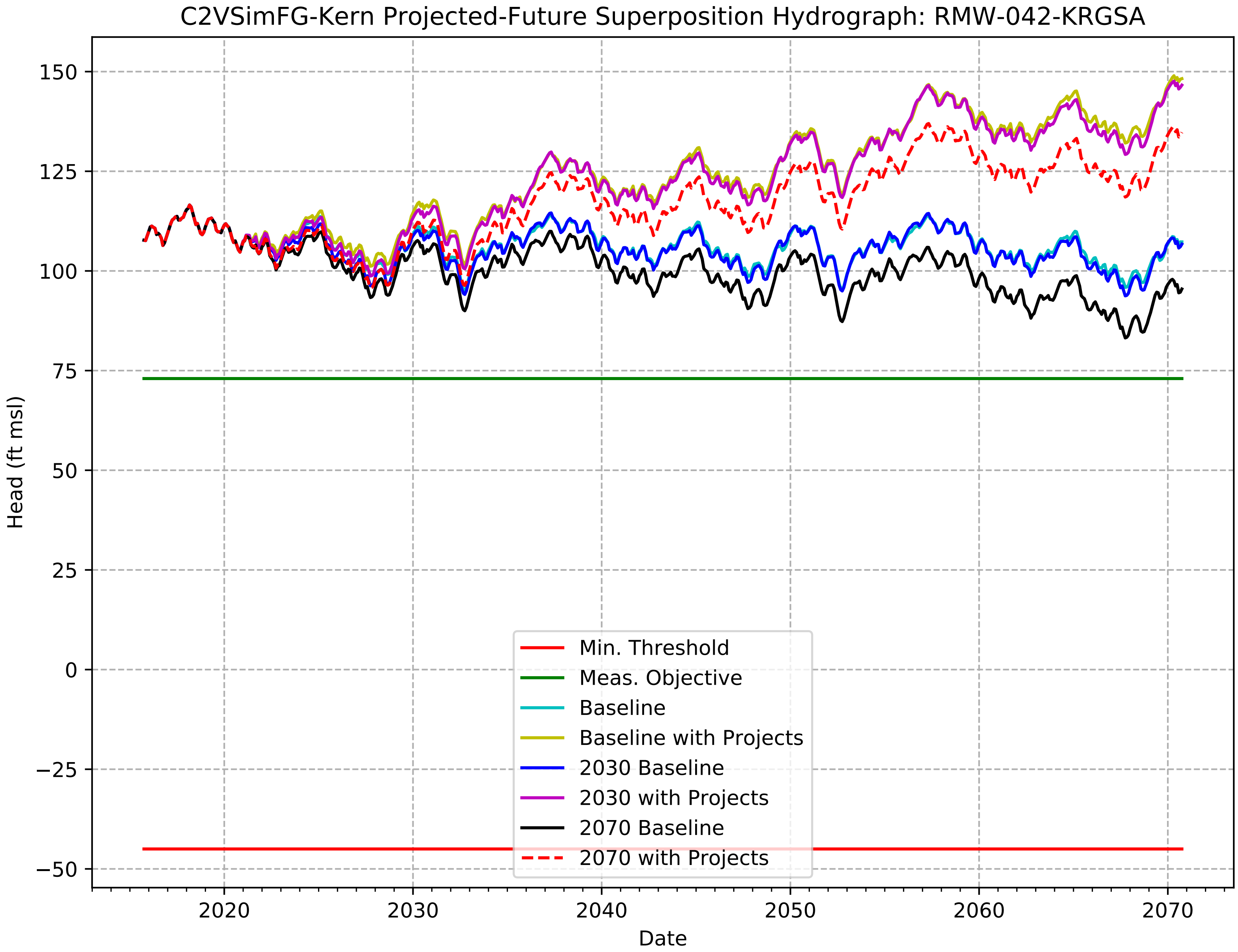
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-037-KRGSA
Head (ft msl)
160
140
120
100
80
60
40
20
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-038-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
180
160
140
120
100
80
60
2020
2030
2040
2050
2060
2070
Date

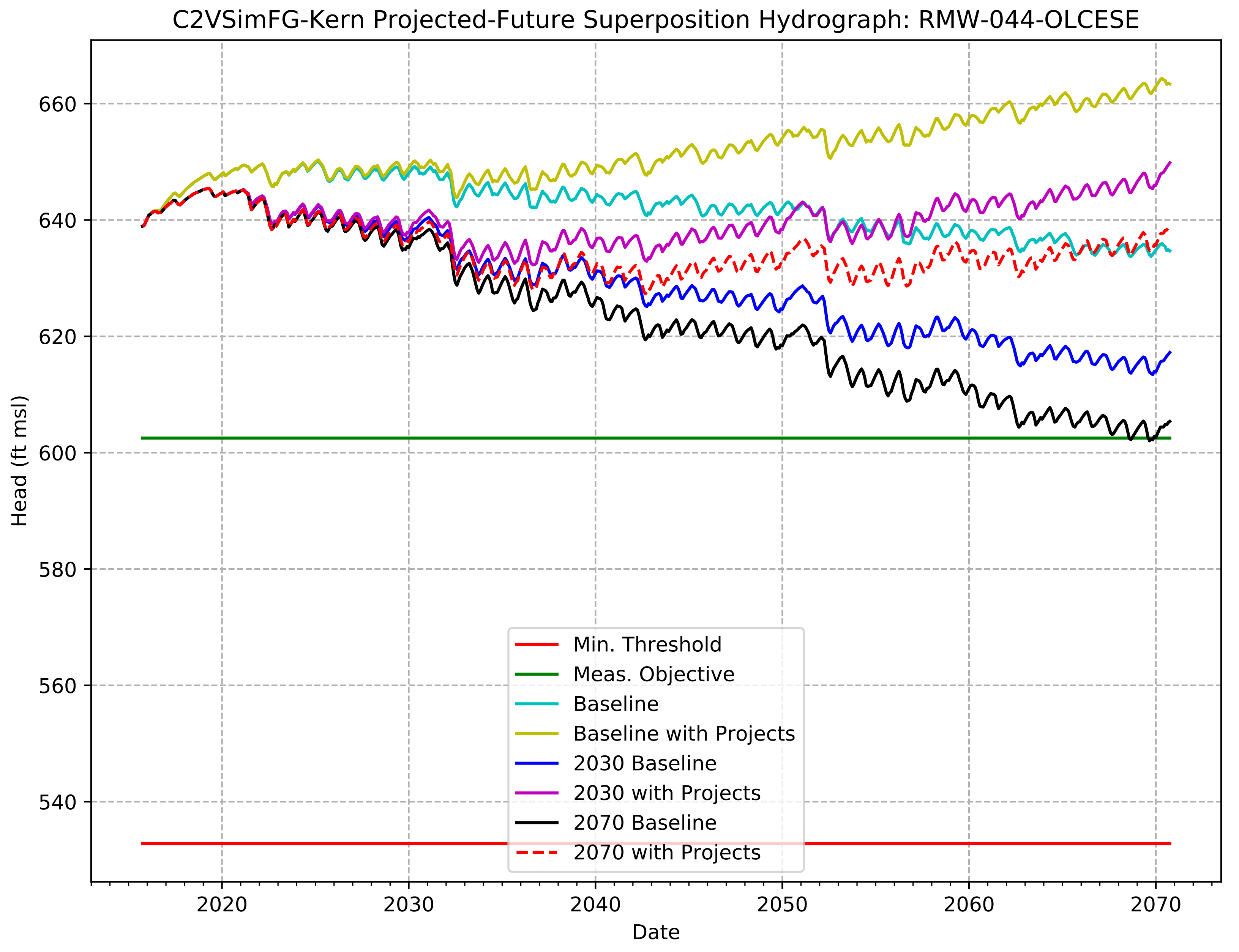

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-040-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
220
200
180
160
140
120
100
80
60
2020
2030
2040
2050
2060
2070
Date



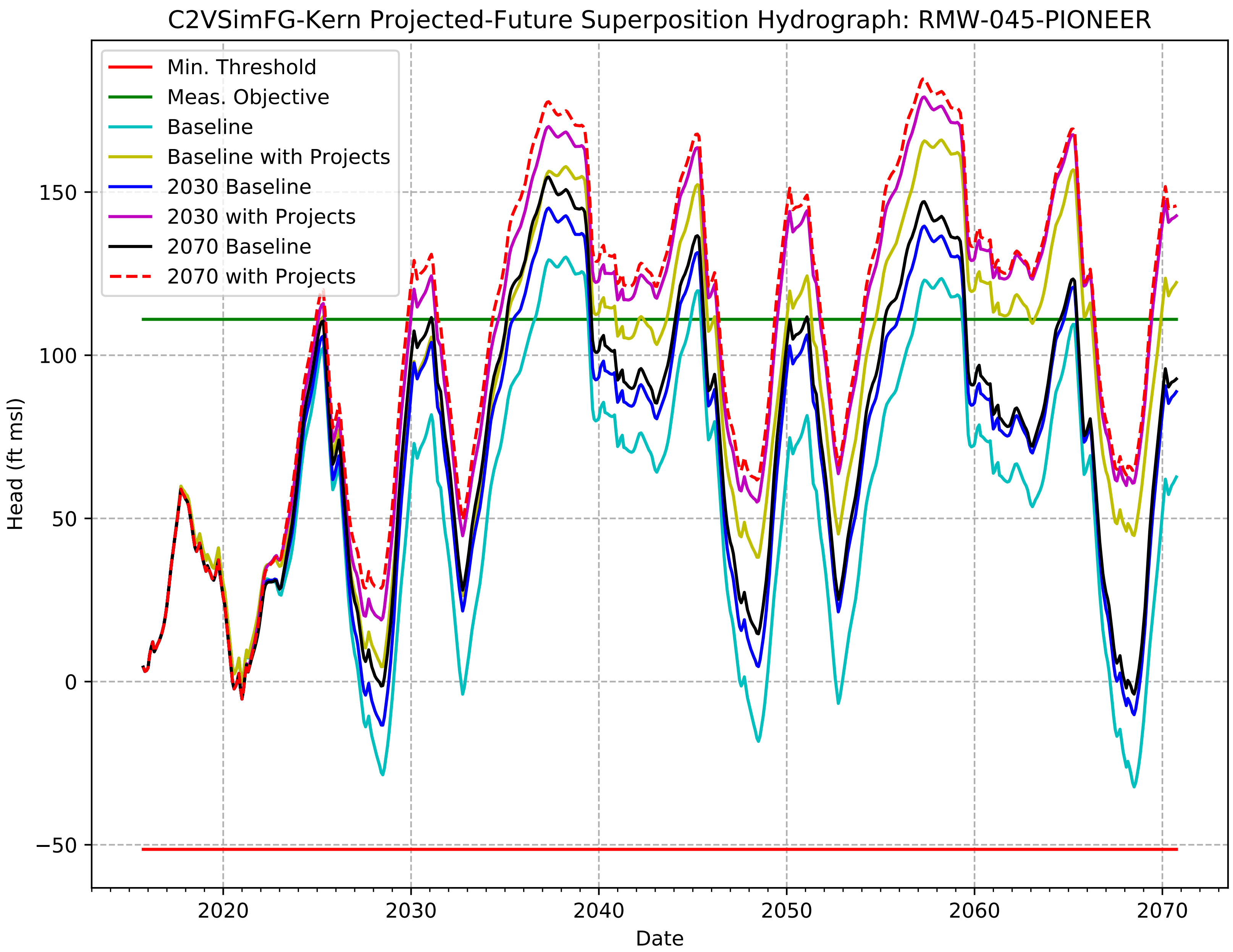
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-041-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
200
180
160
140
120
100
80
60
40
2020
2030
2040
2050
2060
2070

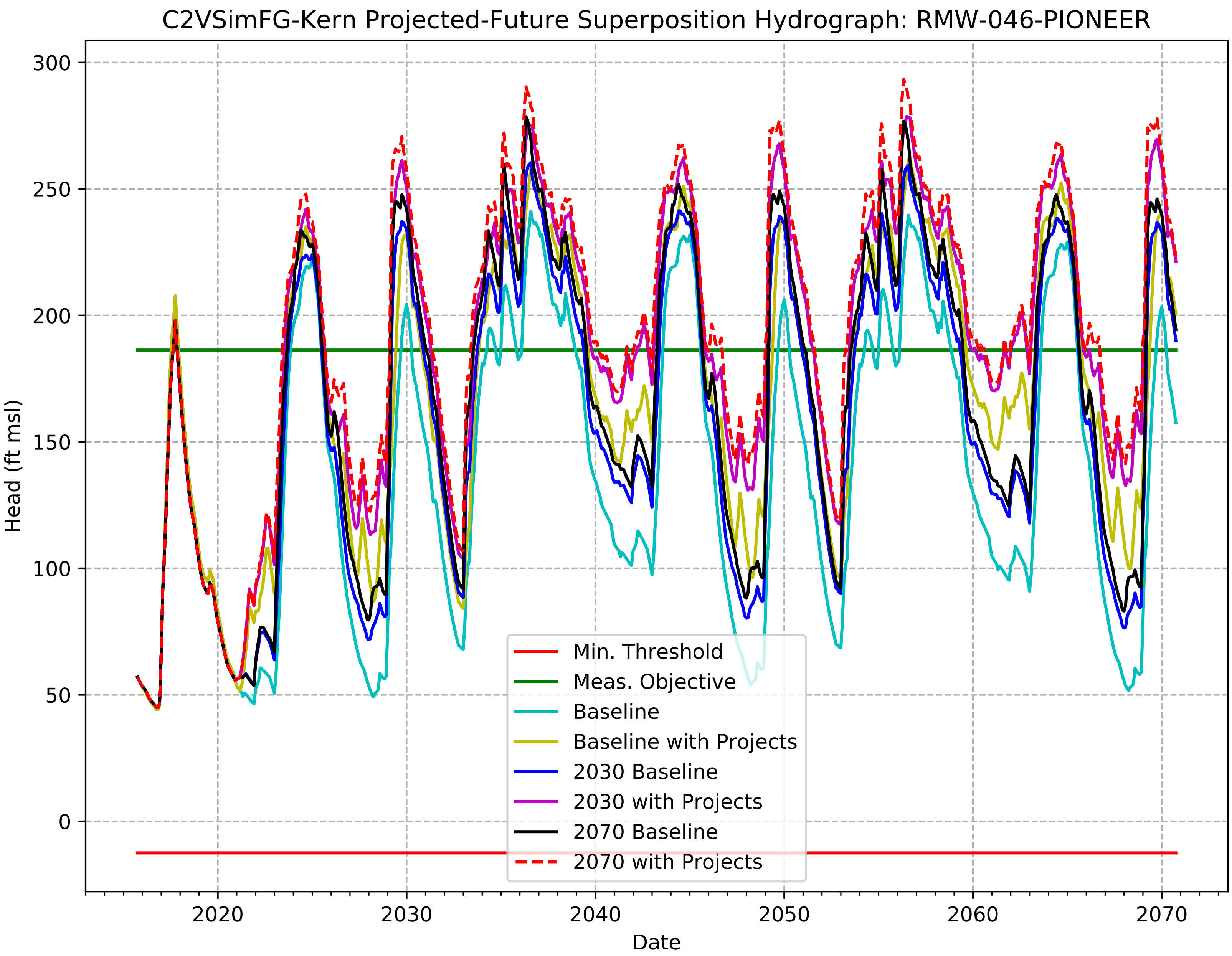


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-042-KRGSA
Head (ft msl)
150
125
100
75
50
25
0
−25
−50
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

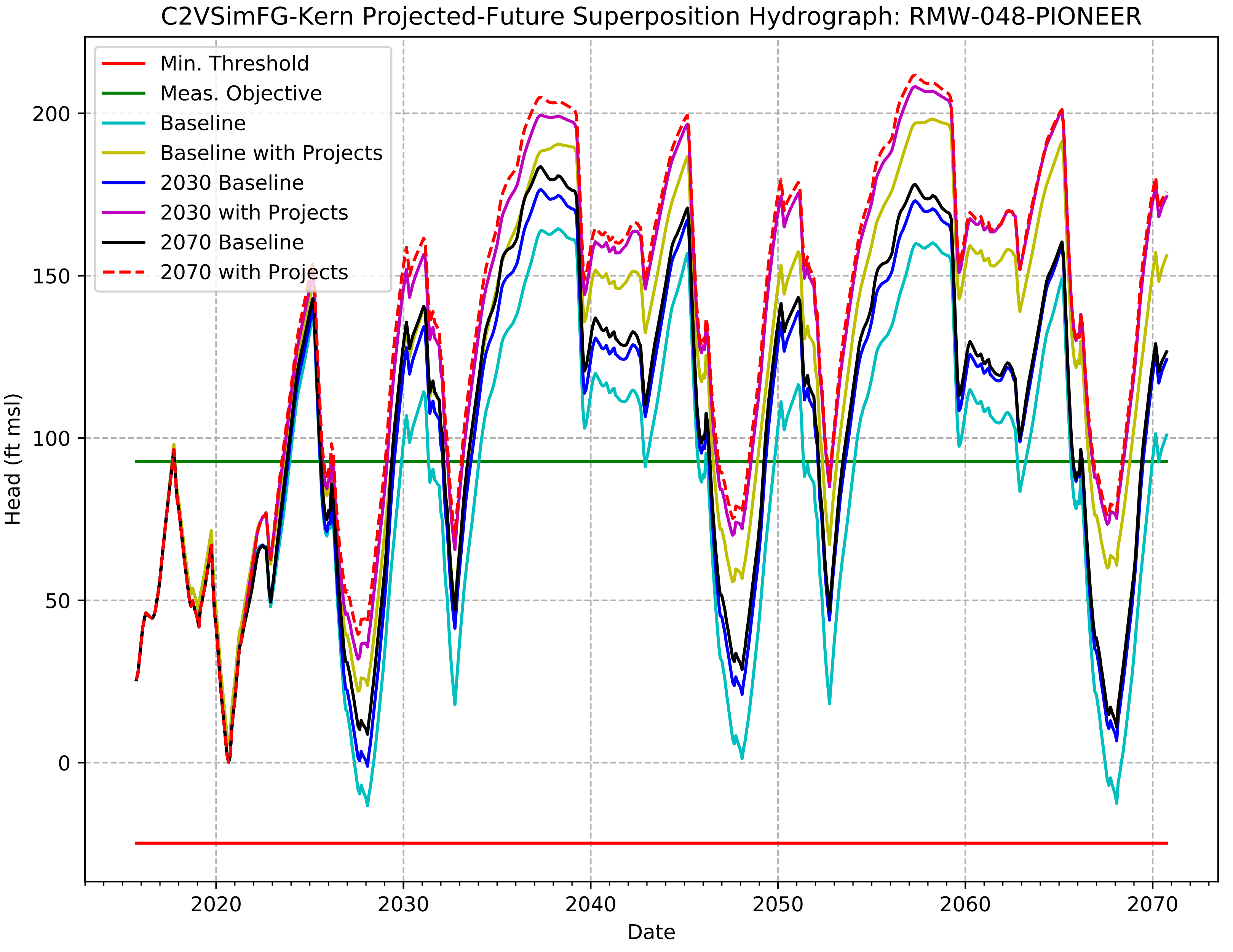


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-044-OLCESE
Head (ft msl)
Date
660
640
620
600
580
560
540
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-045-PIONEER
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
150
100
50
0
−50
2020
2030
2040
2050
2060
2070
Date



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-046-PIONEER
Head (ft msl)
0
50
100
150
200
250
300
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-048-PIONEER
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
0
50
100
150
200
2020
2030
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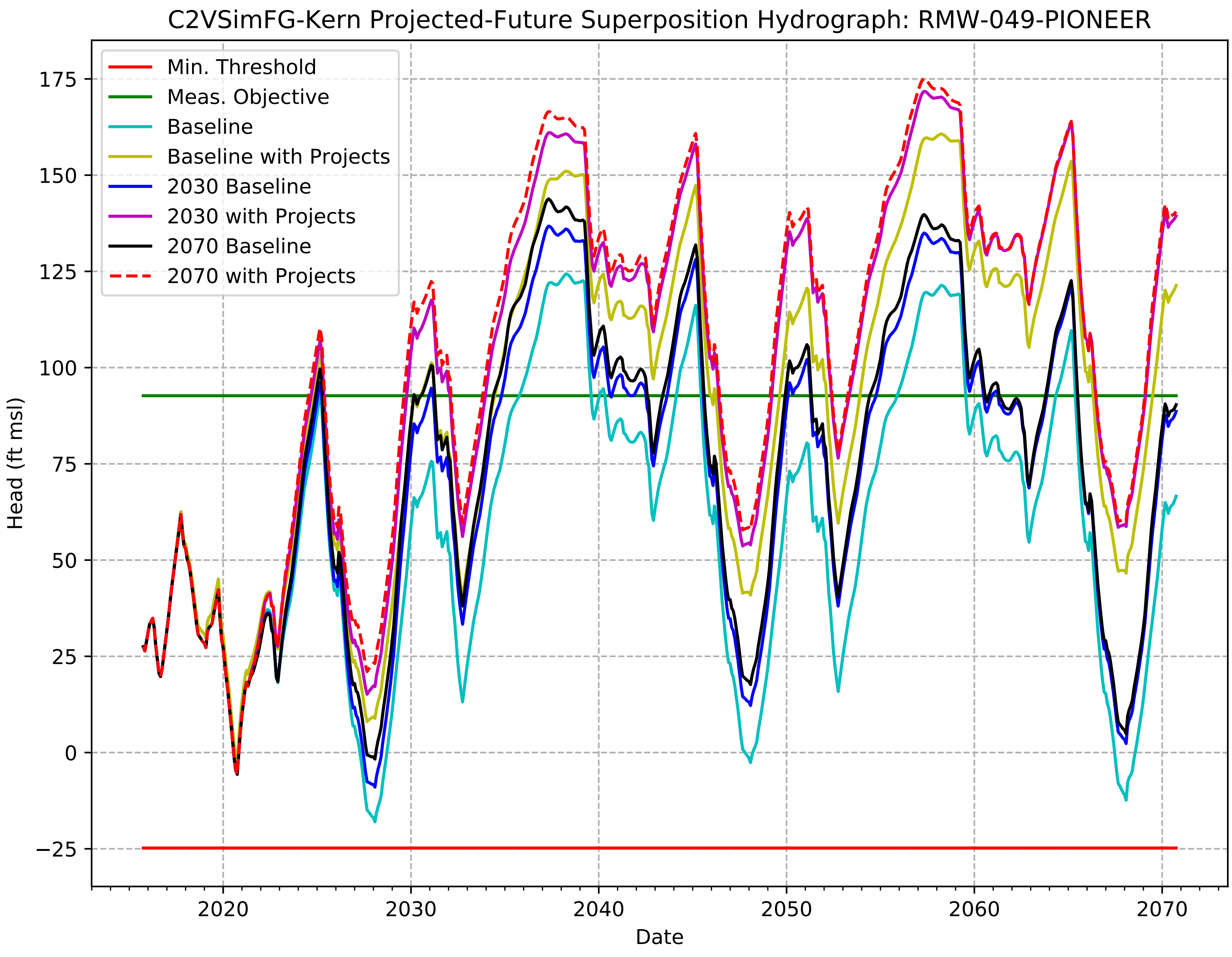
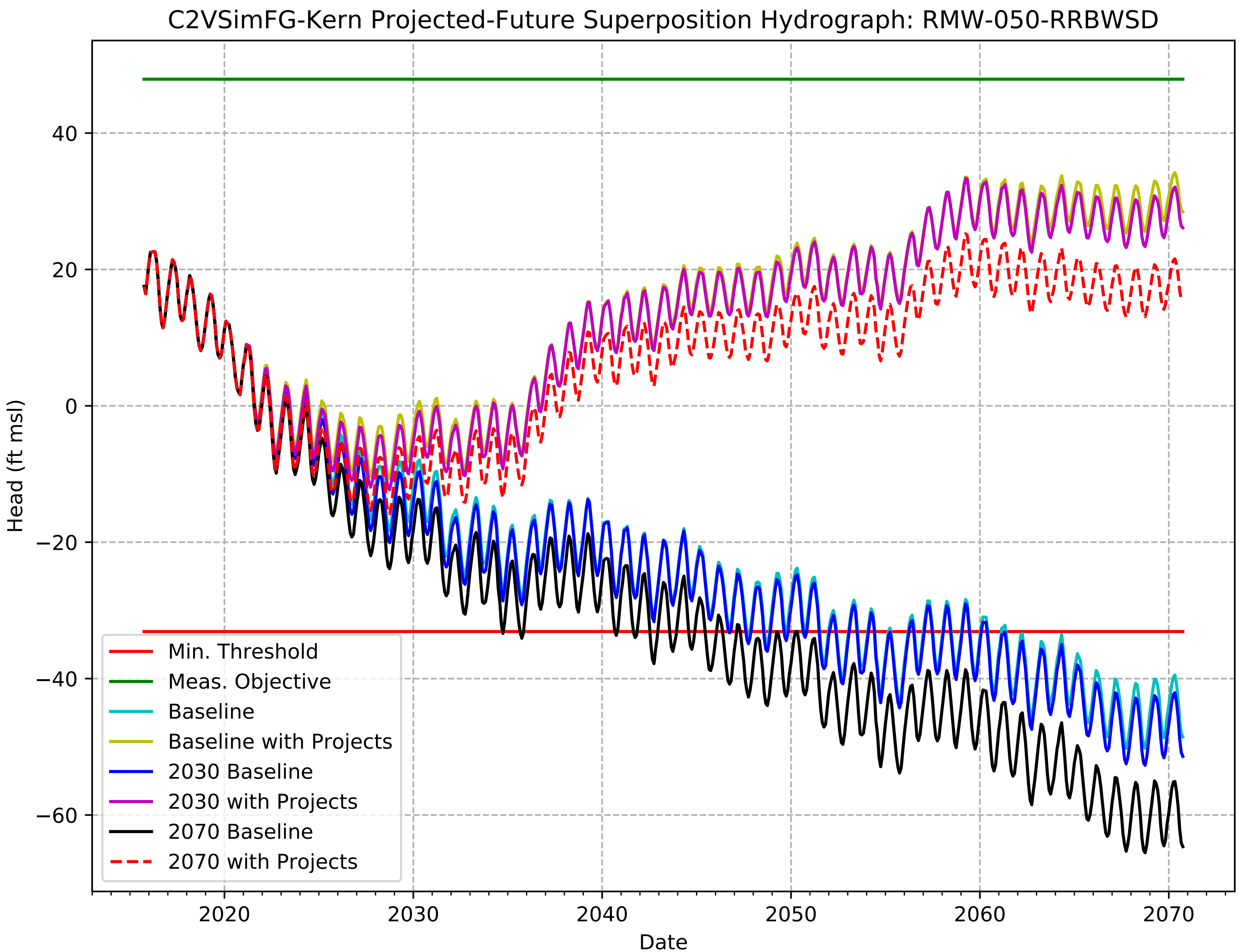
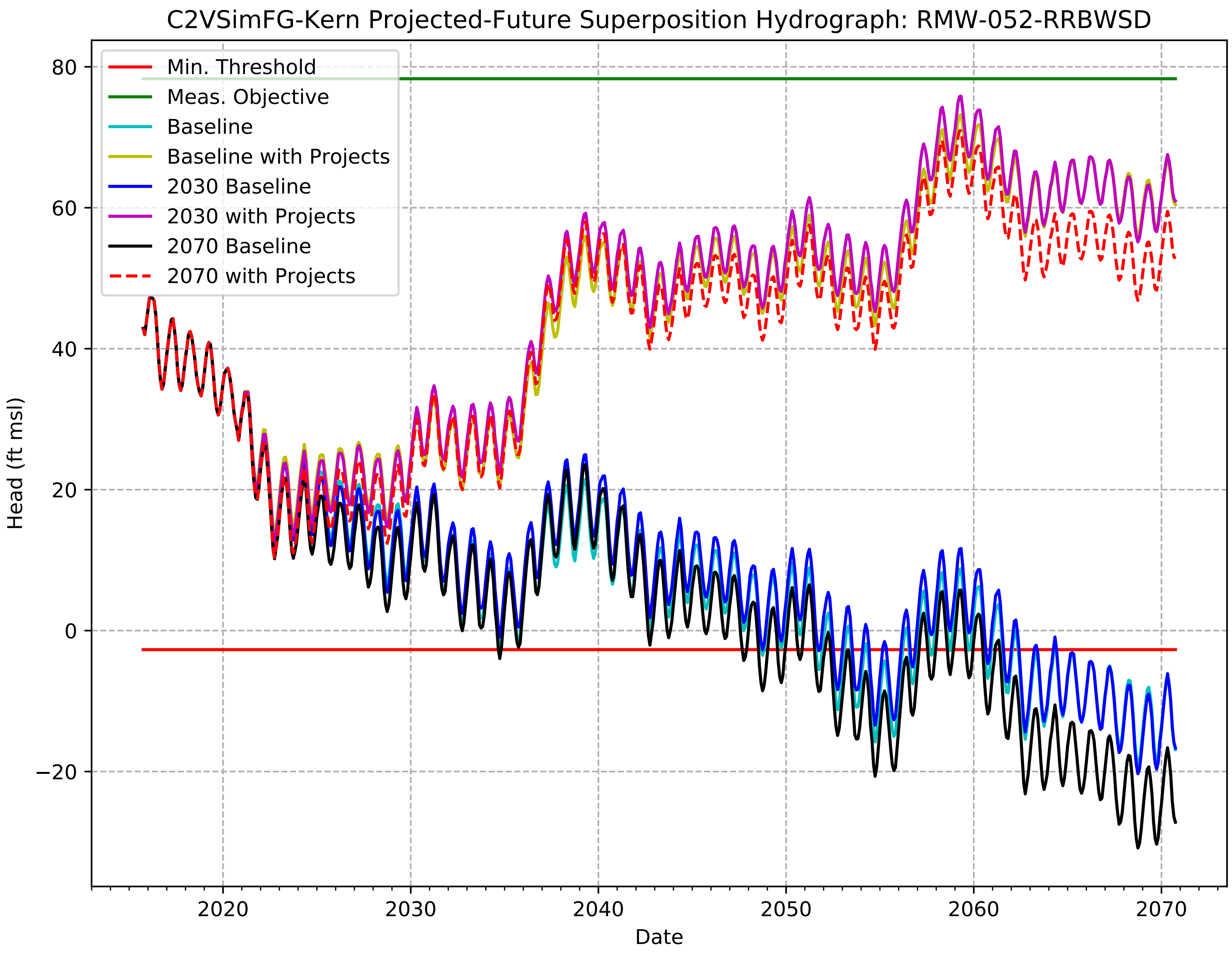
2060
2070


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-049-PIONEER
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
175
150
125
100
75
50
25
0
−25
2020
2030
2040
2050
2060
2070



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-050-RRBWSD
Head (ft msl)
40
20
0
−20
−40
−60
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-052-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
80
60
40
20
0
−20
2020
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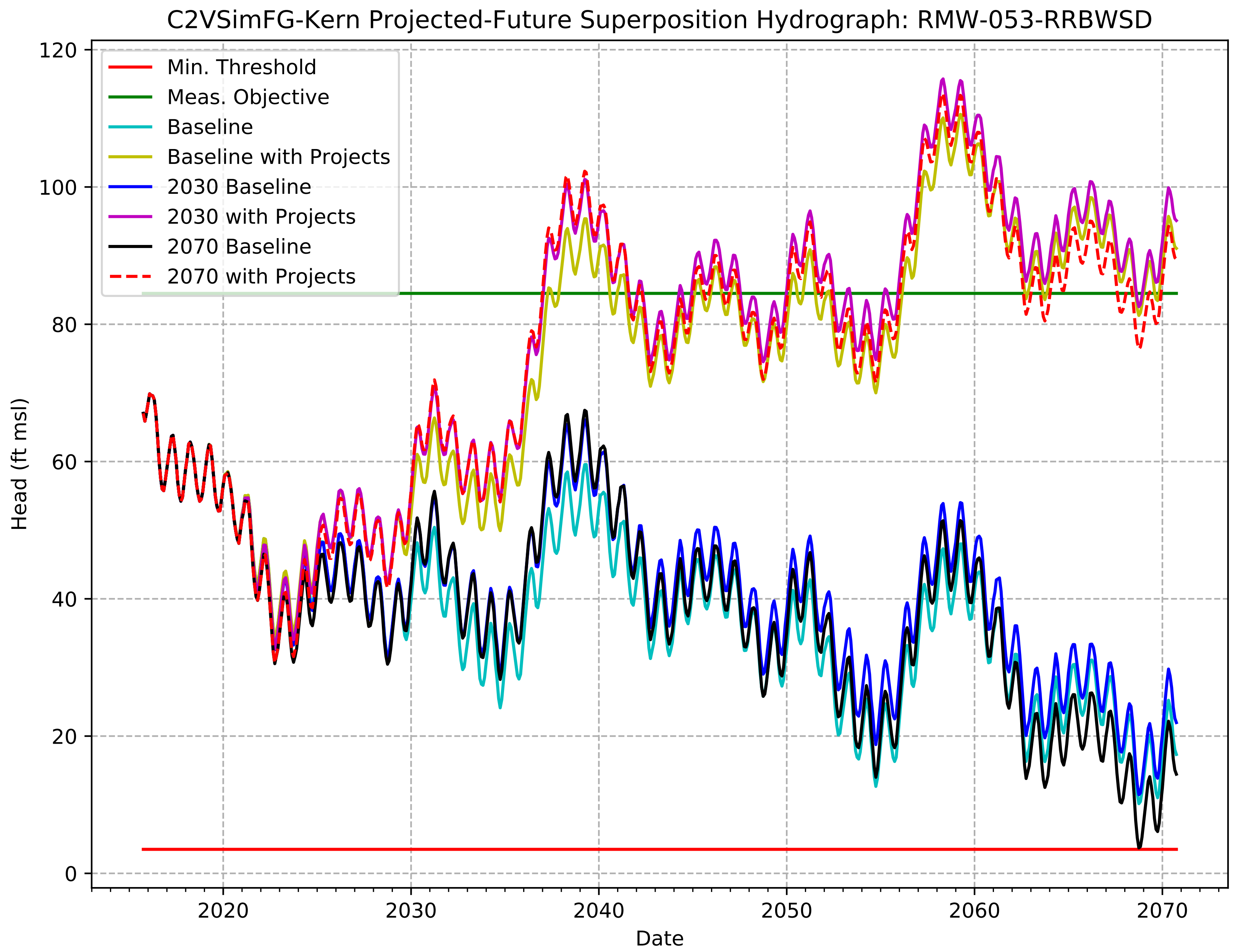
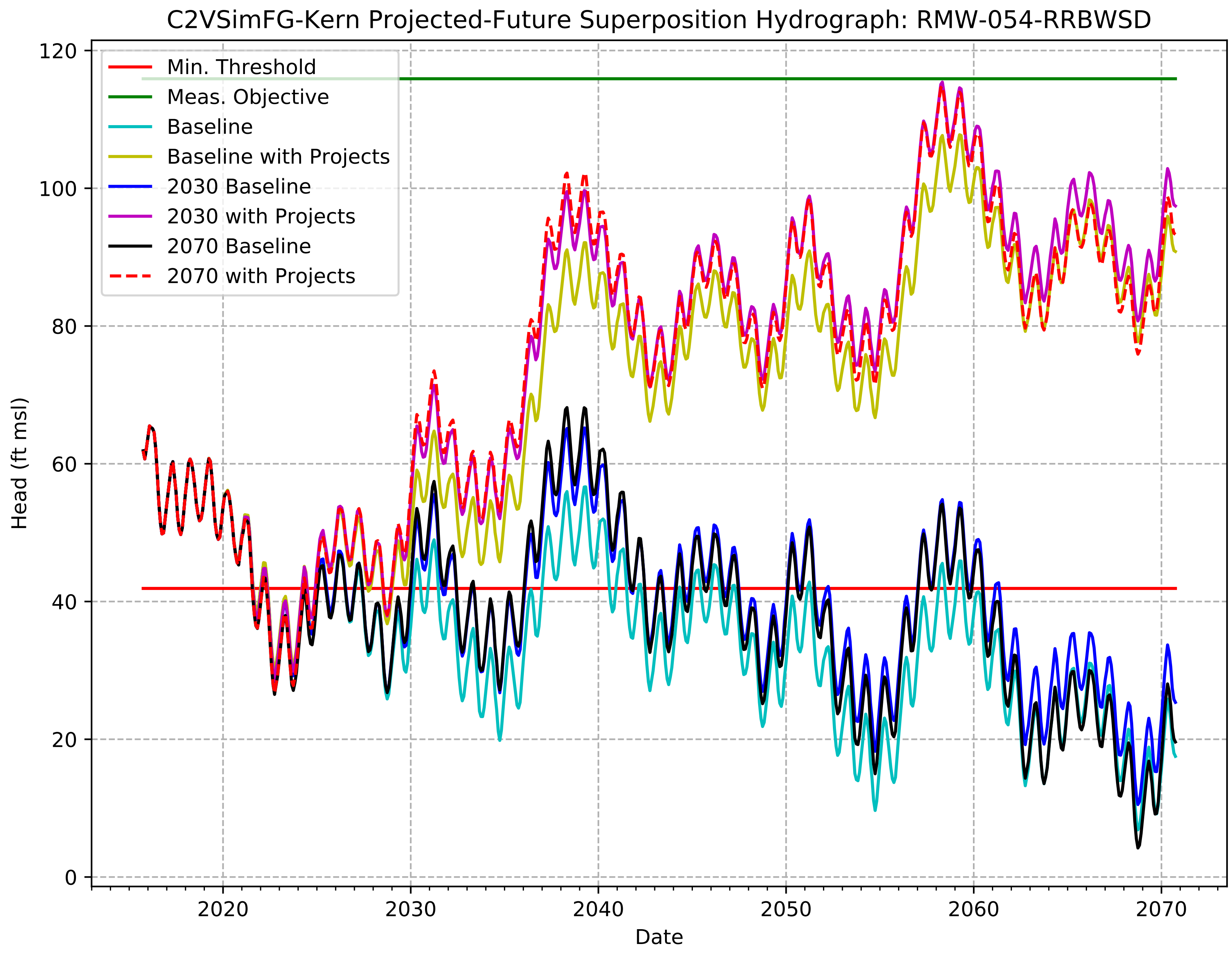
2070


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-053-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
0
20
40
60
80
100
120
2020
2030
2040
2050
2060
2070



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-054-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
0
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40
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80
100
120
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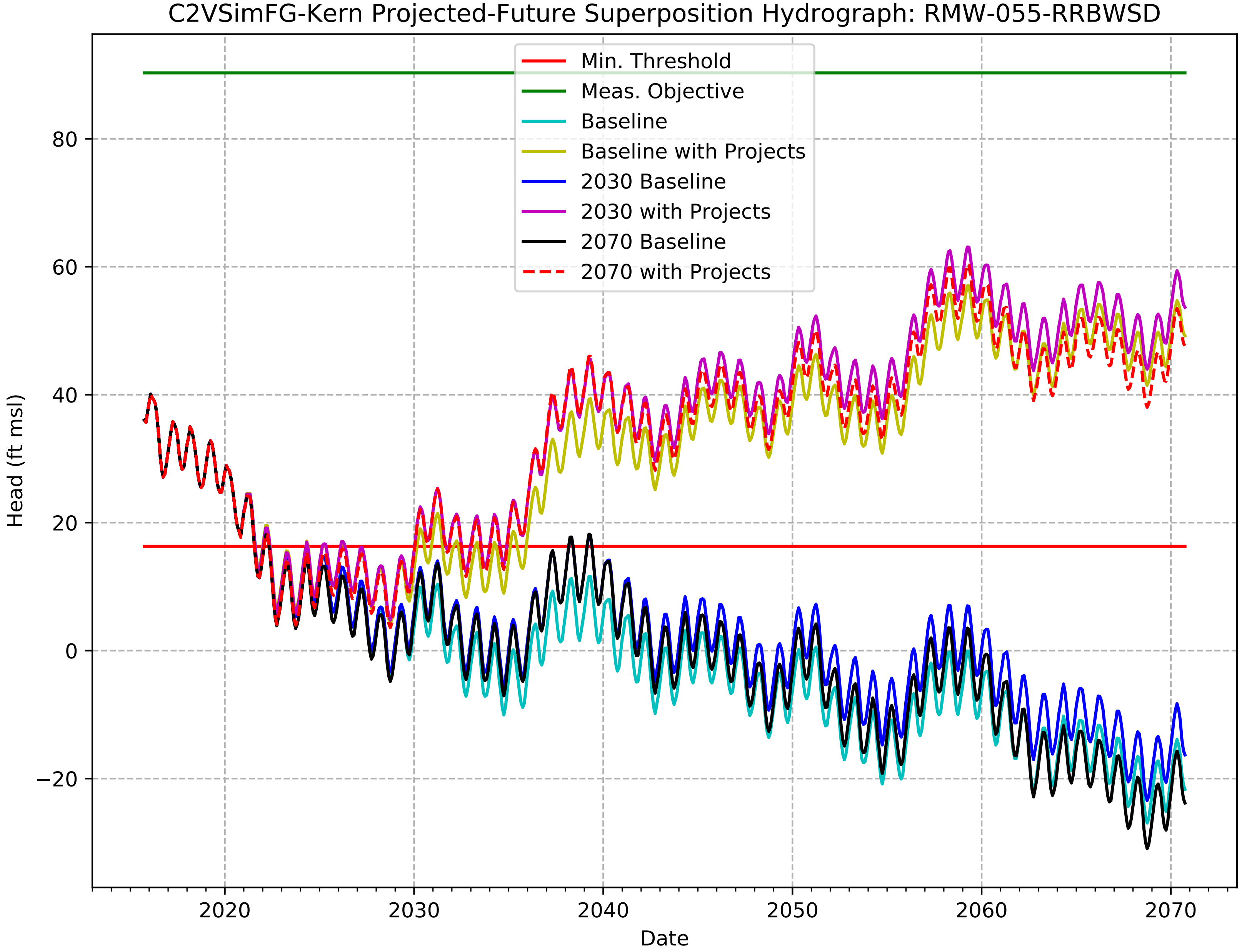
2050
2060
2070



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-055-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
80
60
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−20
2020
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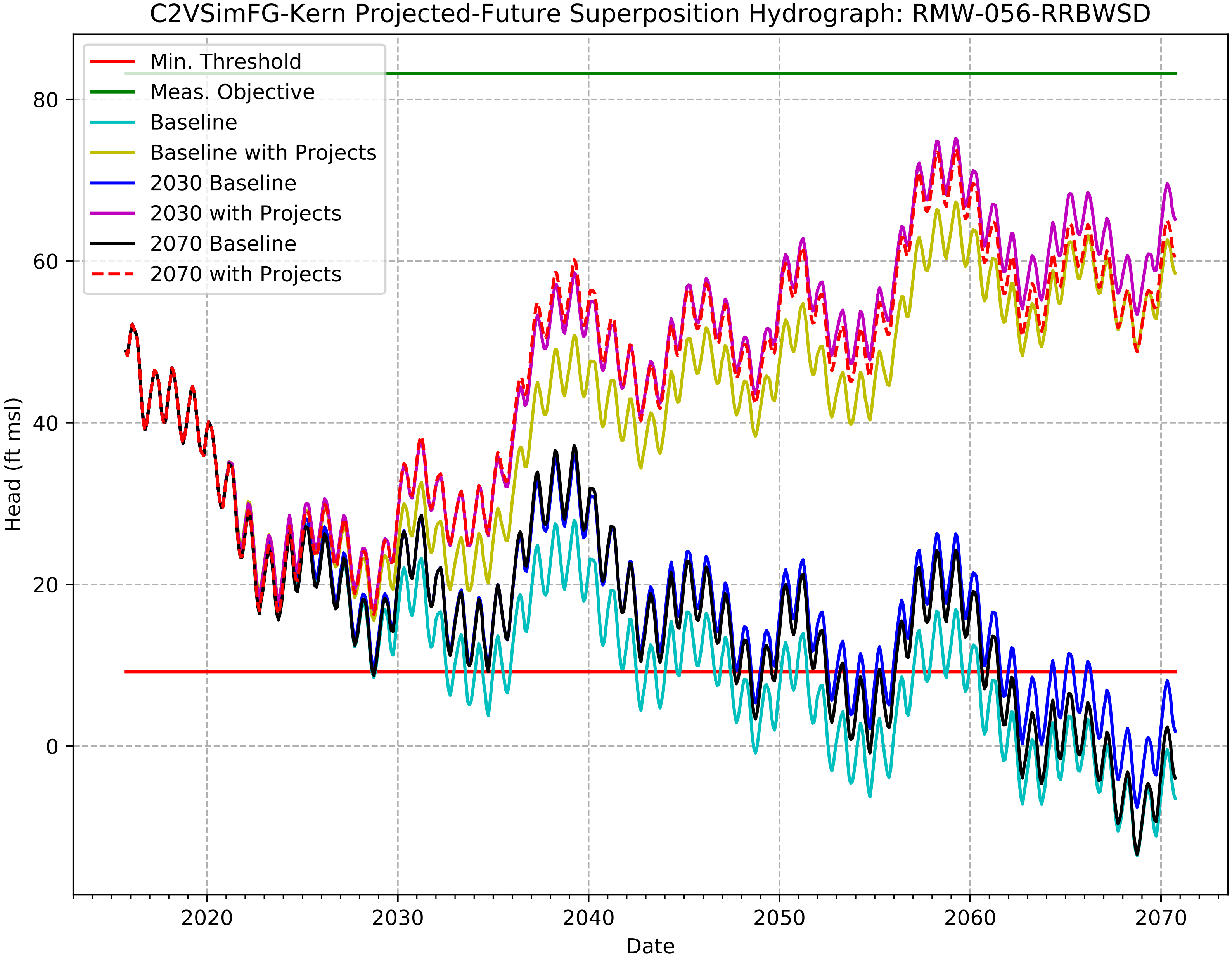
Date



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-056-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
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2070 with Projects
Head (ft msl)
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2020
2030
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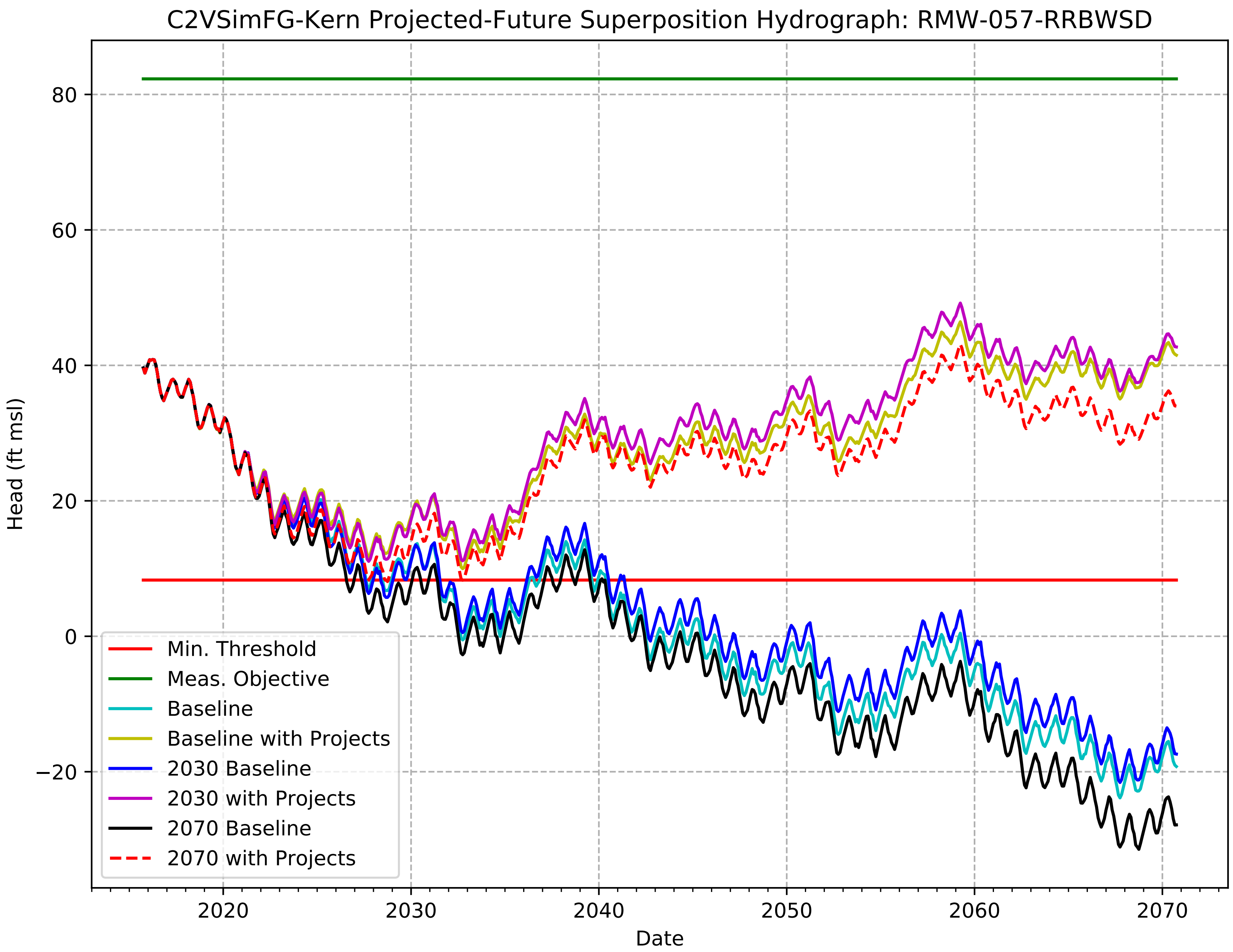
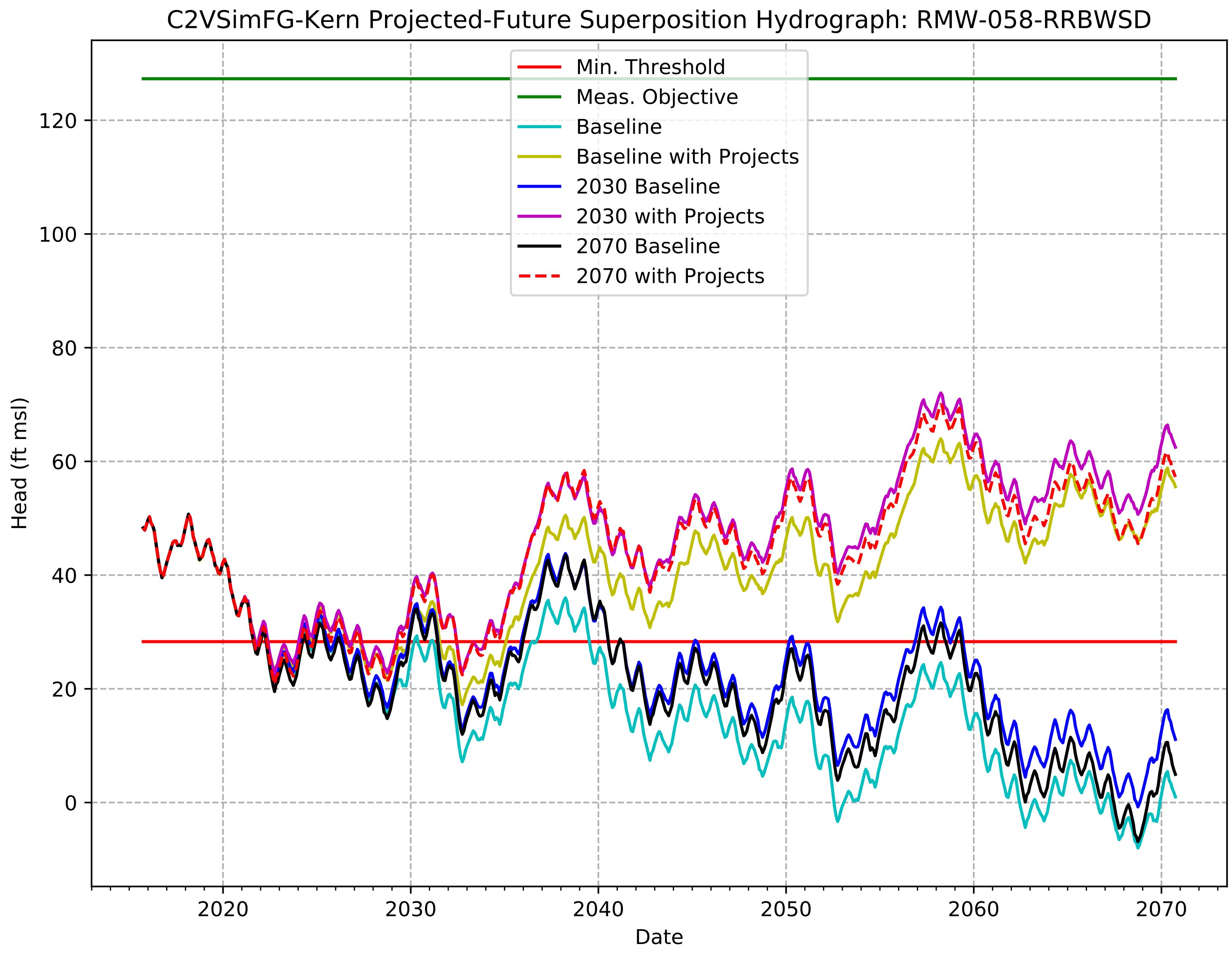
Date



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-057-RRBWSD
Head (ft msl)
80
60
40
20
0
−20
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-058-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
120
100
80
60
40
20
0
2020
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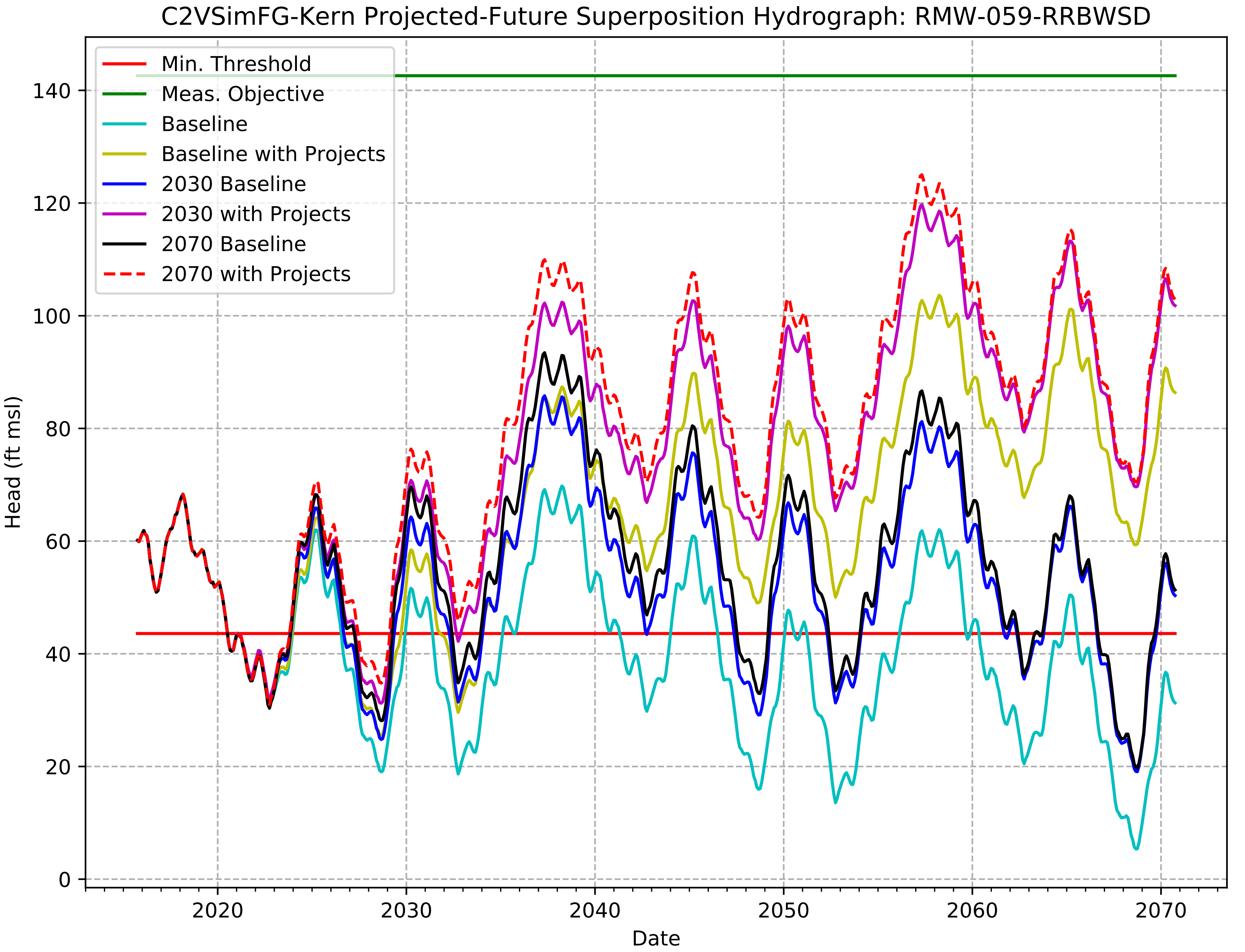
2050
2060
2070
Date


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-059-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
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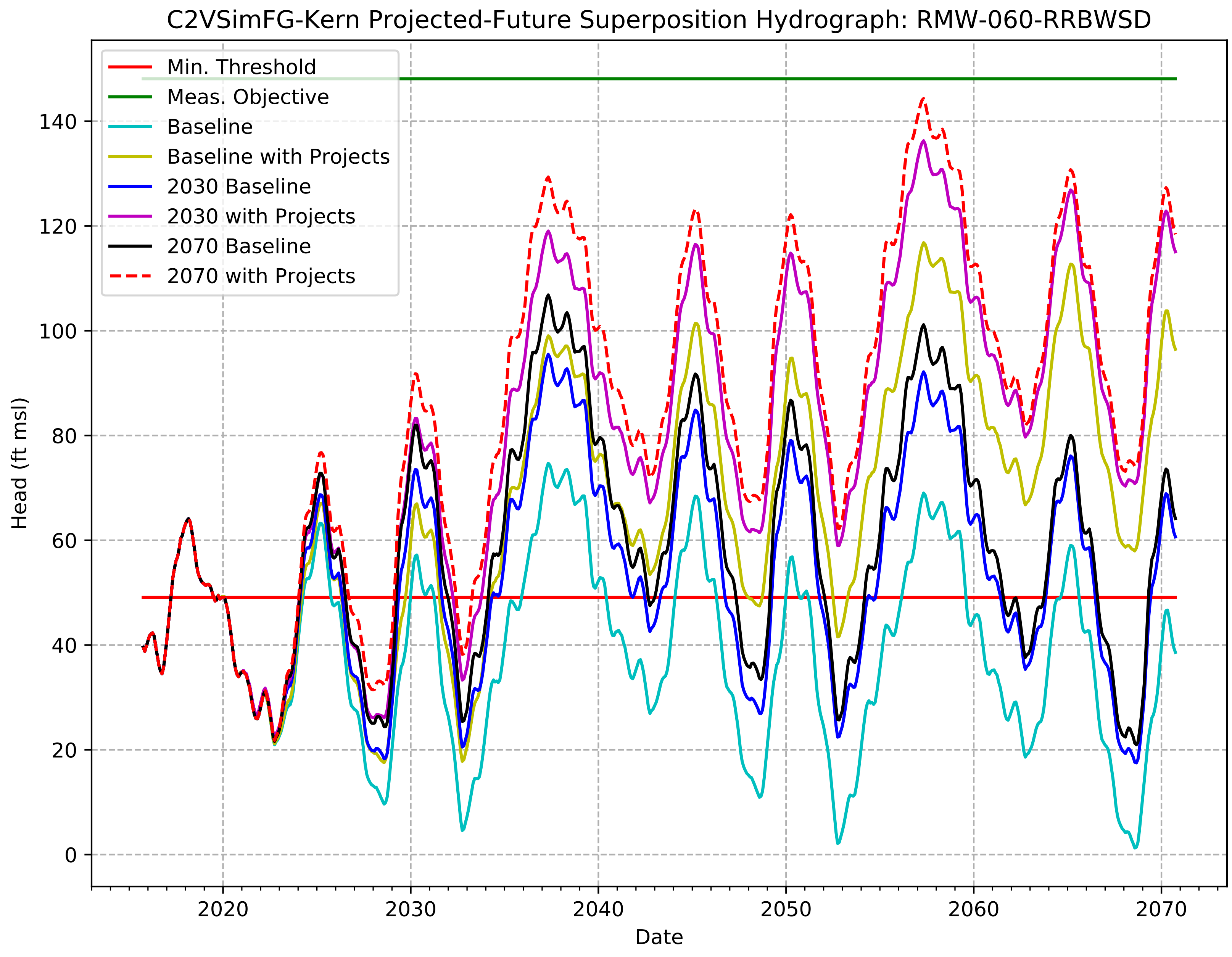
2050
2060
2070
Date



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-060-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
0
20
40
60
80
100
120
140
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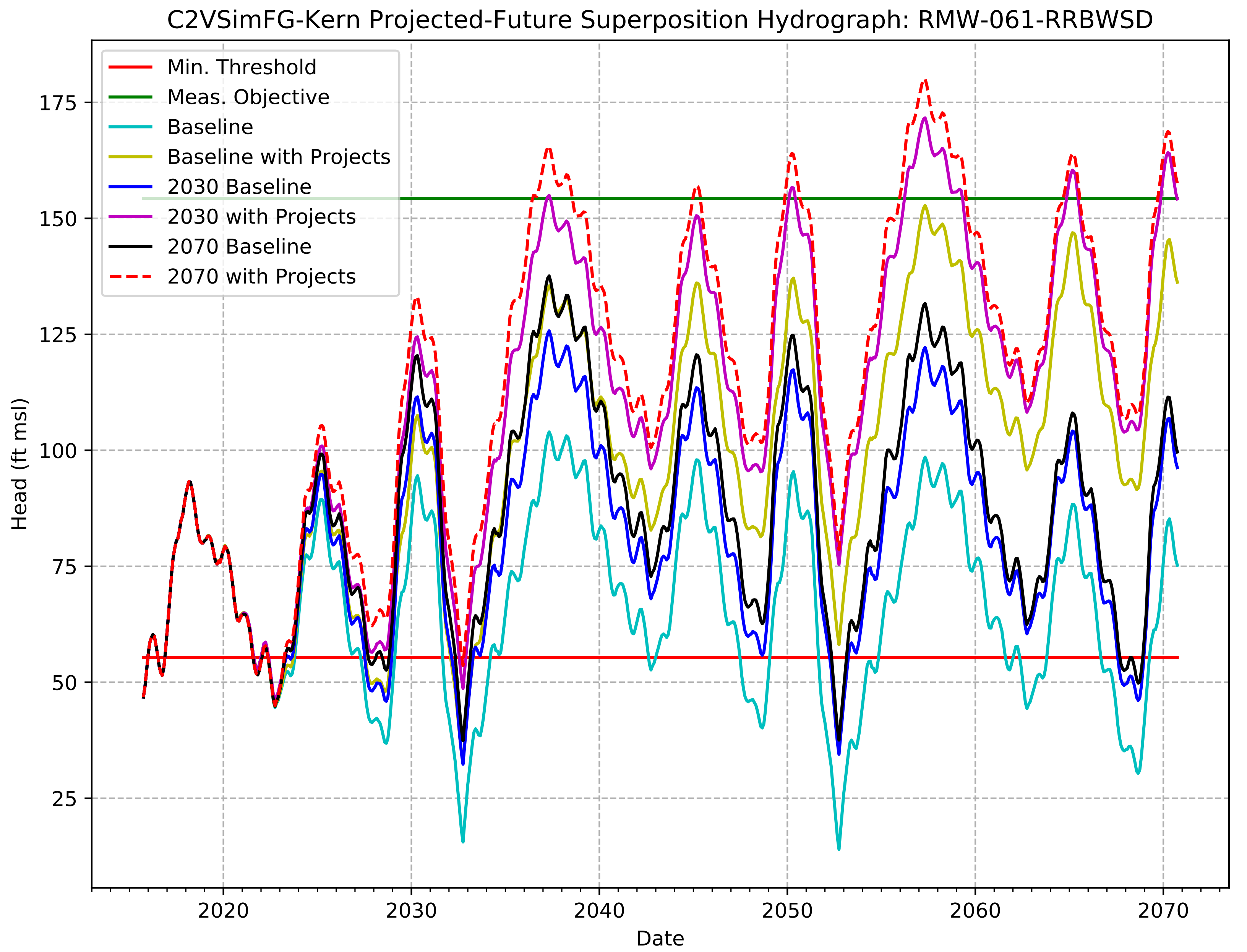
2050
2060
2070
Date



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-061-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
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150
125
100
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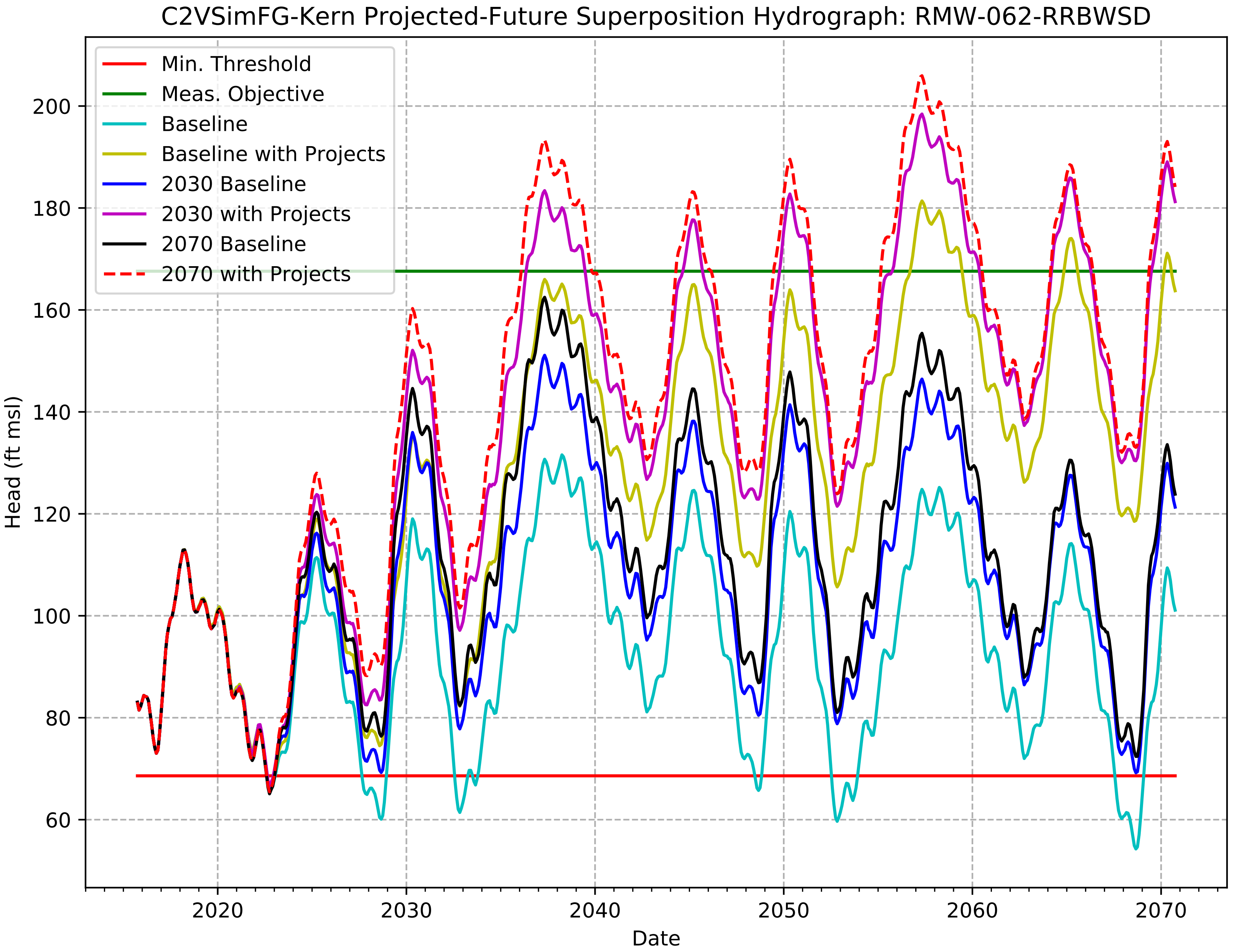
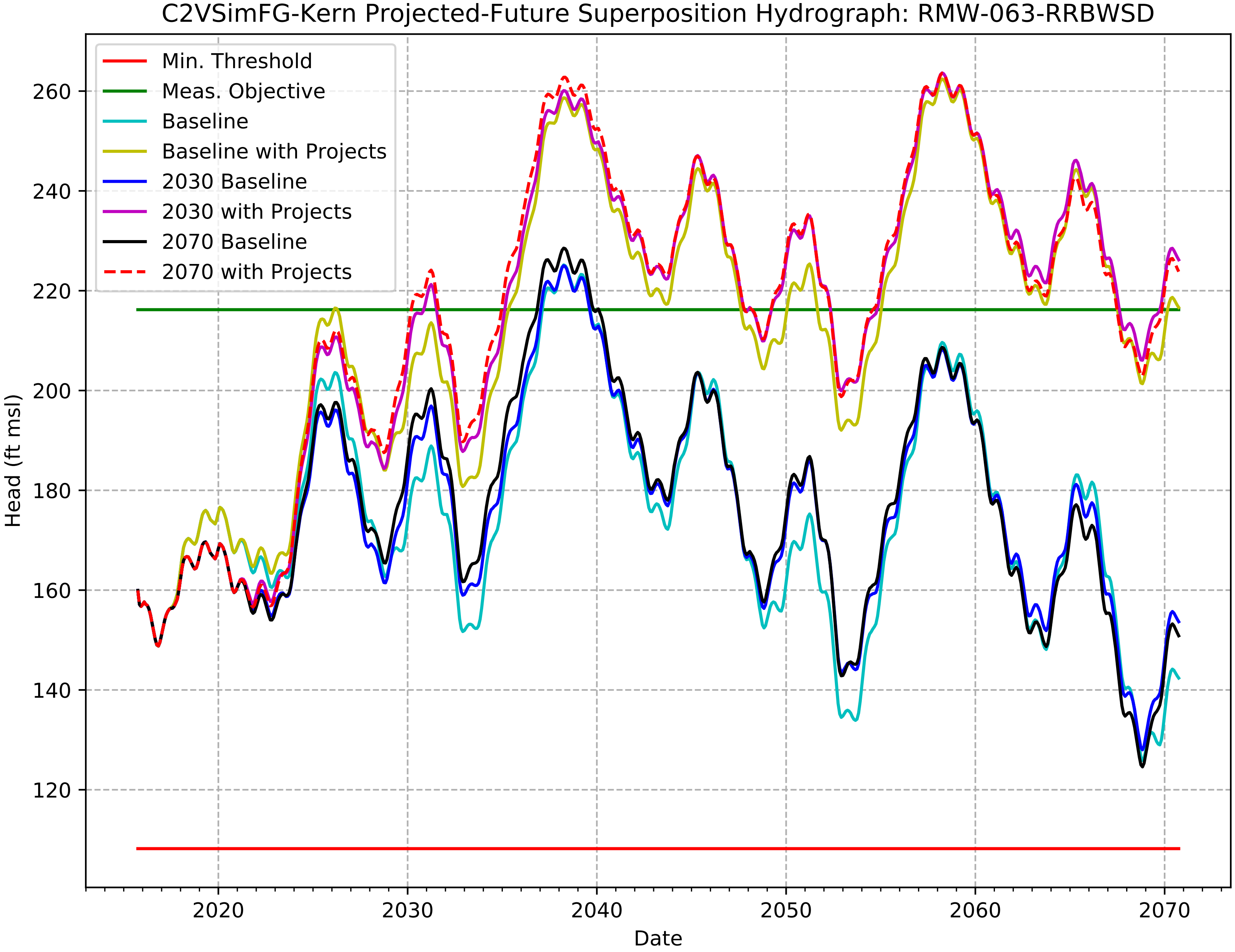
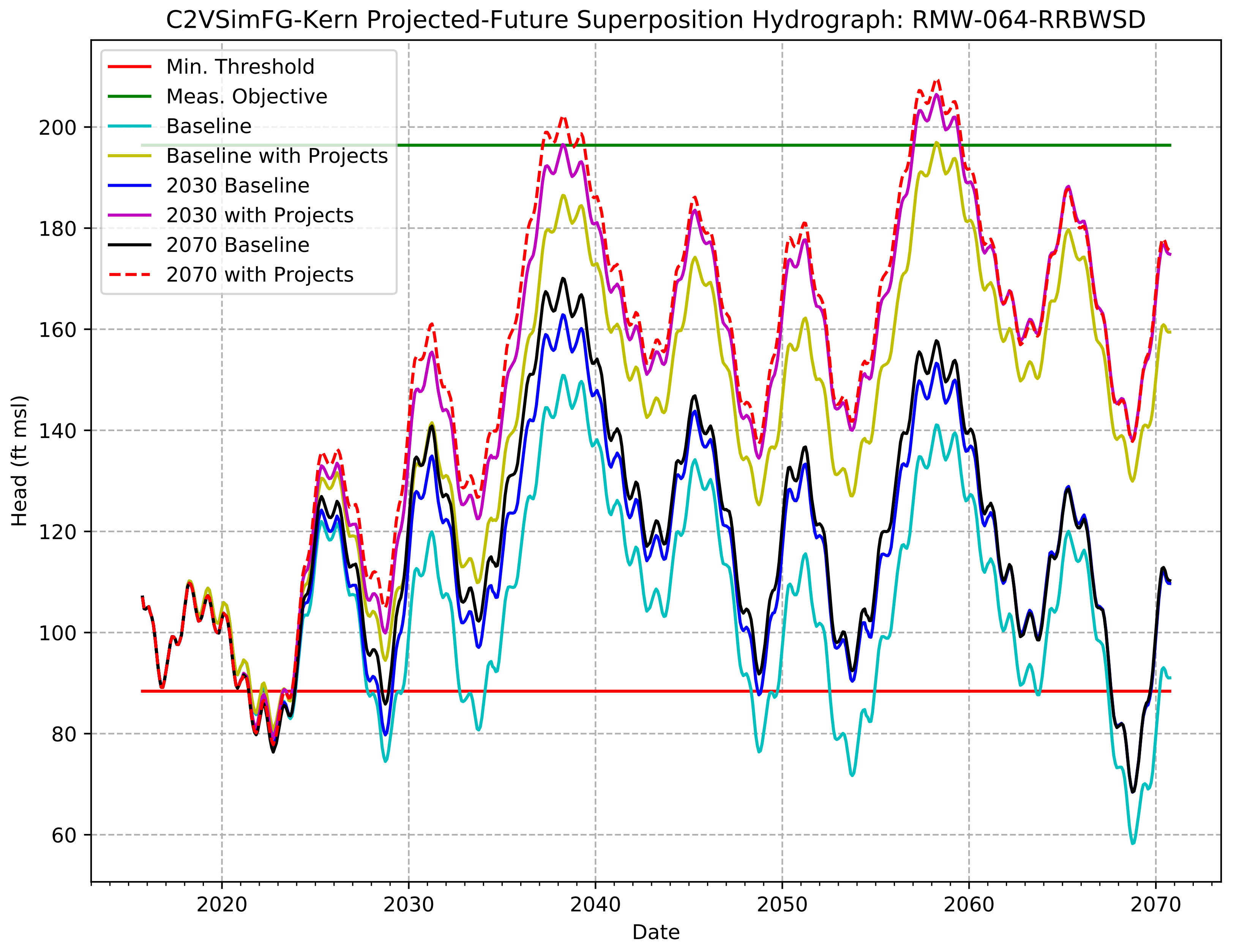
2050
2060
2070
Date

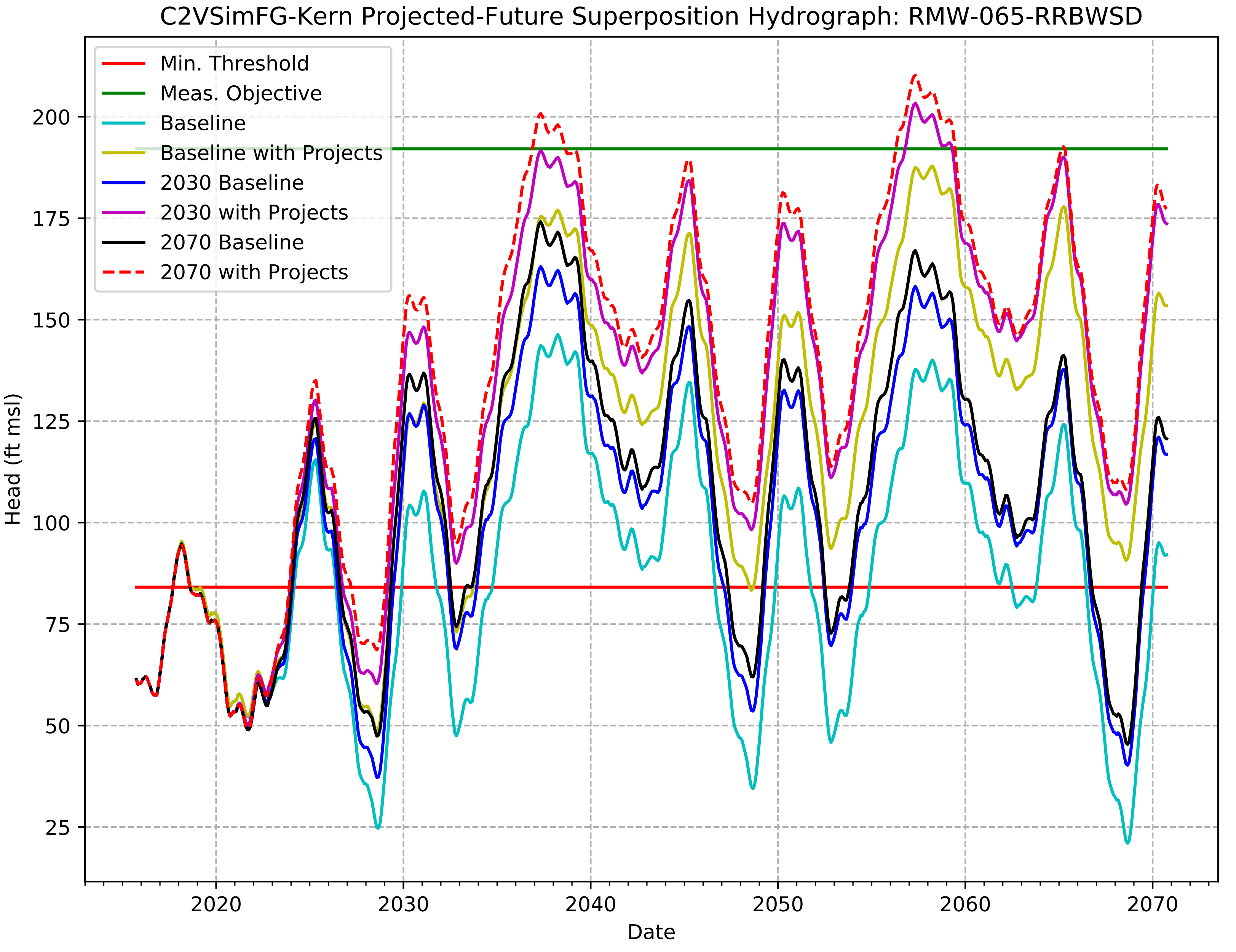


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-062-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
200
180
160
140
120
100
80
60
2020
2030
2040
2050
2060
2070
Date



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-063-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
260
240
220
200
180
160
140
120
2020
2030
2040
2050
2060
2070
Date


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-064-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
60
80
100
120
140
160
180
200
2020
2030
2040
2050
2060
2070


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-065-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
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175
150
125
100
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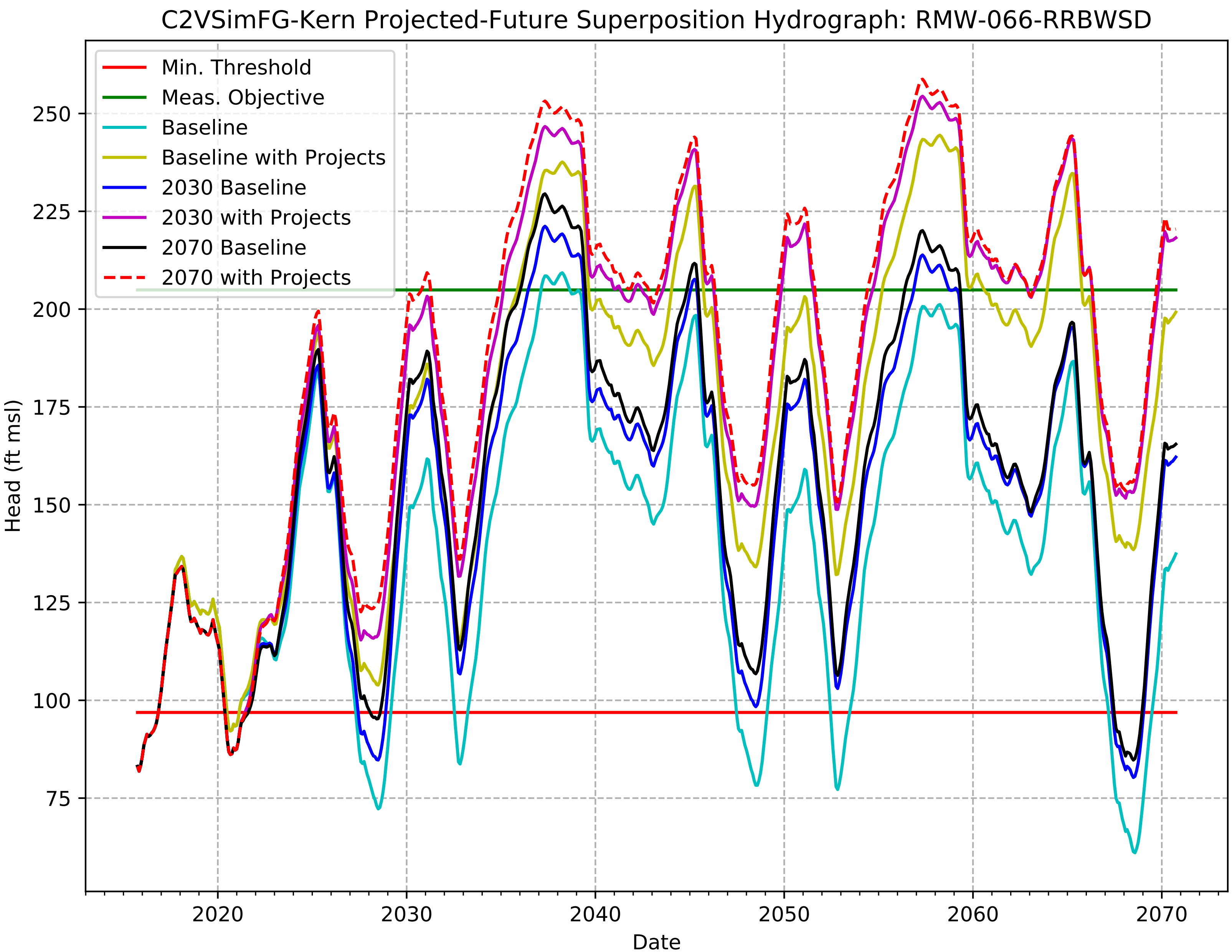
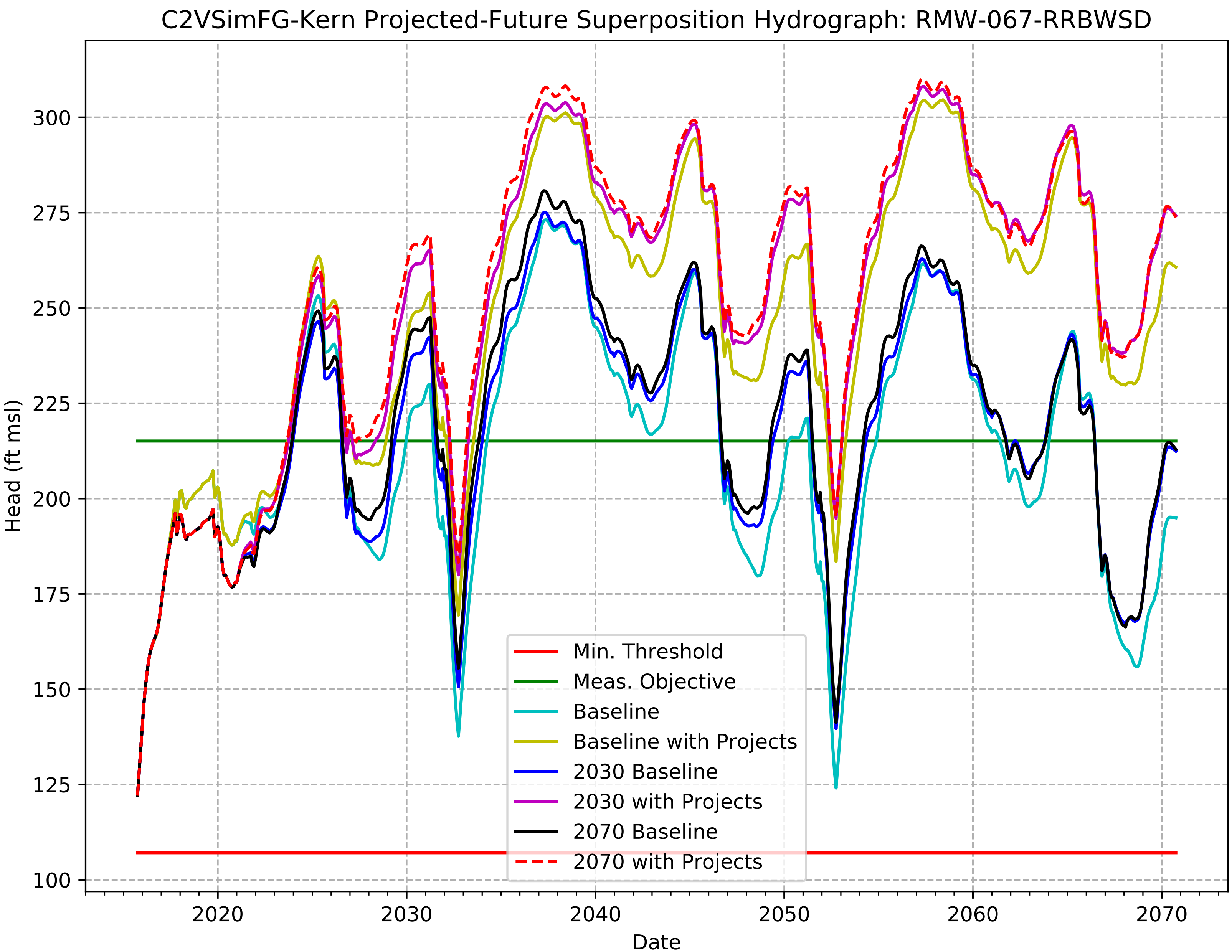
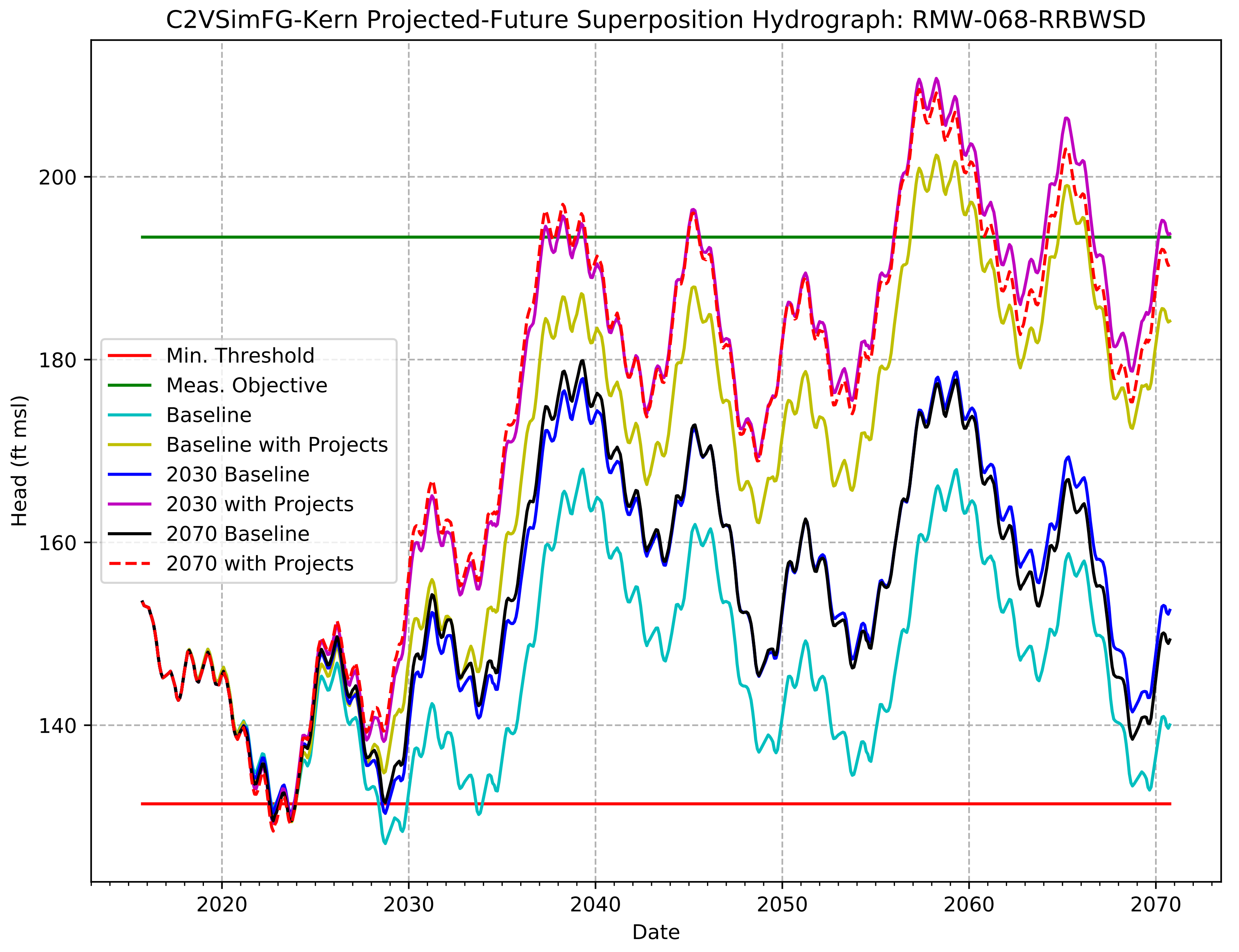
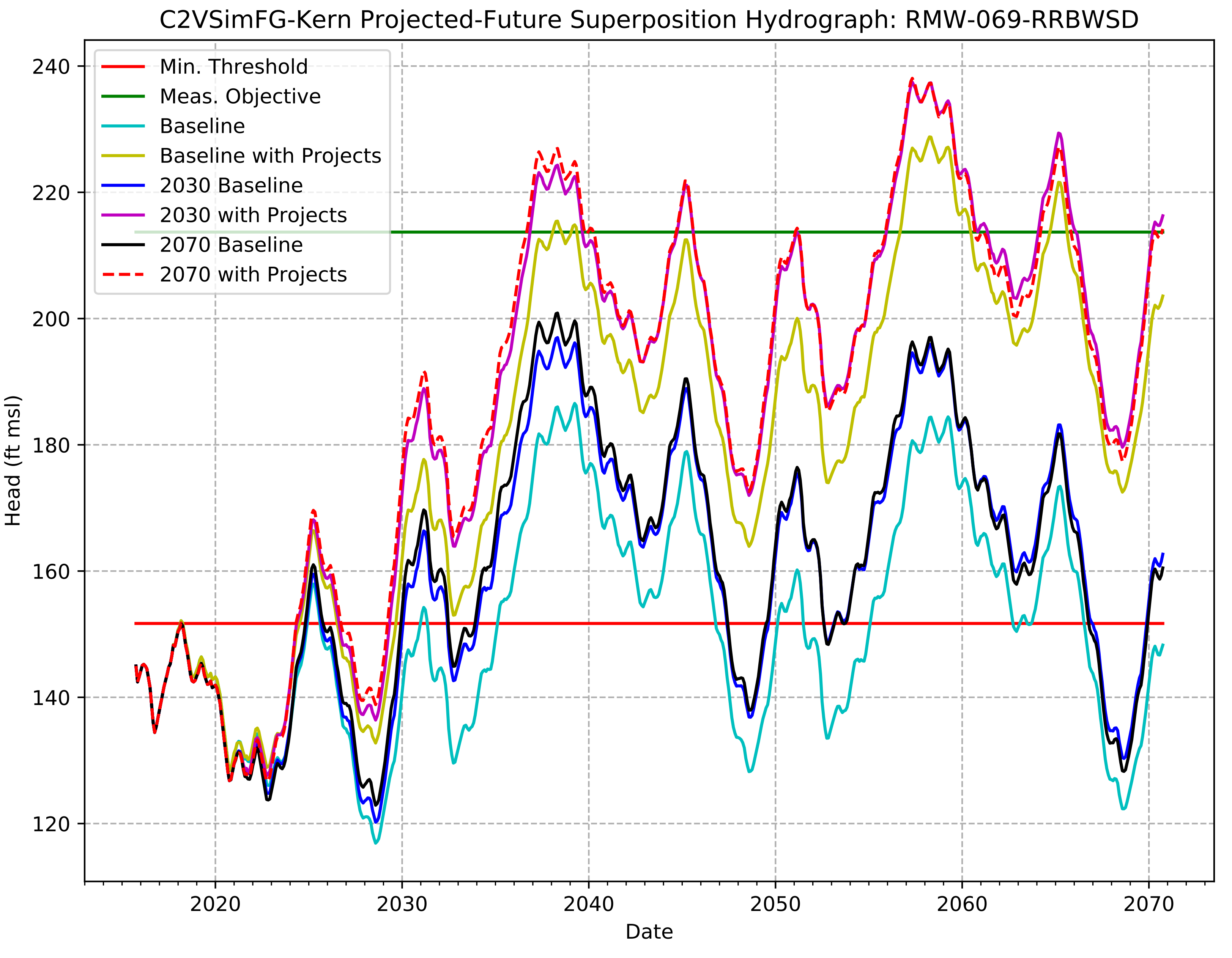
2050
2060
2070
Date


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-066-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
250
225
200
175
150
125
100
75
2020
2030
2040
2050
2060
2070
Date



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-067-RRBWSD
Head (ft msl)
300
275
250
225
200
175
150
125
100
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-068-RRBWSD
Head (ft msl)
200
180
160
140
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-069-RRBWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
240
220
200
180
160
140
120
2020
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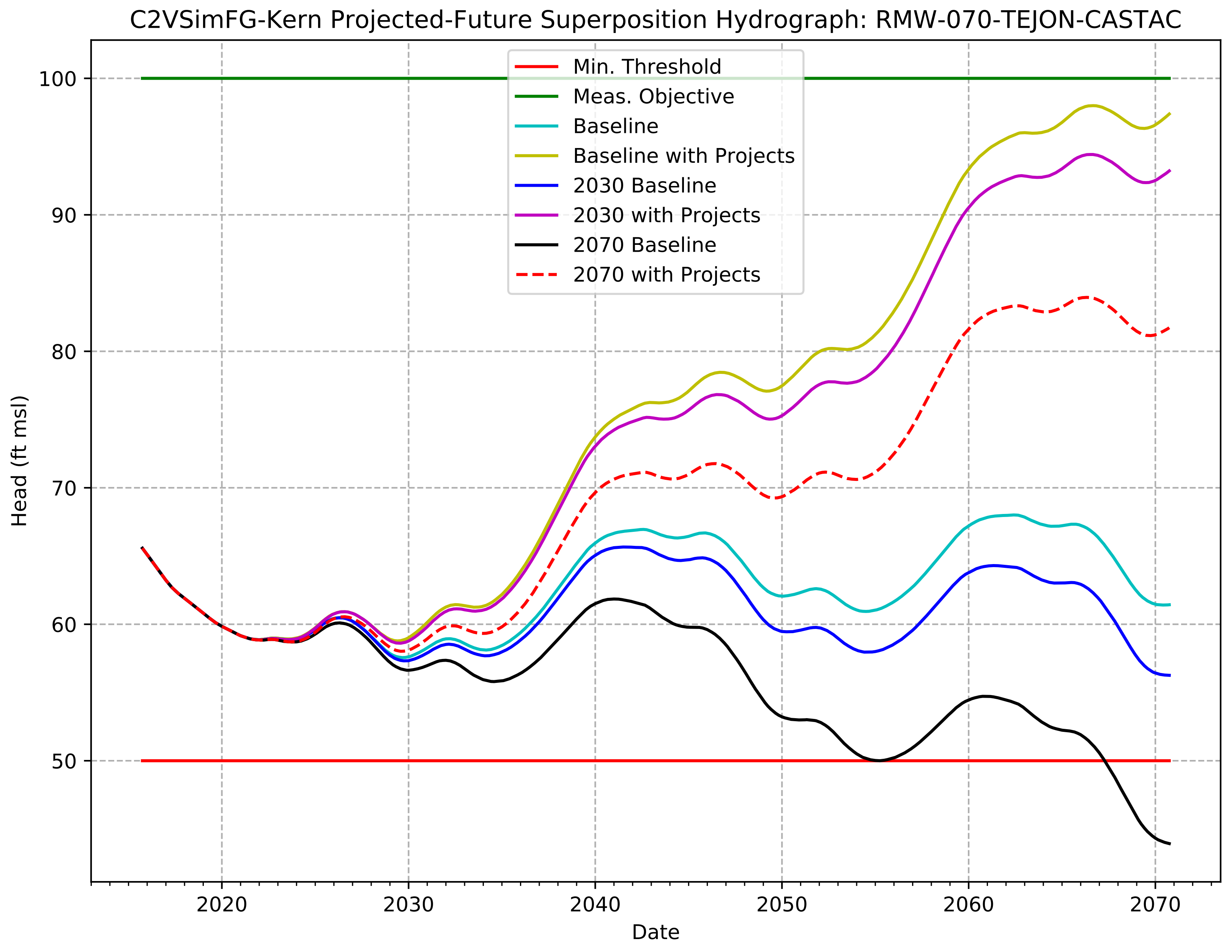
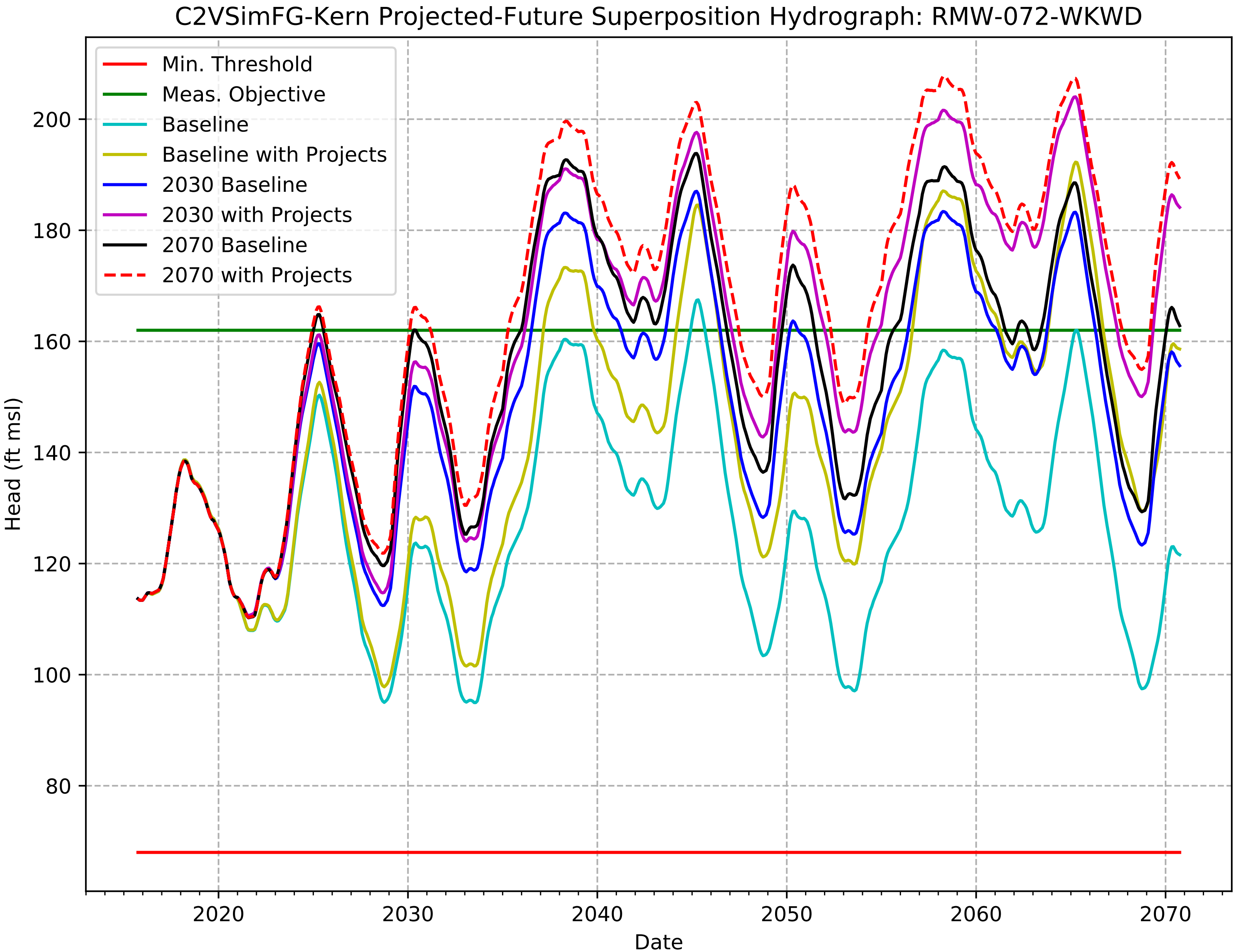
2050
2060
2070
Date


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-070-TEJON-CASTAC
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
100
90
80
70
60
50
2020
2030
2040
2050
2060
2070


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-072-WKWD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
200
180
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100
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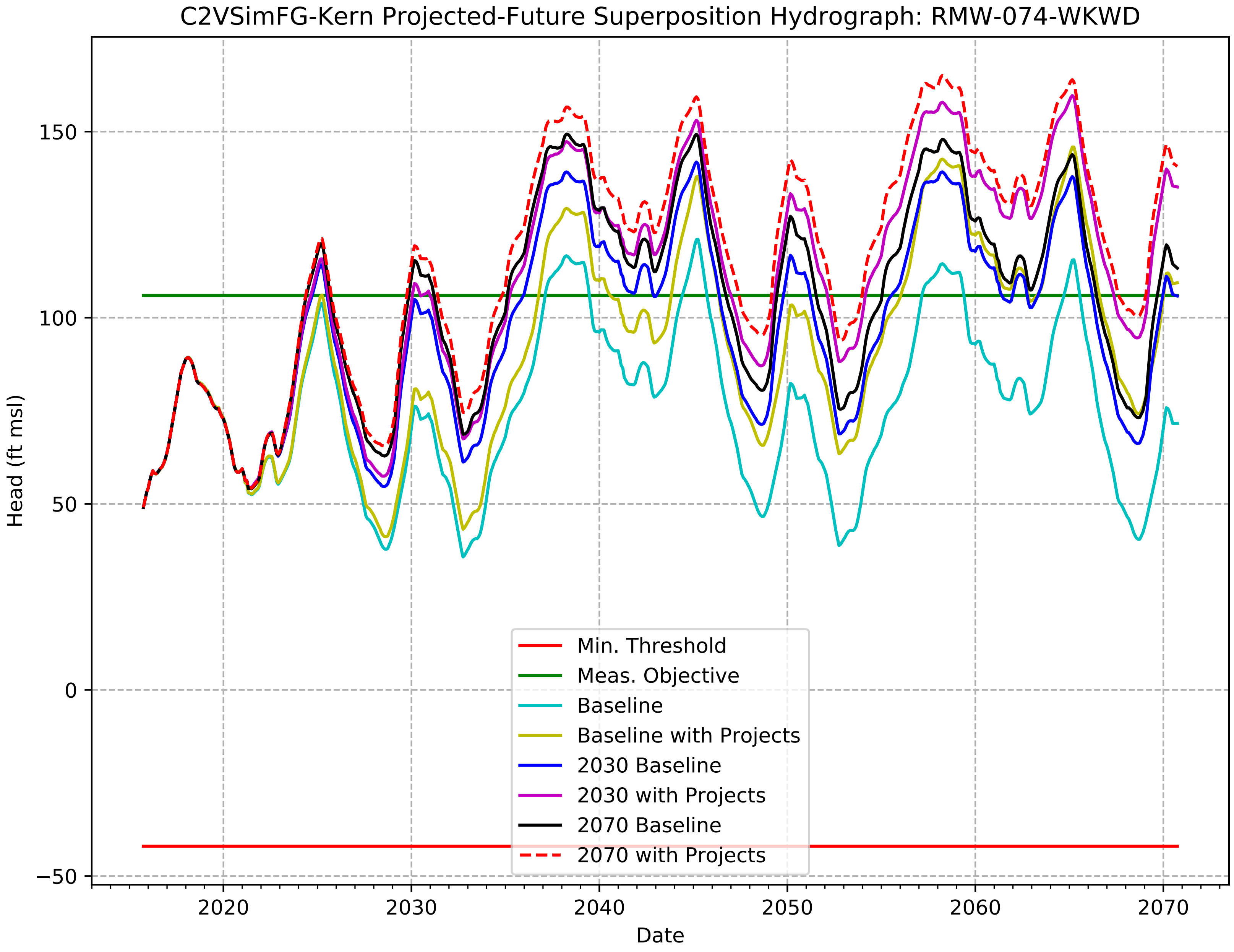
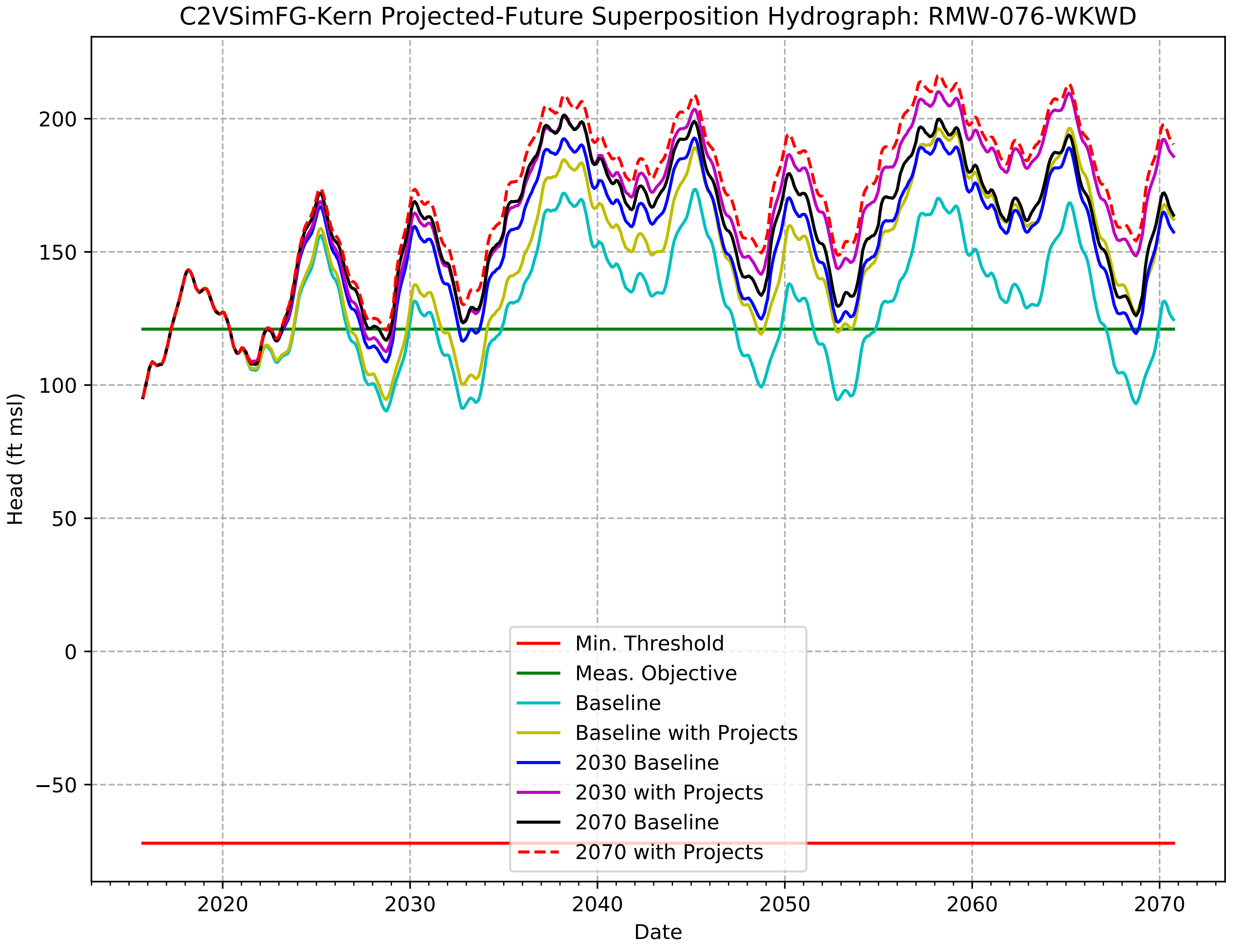
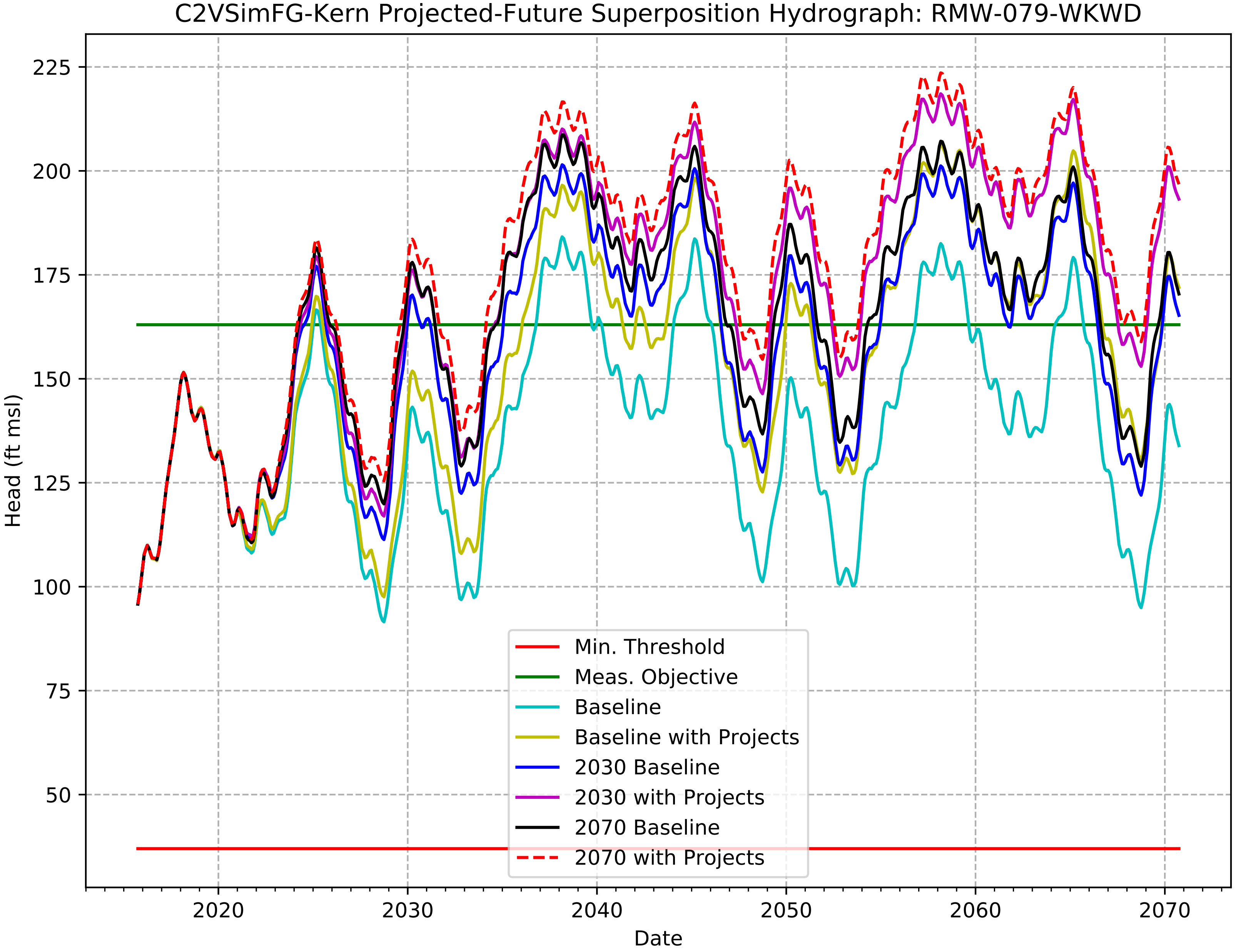
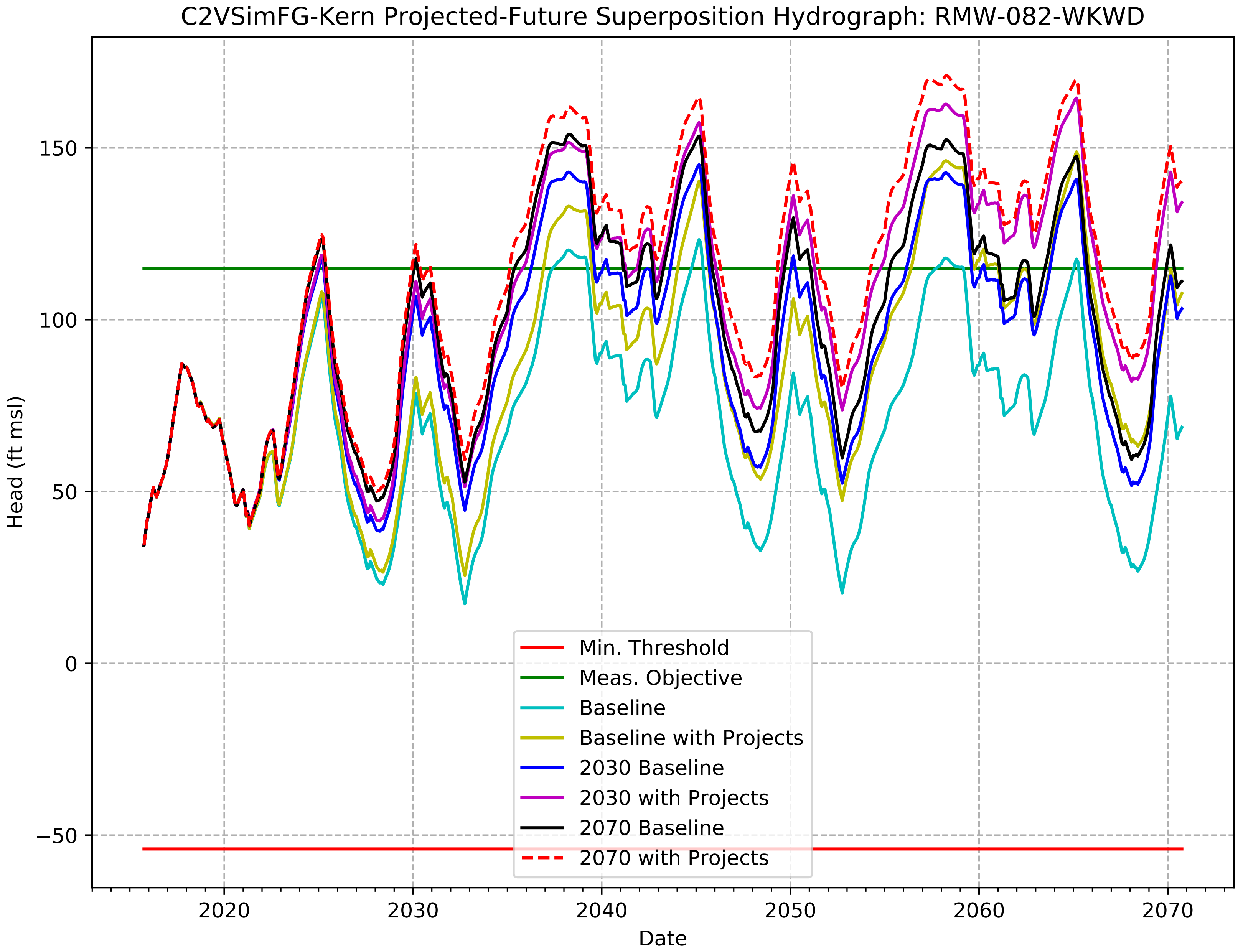
2020
2030
2040
2050
2060
2070
Date

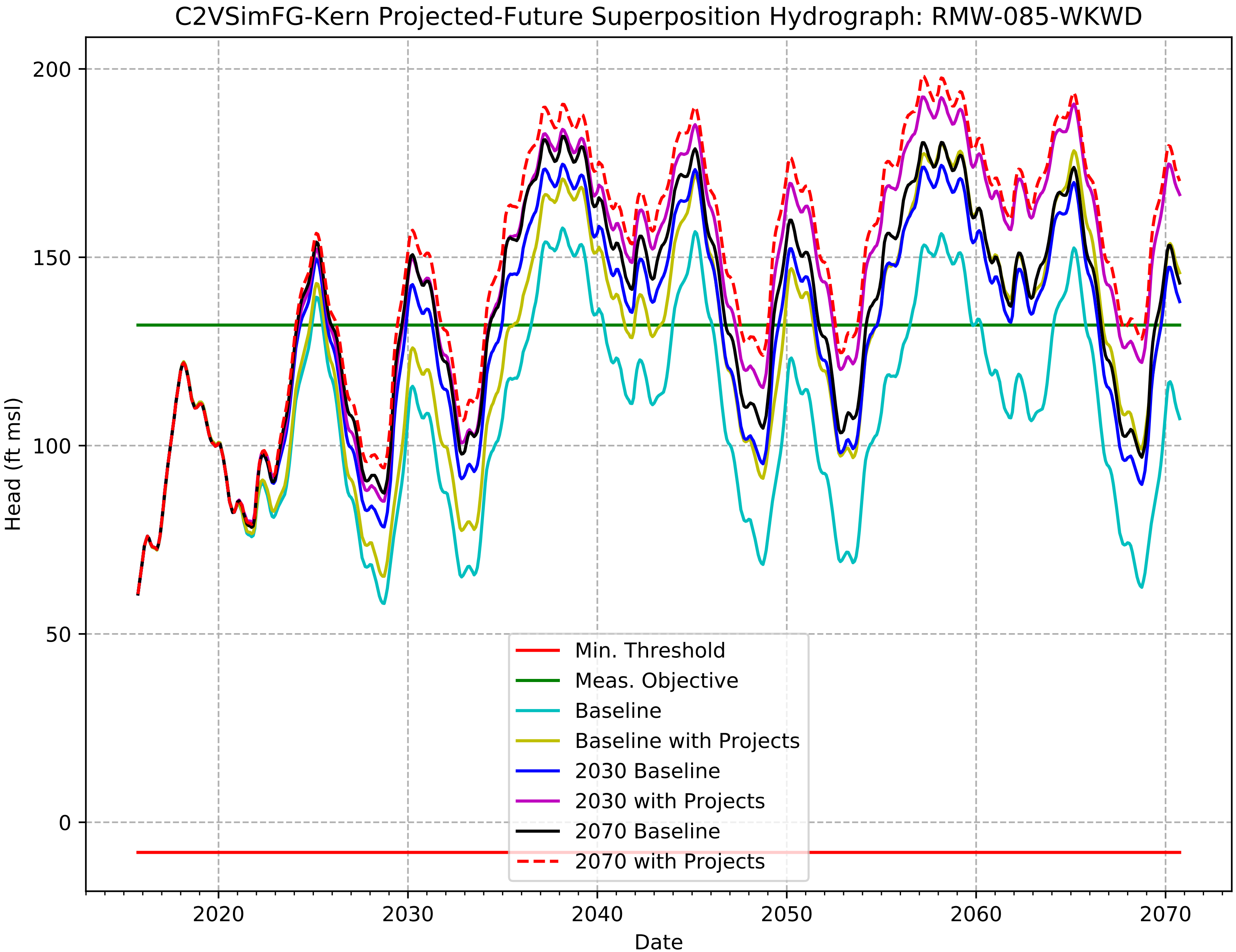


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-074-WKWD
Head (ft msl)
150
100
50
0
−50
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

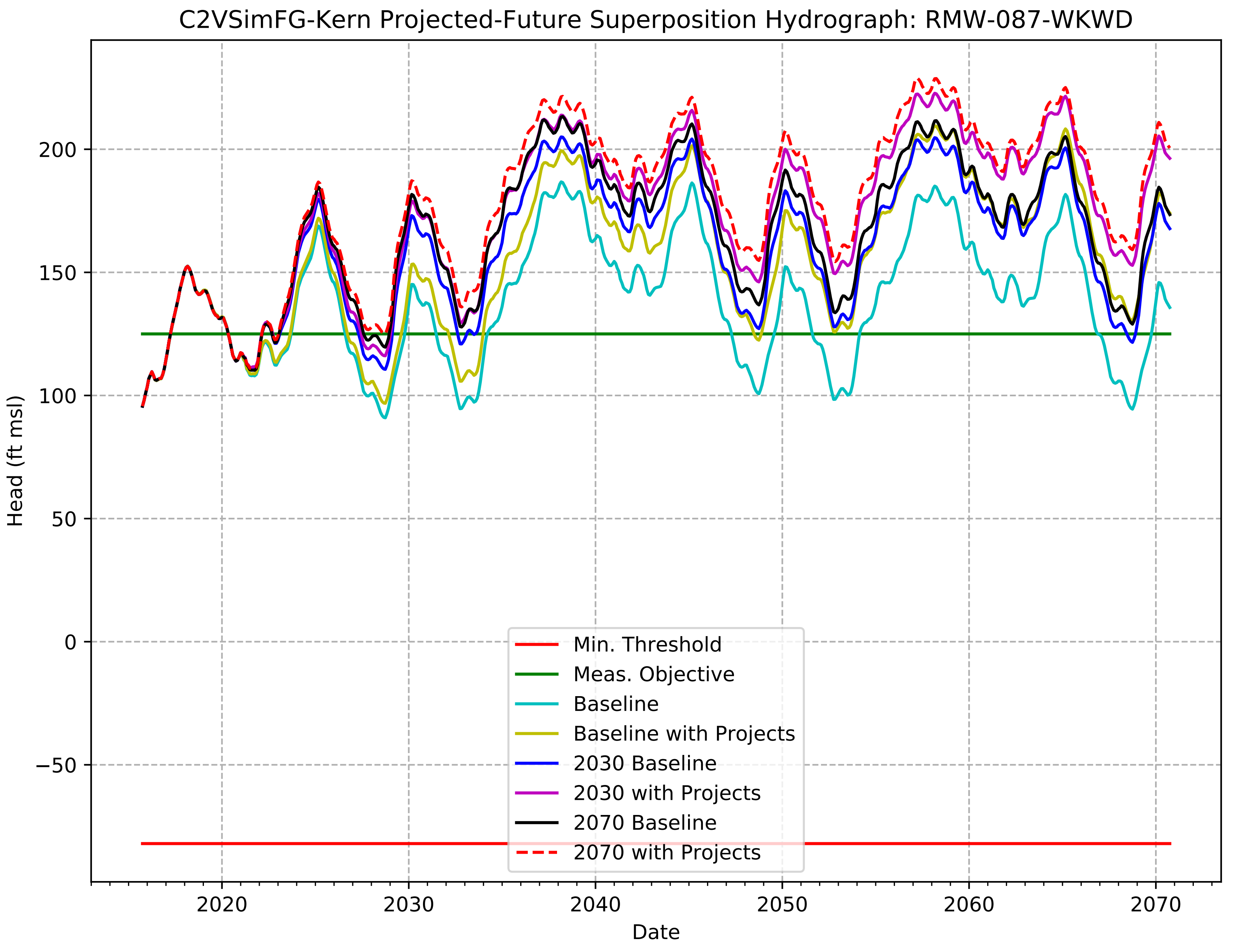

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-076-WKWD
Head (ft msl)
200
150
100
50
0
−50
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-079-WKWD
Head (ft msl)
225
200
175
150
125
100
75
50
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

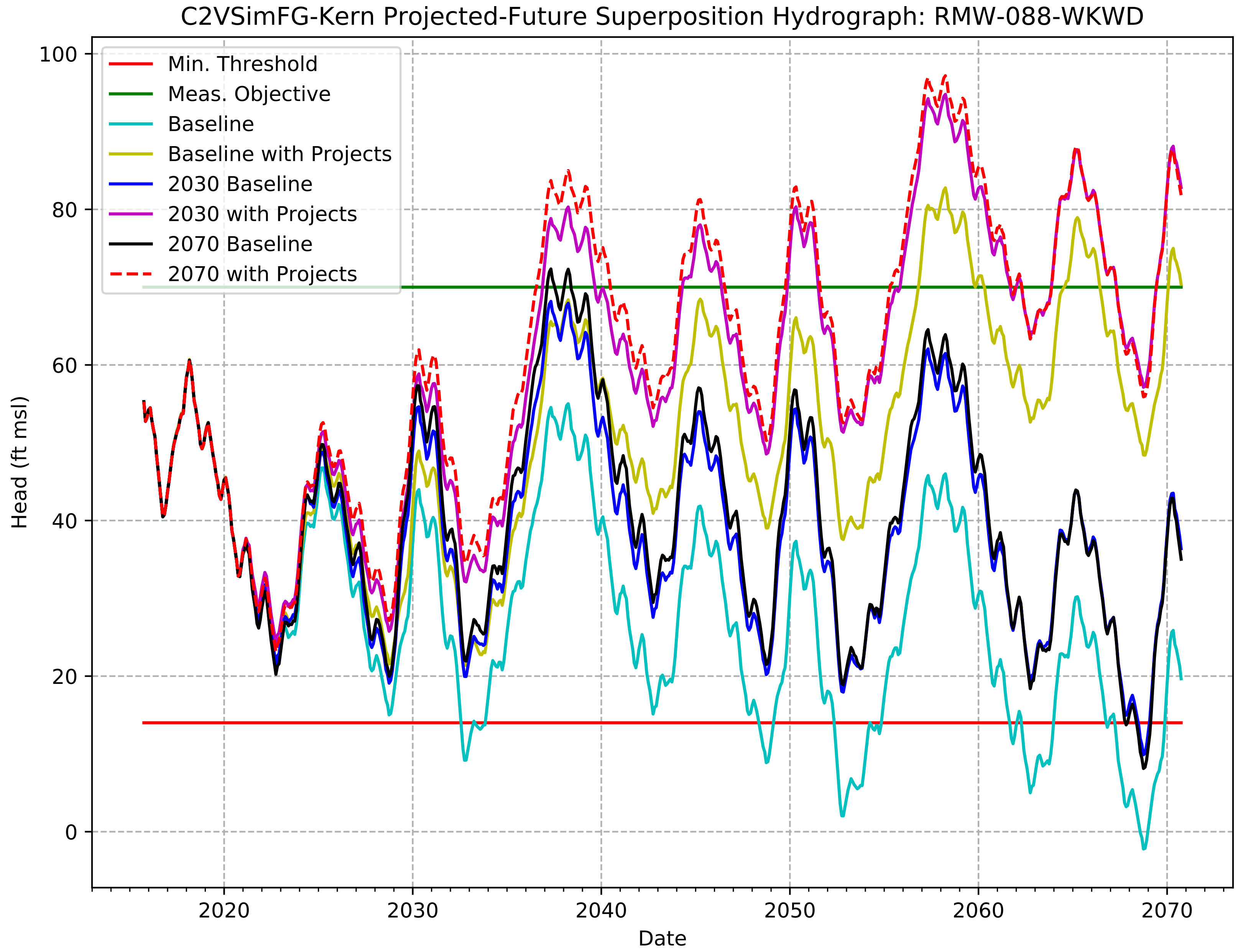

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-082-WKWD
Head (ft msl)
Date
150
100
50
0
−50
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

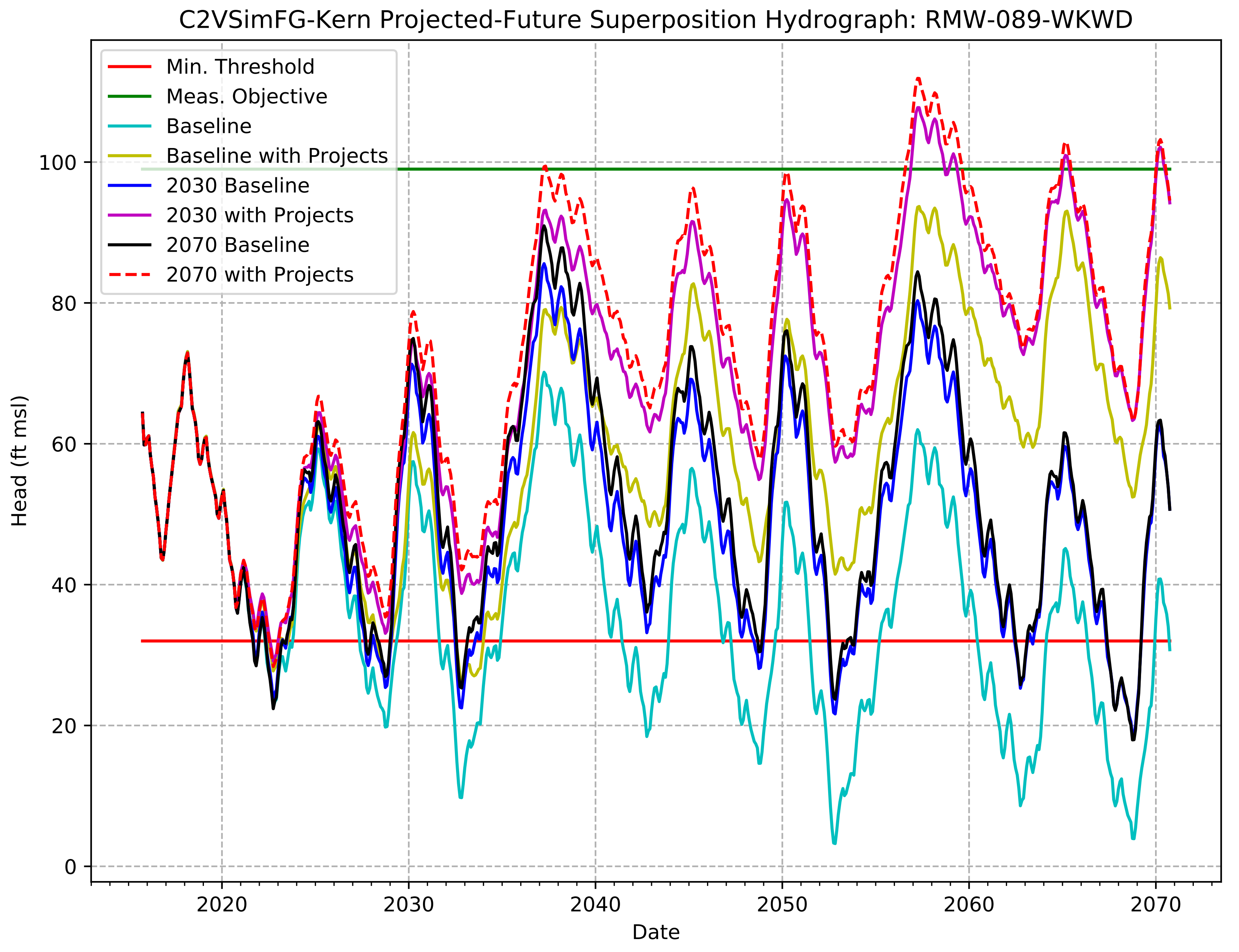


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-085-WKWD
Head (ft msl)
Date
200
150
100
50
0
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-087-WKWD
Head (ft msl)
200
150
100
50
0
−50
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-088-WKWD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
0
20
40
60
80
100
2020
2030
2040
2050
2060
2070



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-089-WKWD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
0
20
40
60
80
100
2020
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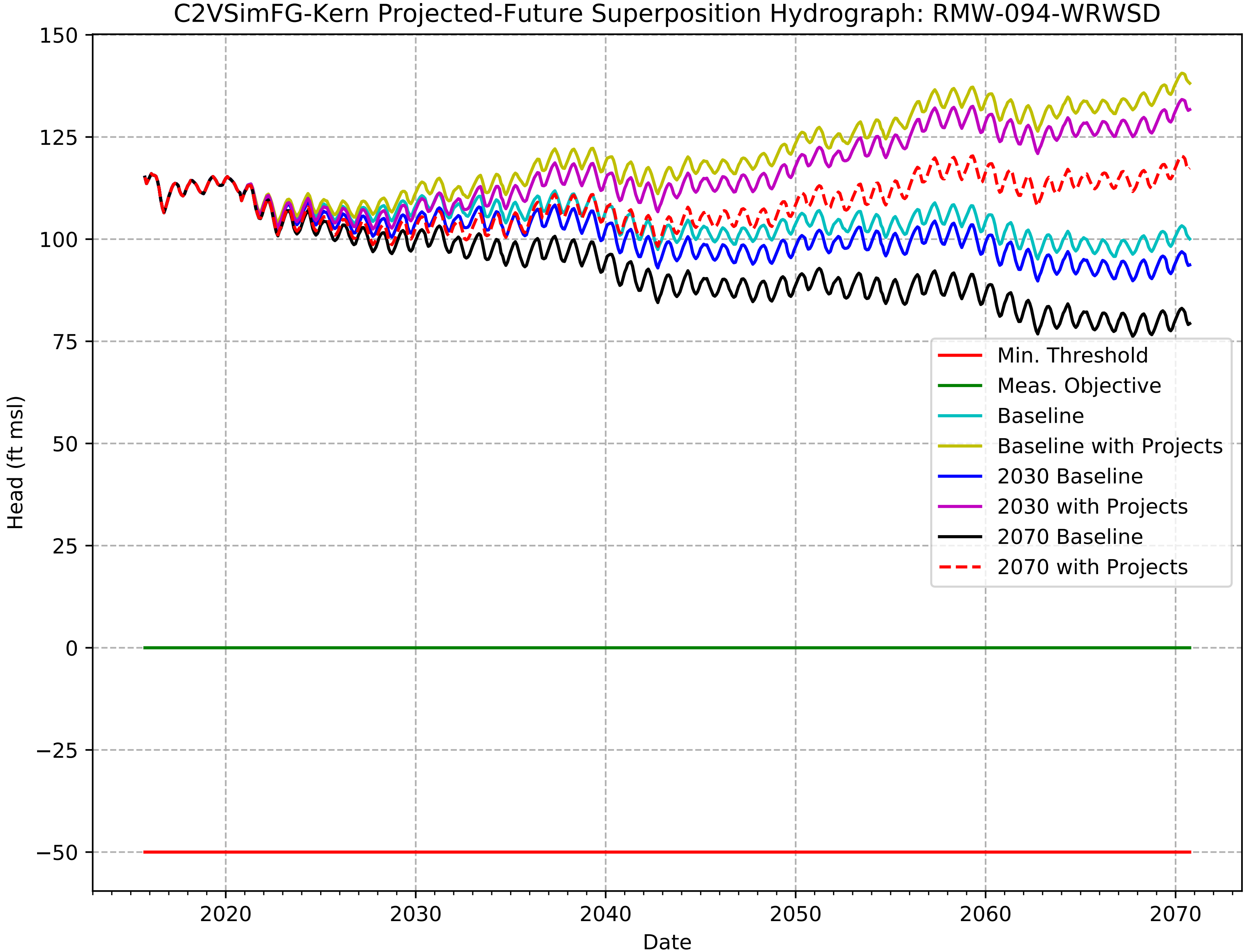
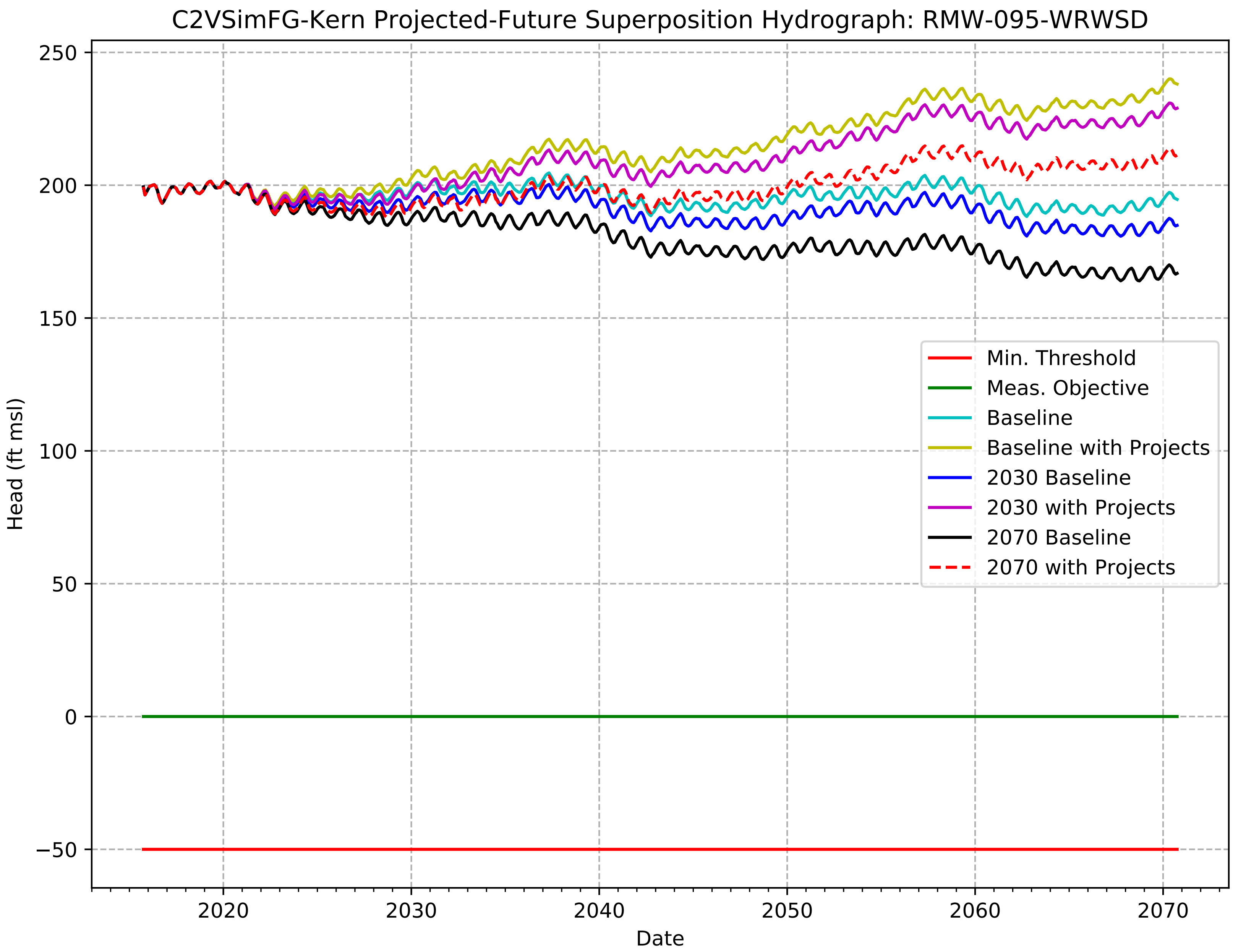
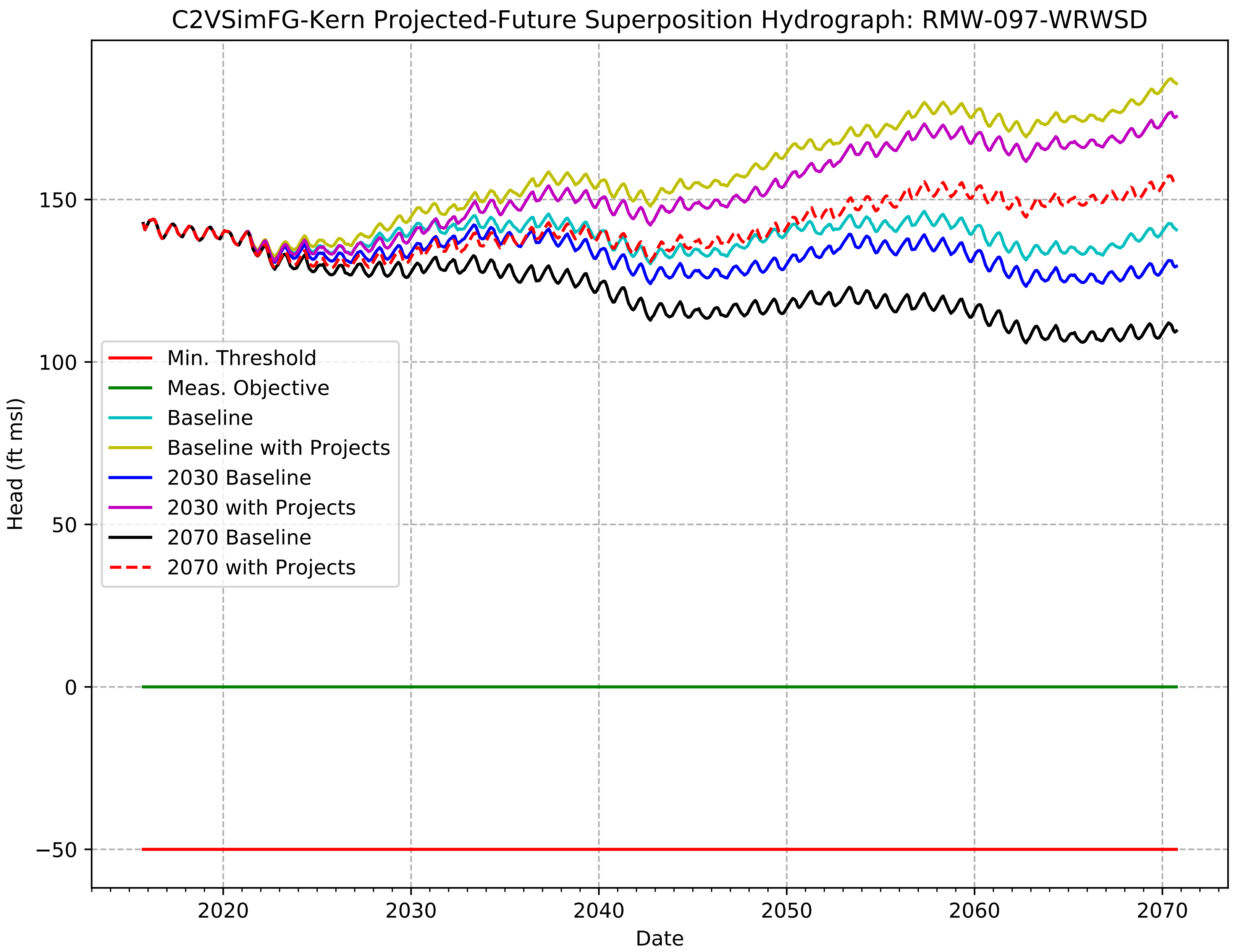
2040
2050
2060
2070

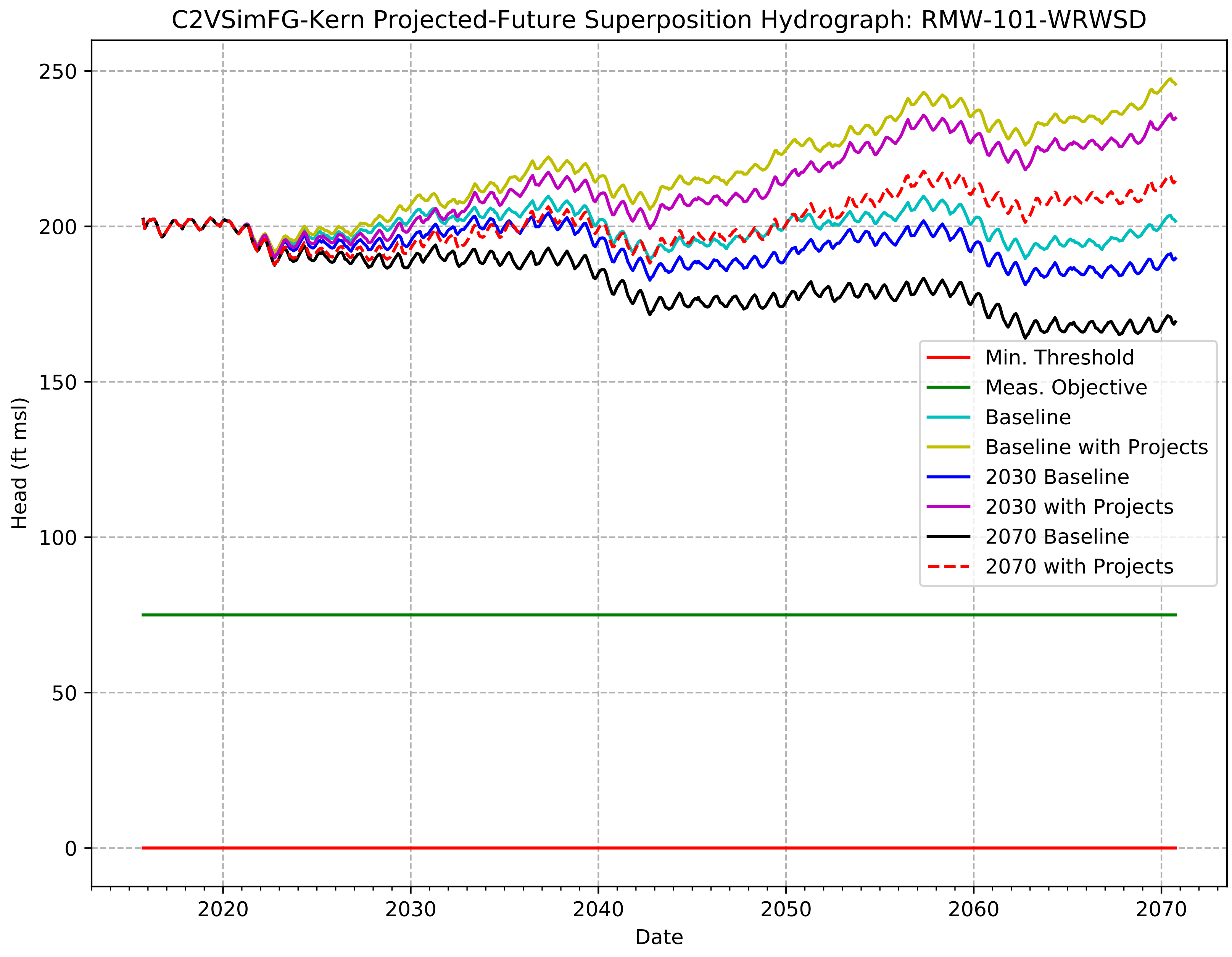


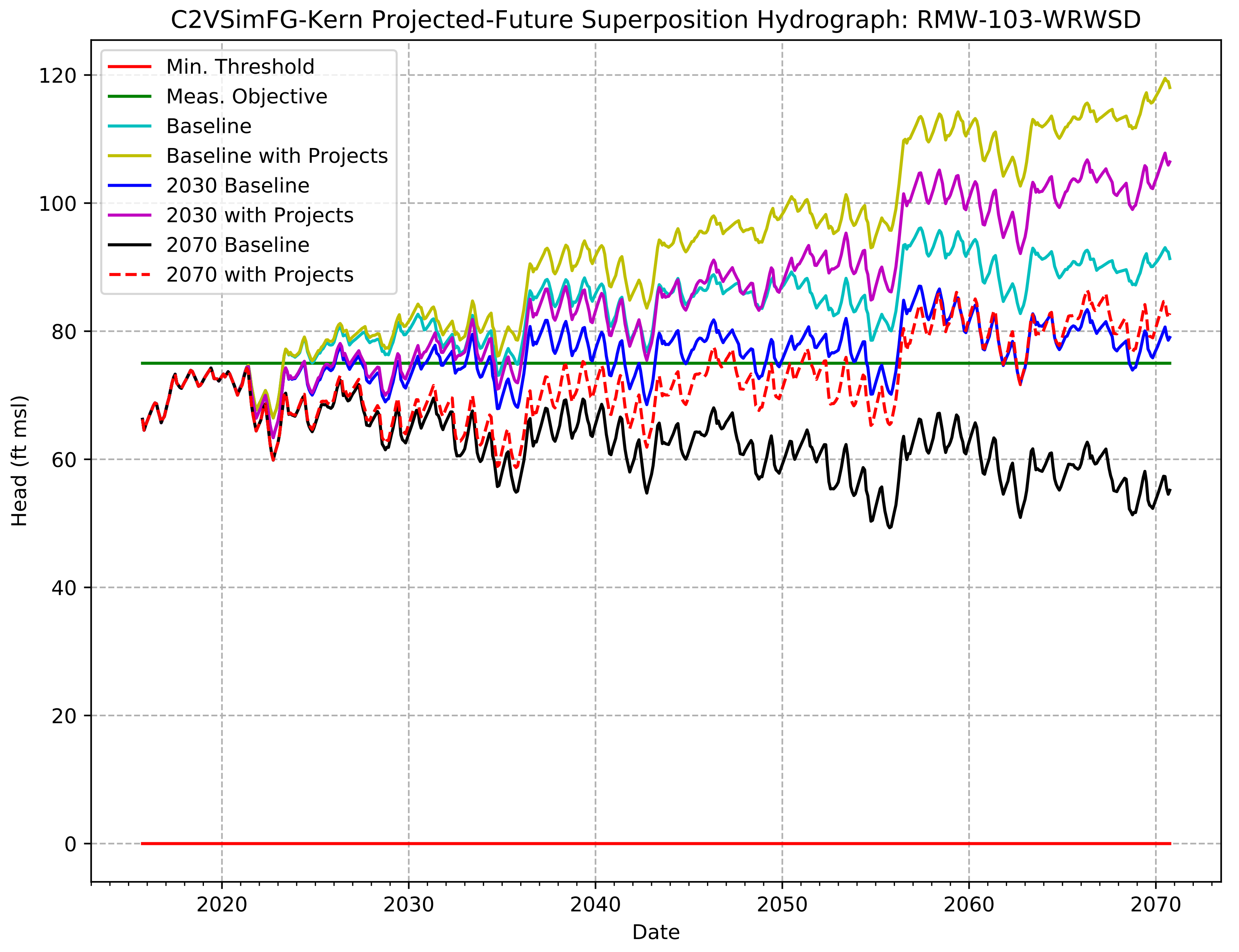
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-094-WRWSD
Head (ft msl)
150
125
100
75
50
25
0
−25
−50
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

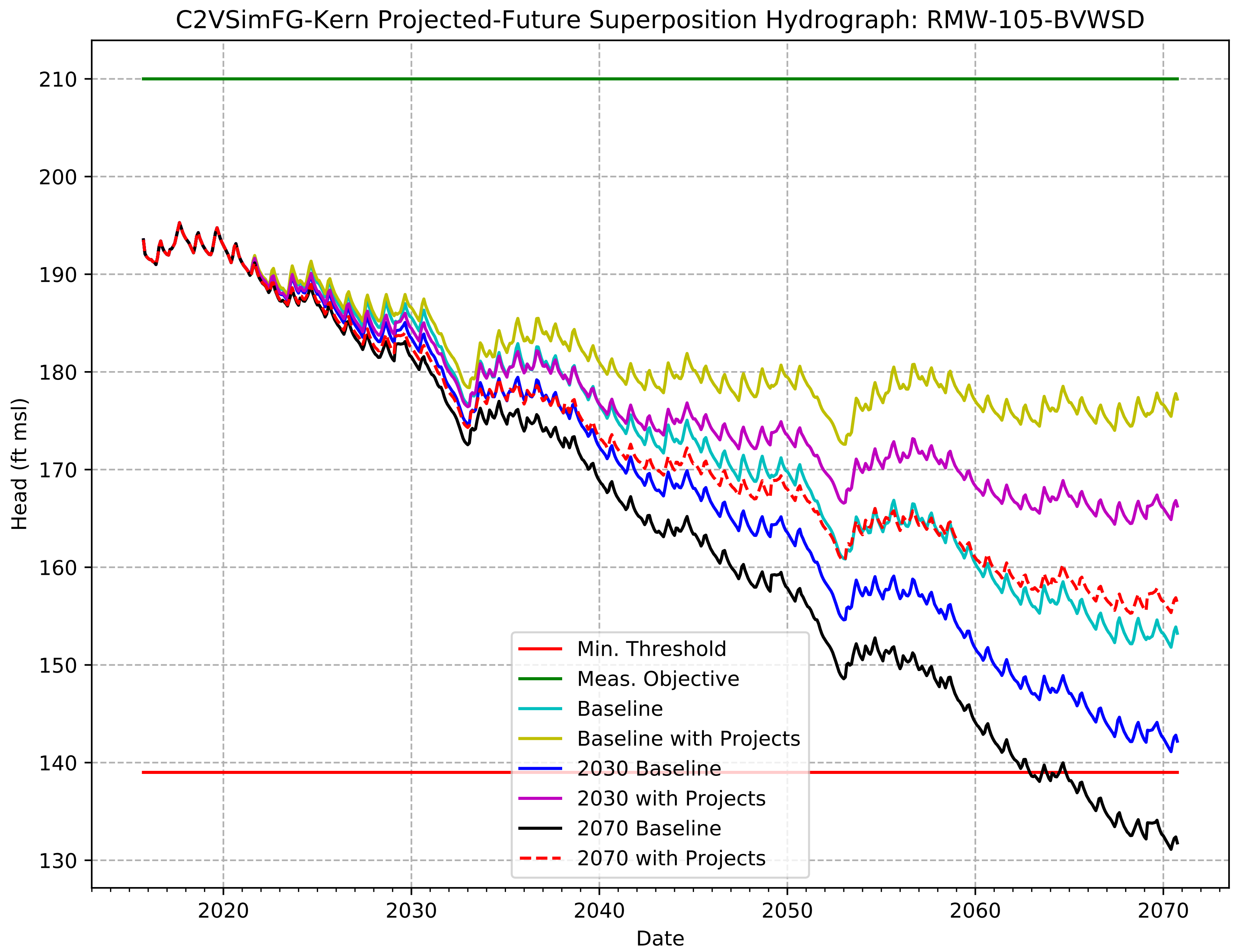


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-095-WRWSD
Head (ft msl)
250
200
150
100
50
0
−50
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

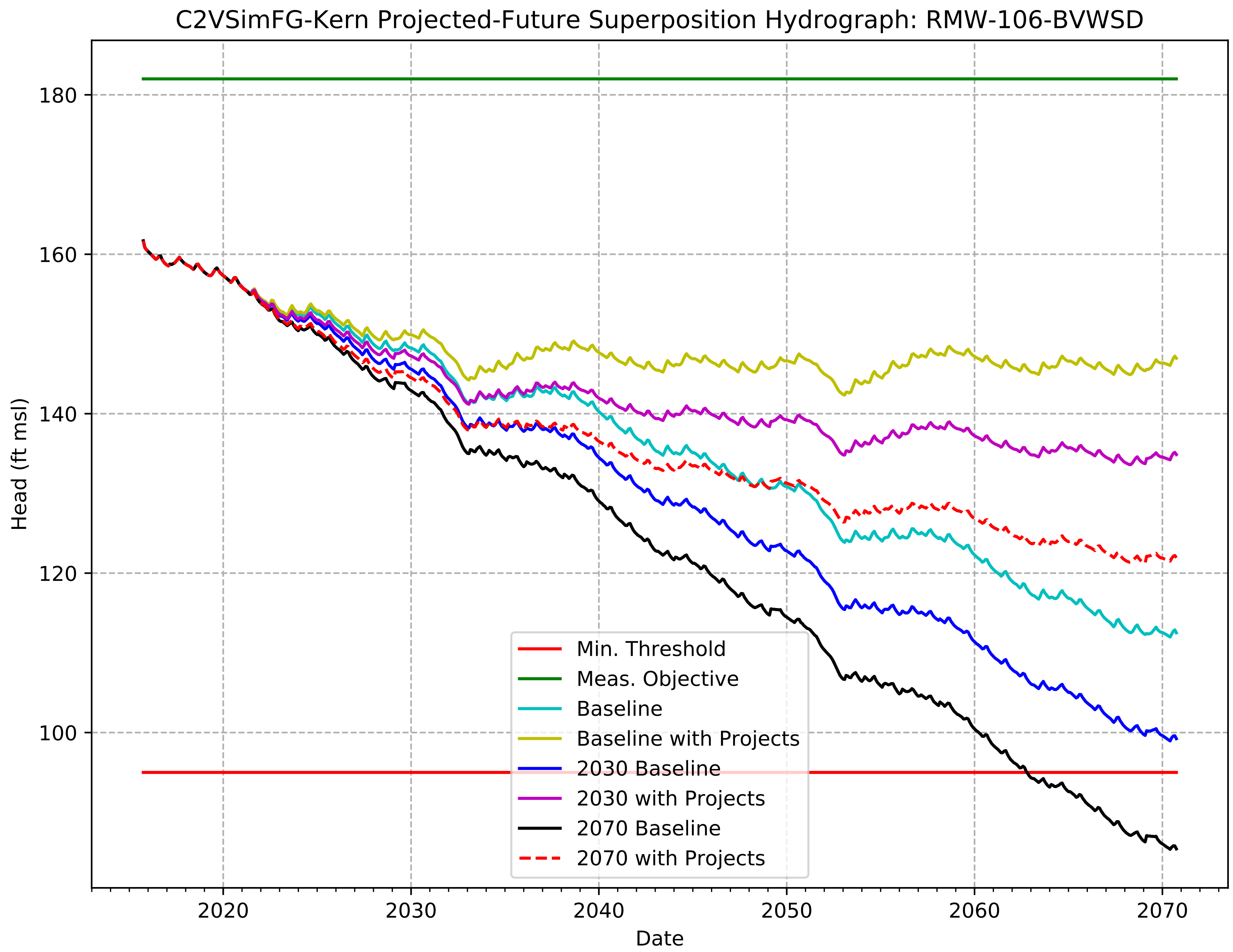

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-097-WRWSD
Head (ft msl)
150
100
50
0
−50
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

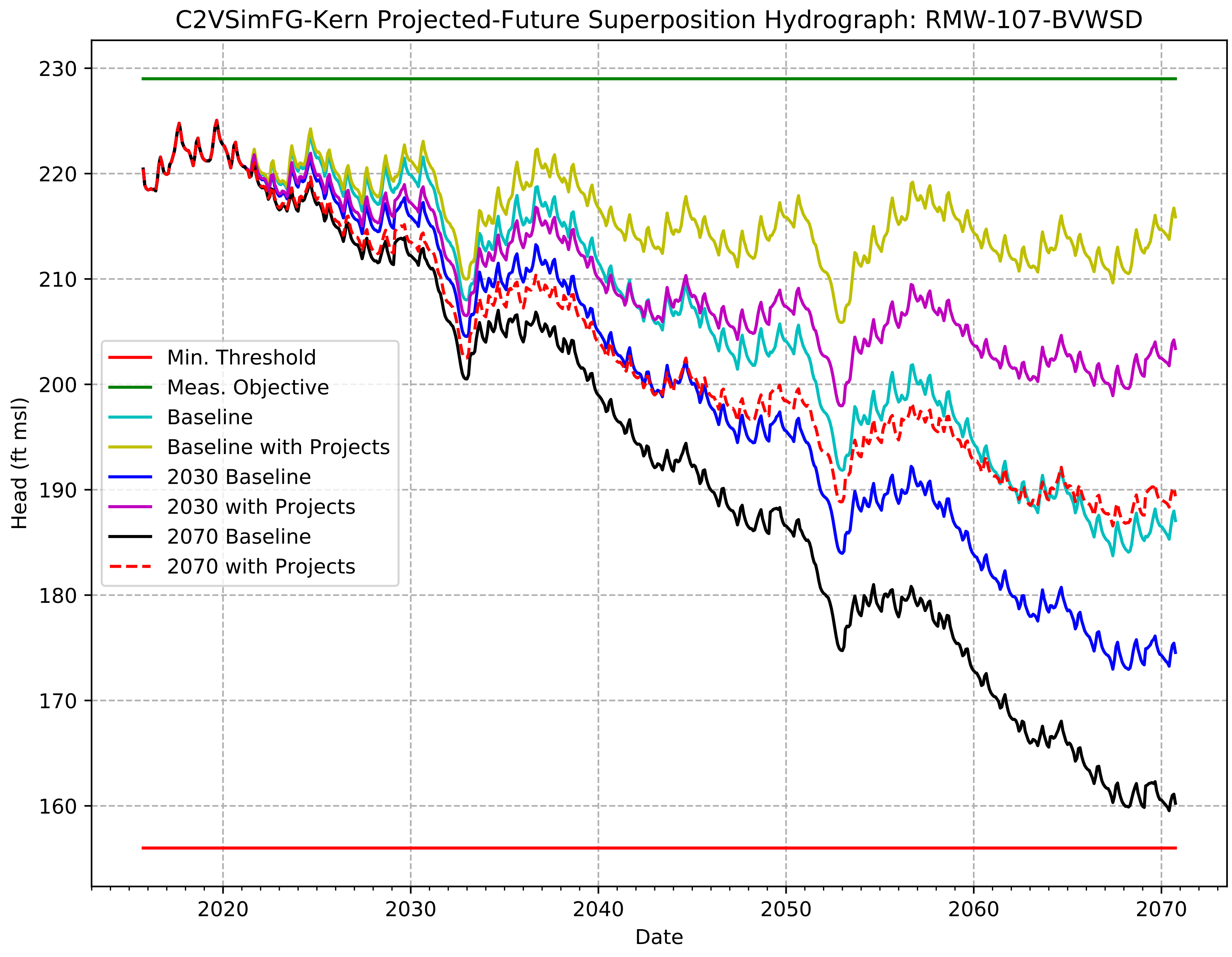

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-101-WRWSD
Head (ft msl)
Date
0
50
100
150
200
250
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-103-WRWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
0
20
40
60
80
100
120
2020
2030
2040
2050
2060
2070
Date

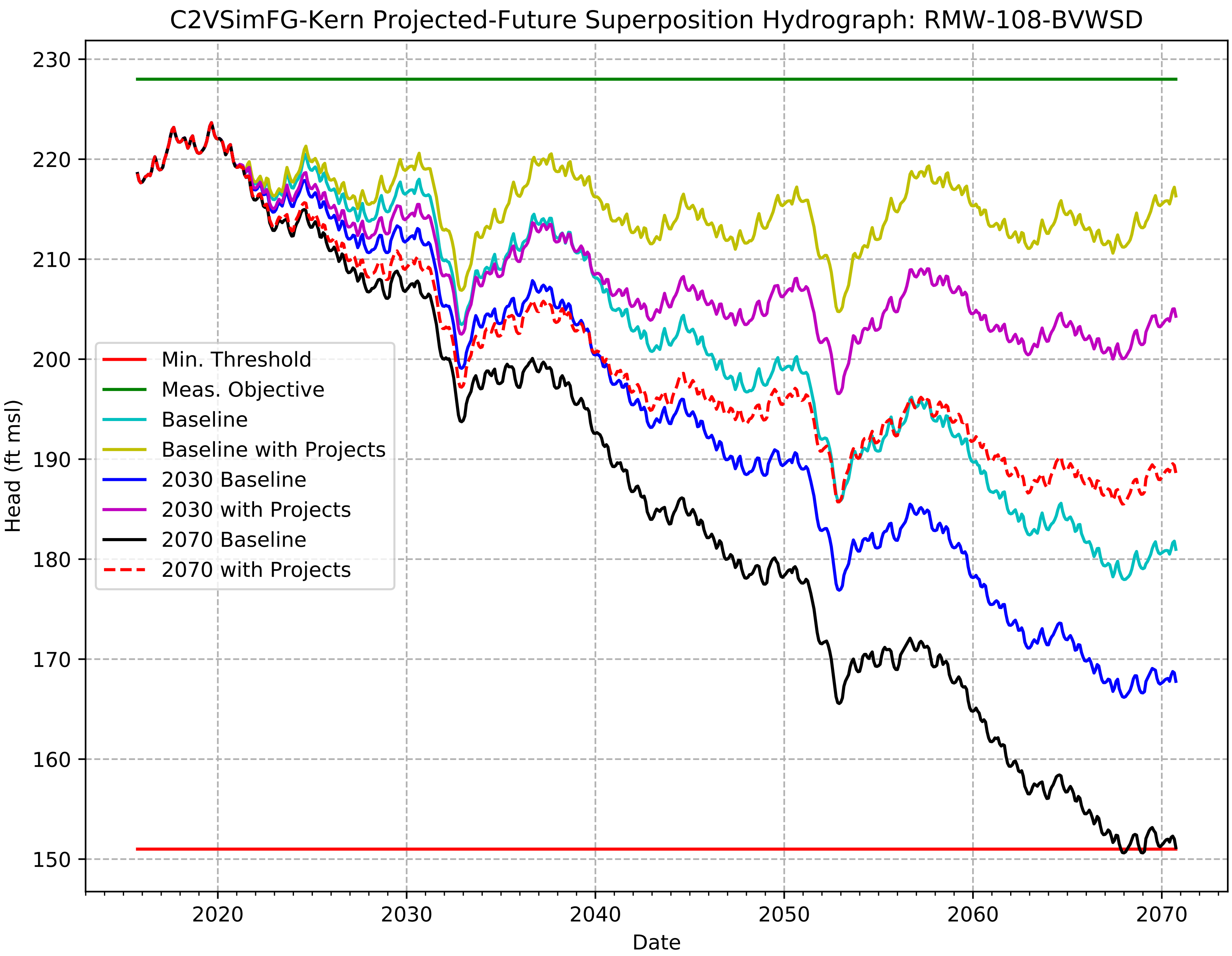


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-105-BVWSD
Head (ft msl)
210
200
190
180
170
160
150
140
130
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-106-BVWSD
Head (ft msl)
180
160
140
120
100
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-107-BVWSD
Head (ft msl)
Date
230
220
210
200
190
180
170
160
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-108-BVWSD
Head (ft msl)
Date
230
220
210
200
190
180
170
160
150
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
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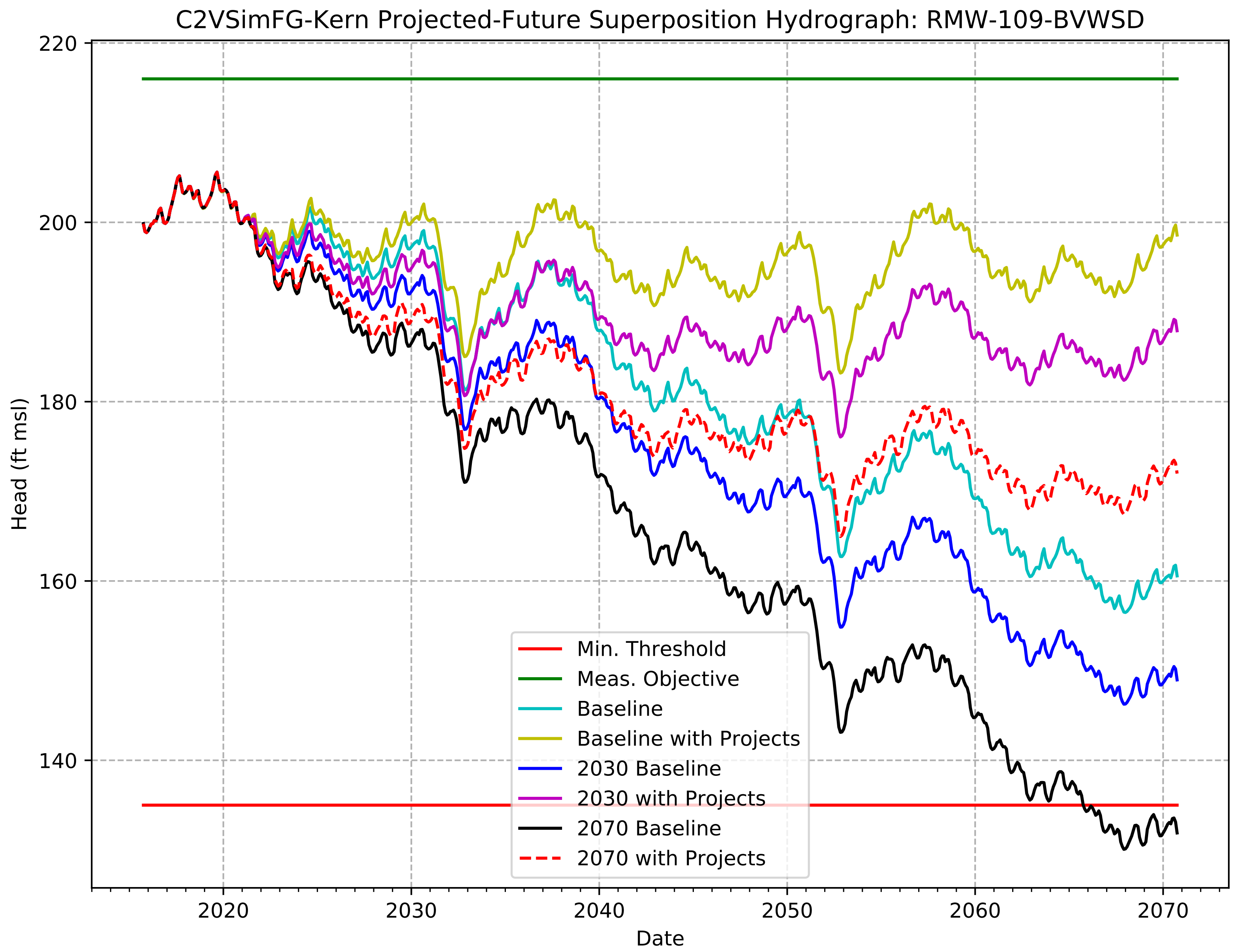
2070 with Projects



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-109-BVWSD
Head (ft msl)
220
200
180
160
140
2020
2030
2040
2050
2060
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Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
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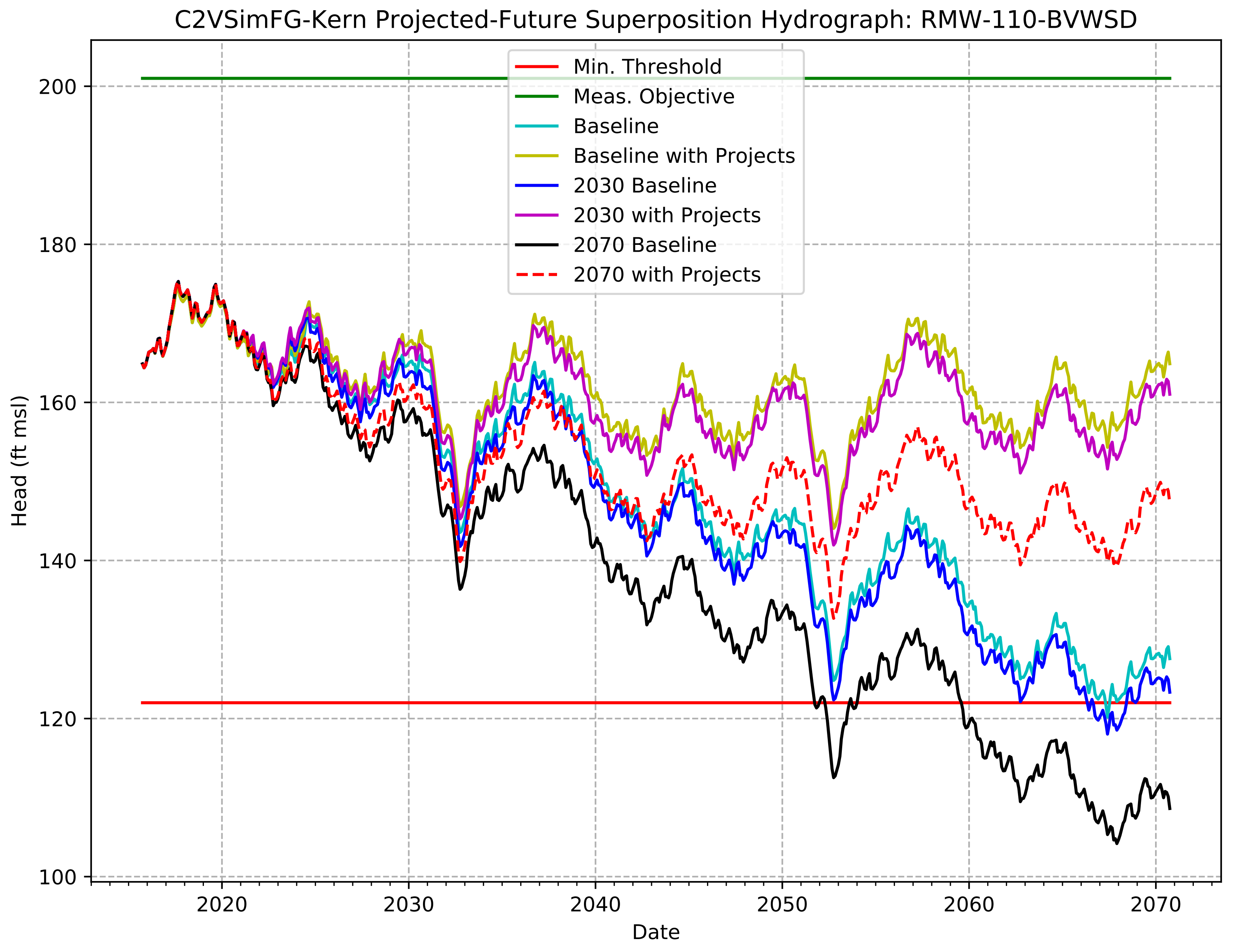
2070 with Projects



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-110-BVWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
200
180
160
140
120
100
2020
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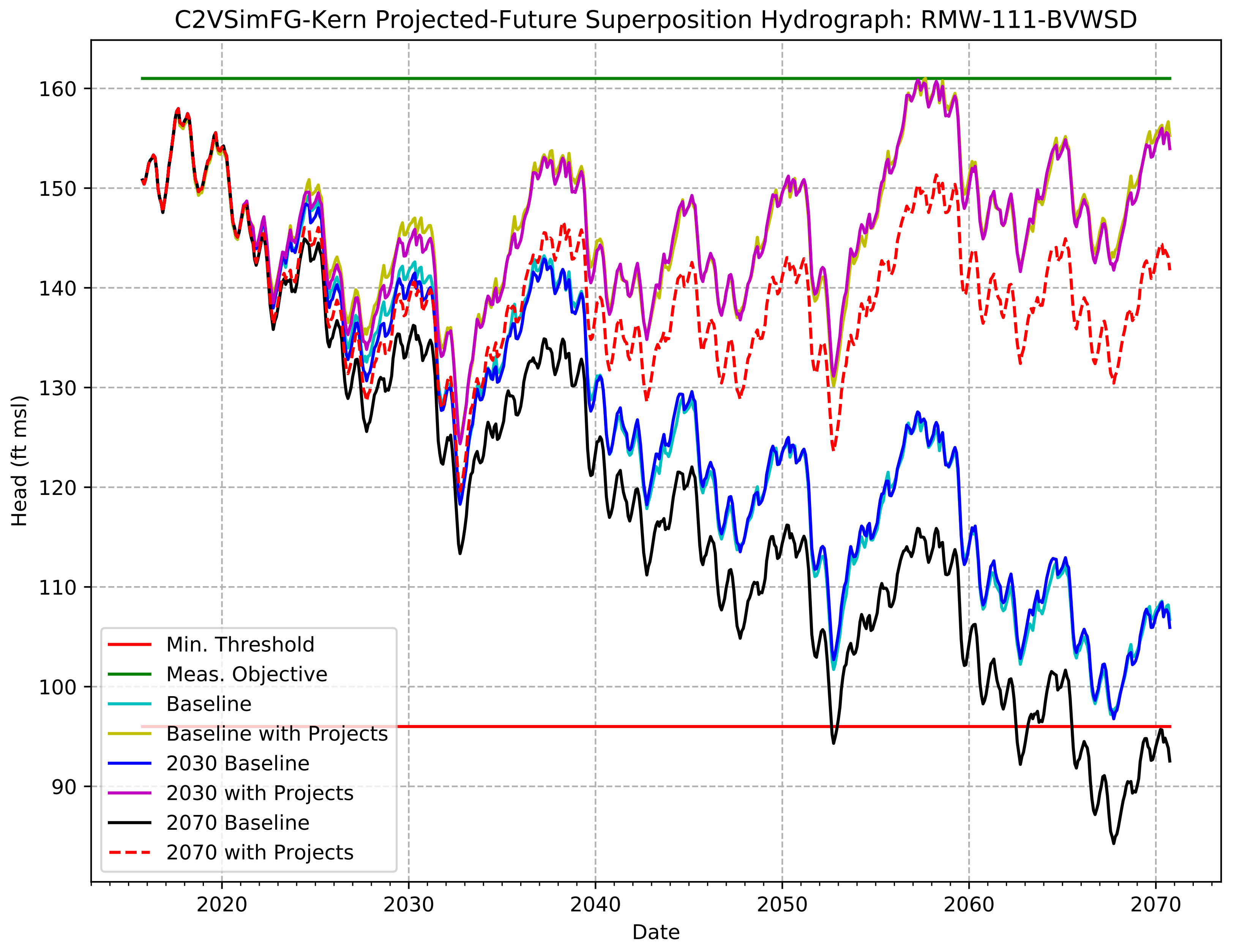
2040
2050
2060
2070



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-111-BVWSD
Head (ft msl)
Date
160
150
140
130
120
110
100
90
2020
2030
2040
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2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
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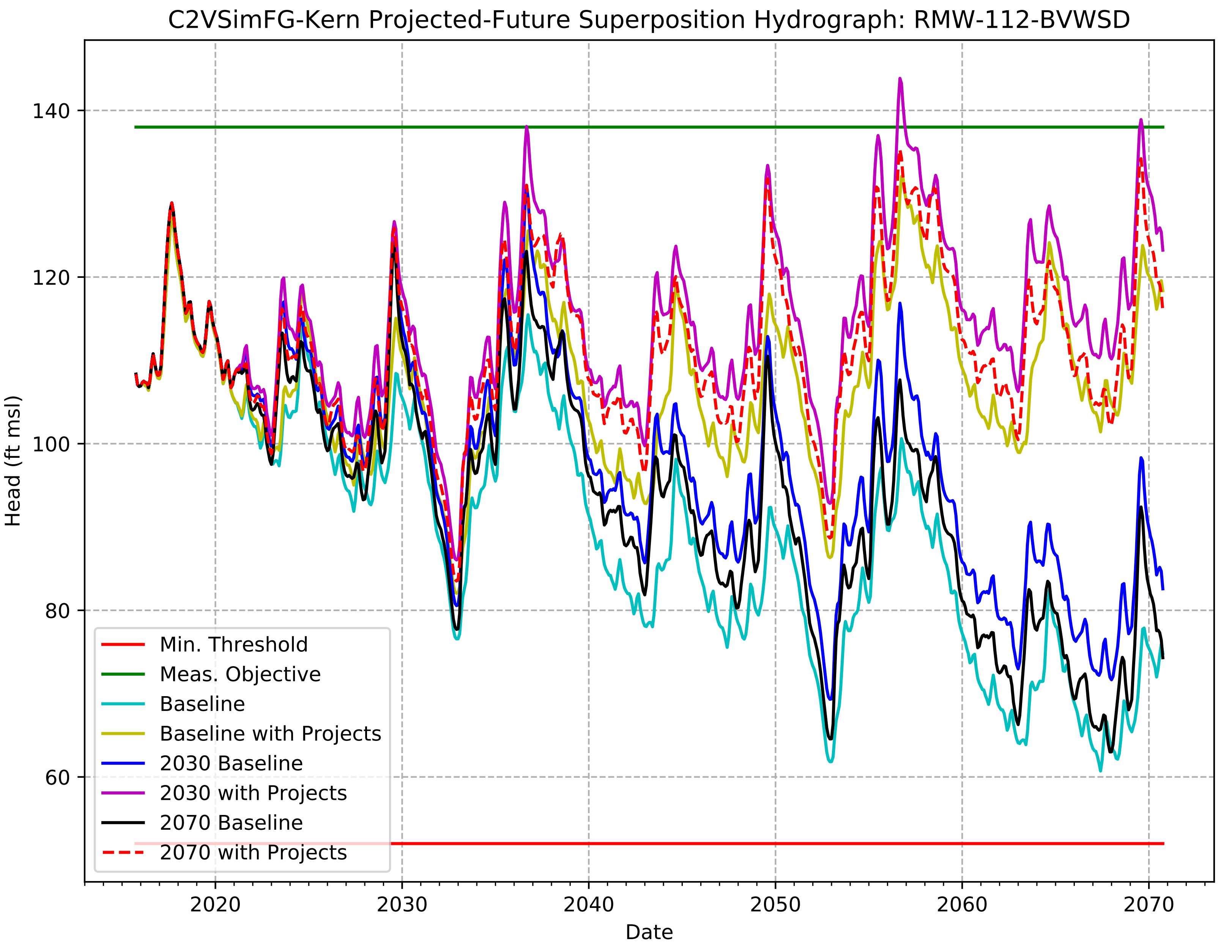
2070 Baseline
2070 with Projects



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-112-BVWSD
Head (ft msl)
Date
140
120
100
80
60
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
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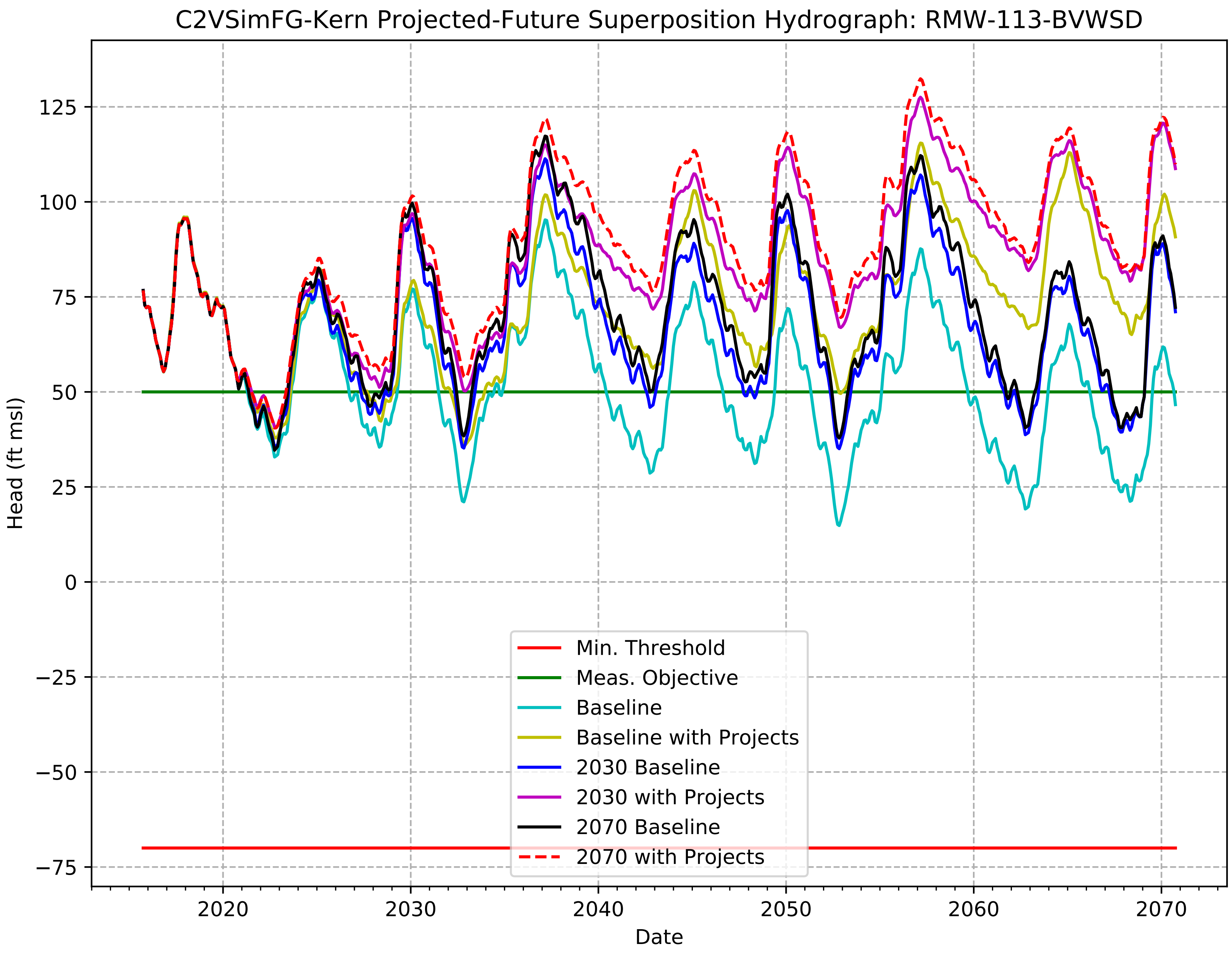
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-113-BVWSD
Head (ft msl)
125
100
75
50
25
0
−25
−50
−75
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
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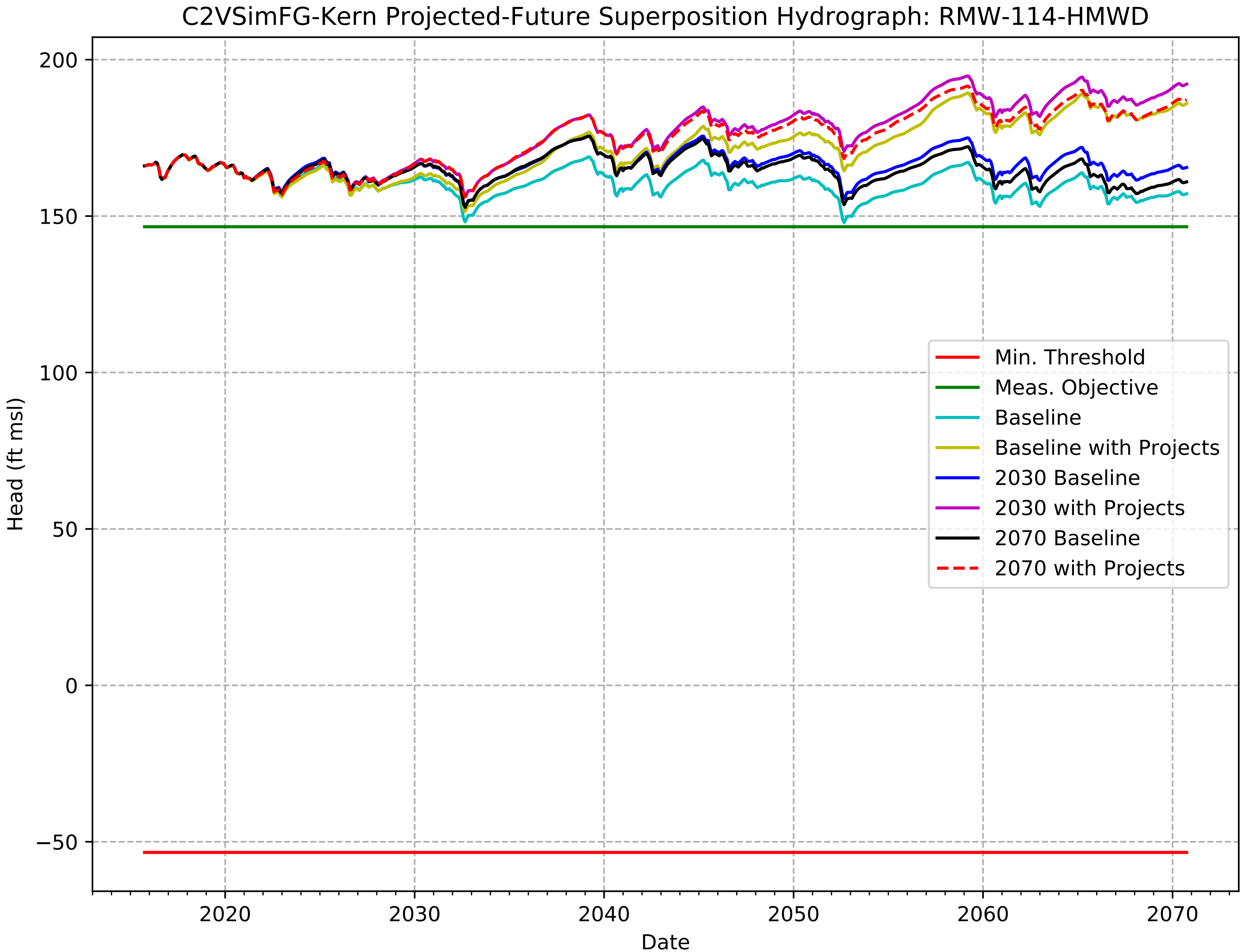
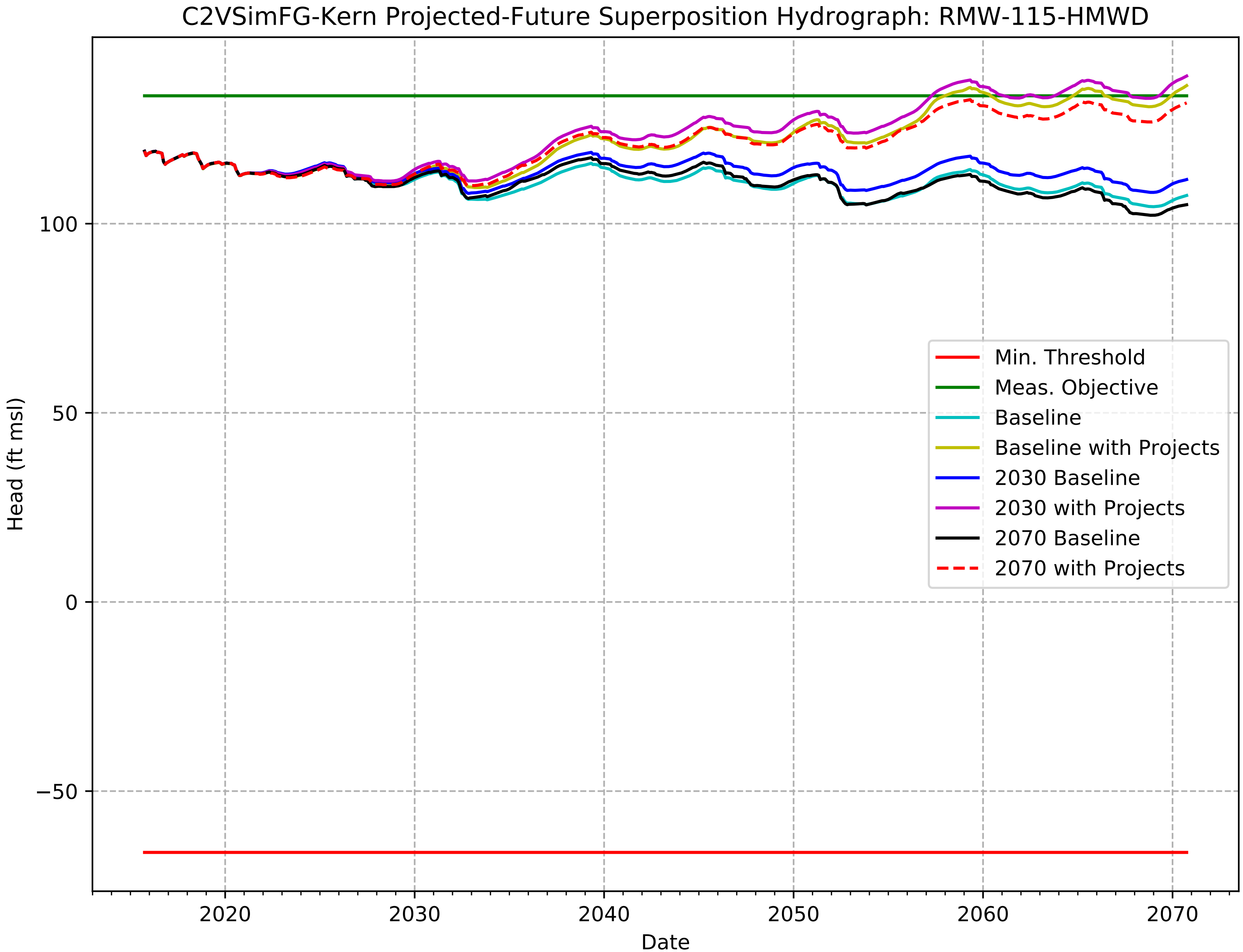
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-114-HMWD
Head (ft msl)
200
150
100
50
0
−50
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-115-HMWD
Head (ft msl)
100
50
0
−50
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
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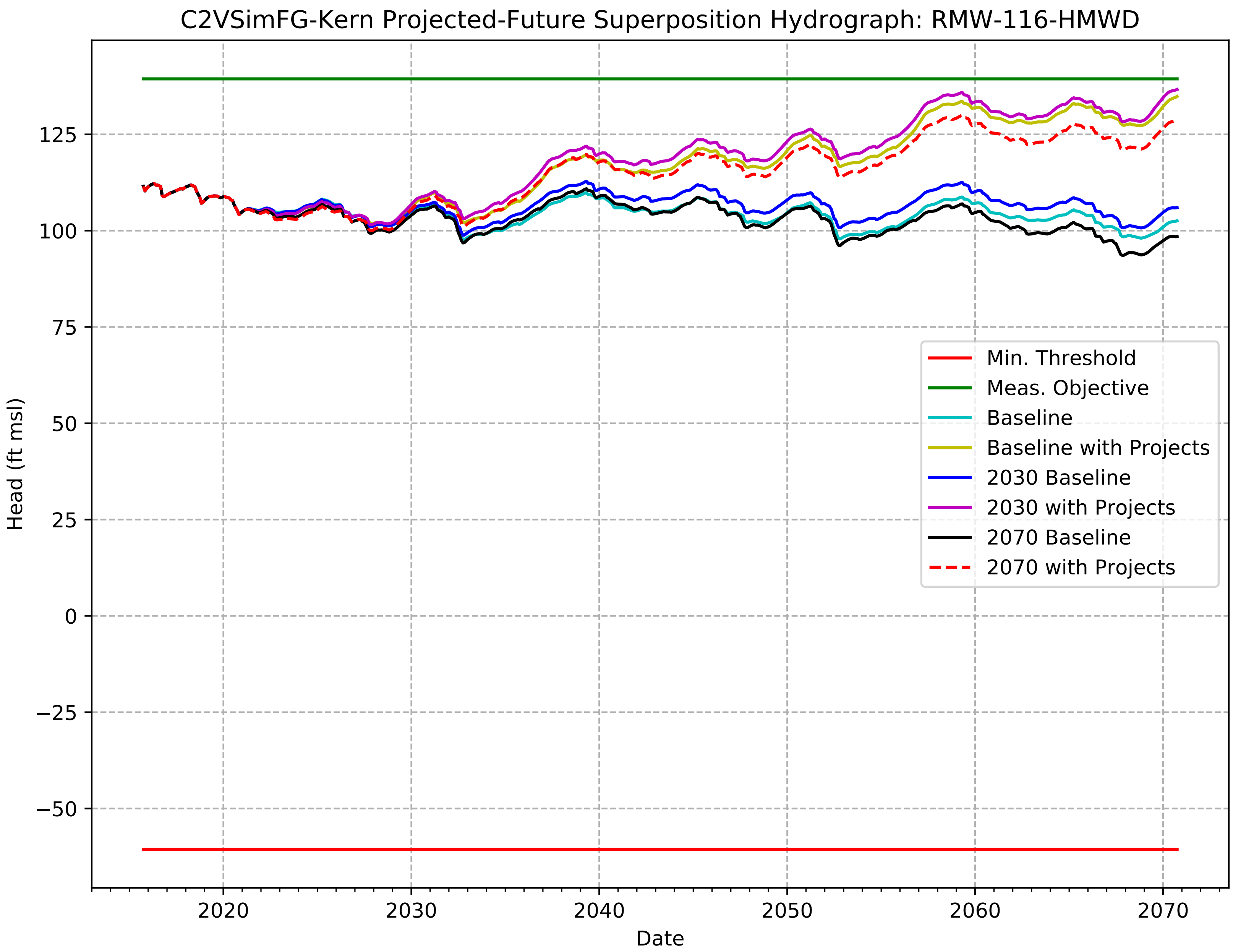
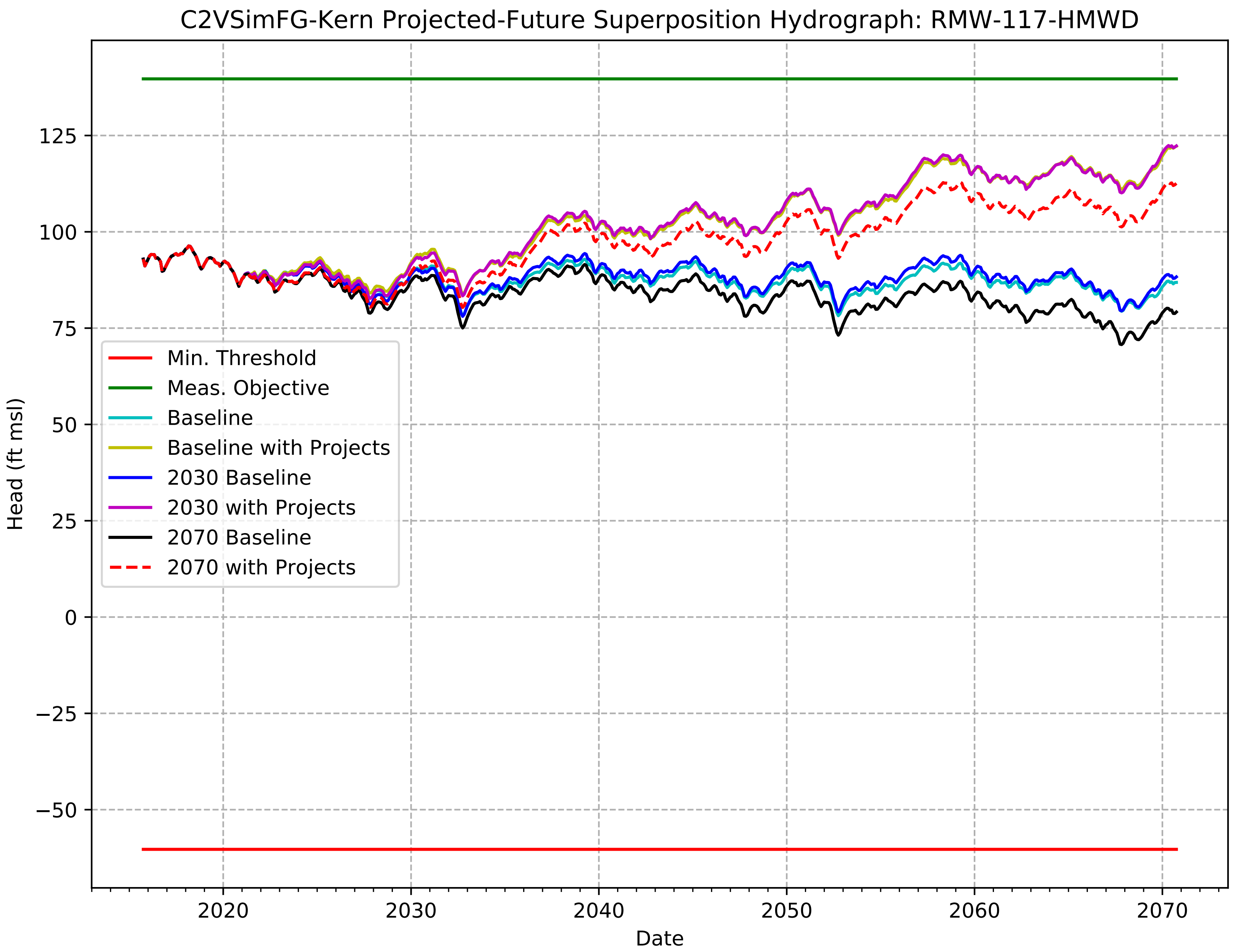
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-116-HMWD
Head (ft msl)
125
100
75
50
25
0
−25
−50
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-117-HMWD
Head (ft msl)
Date
125
100
75
50
25
0
−25
−50
2020
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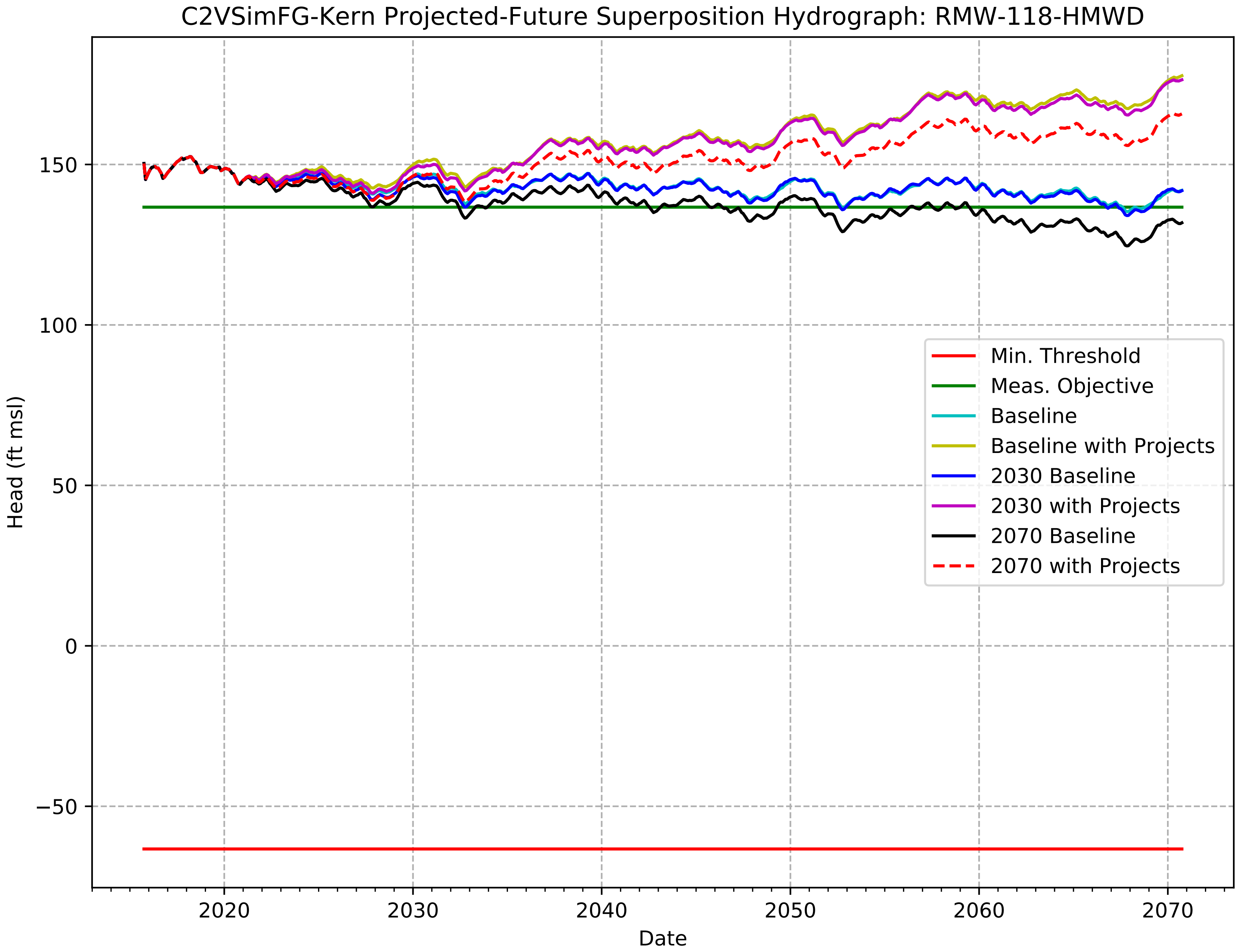
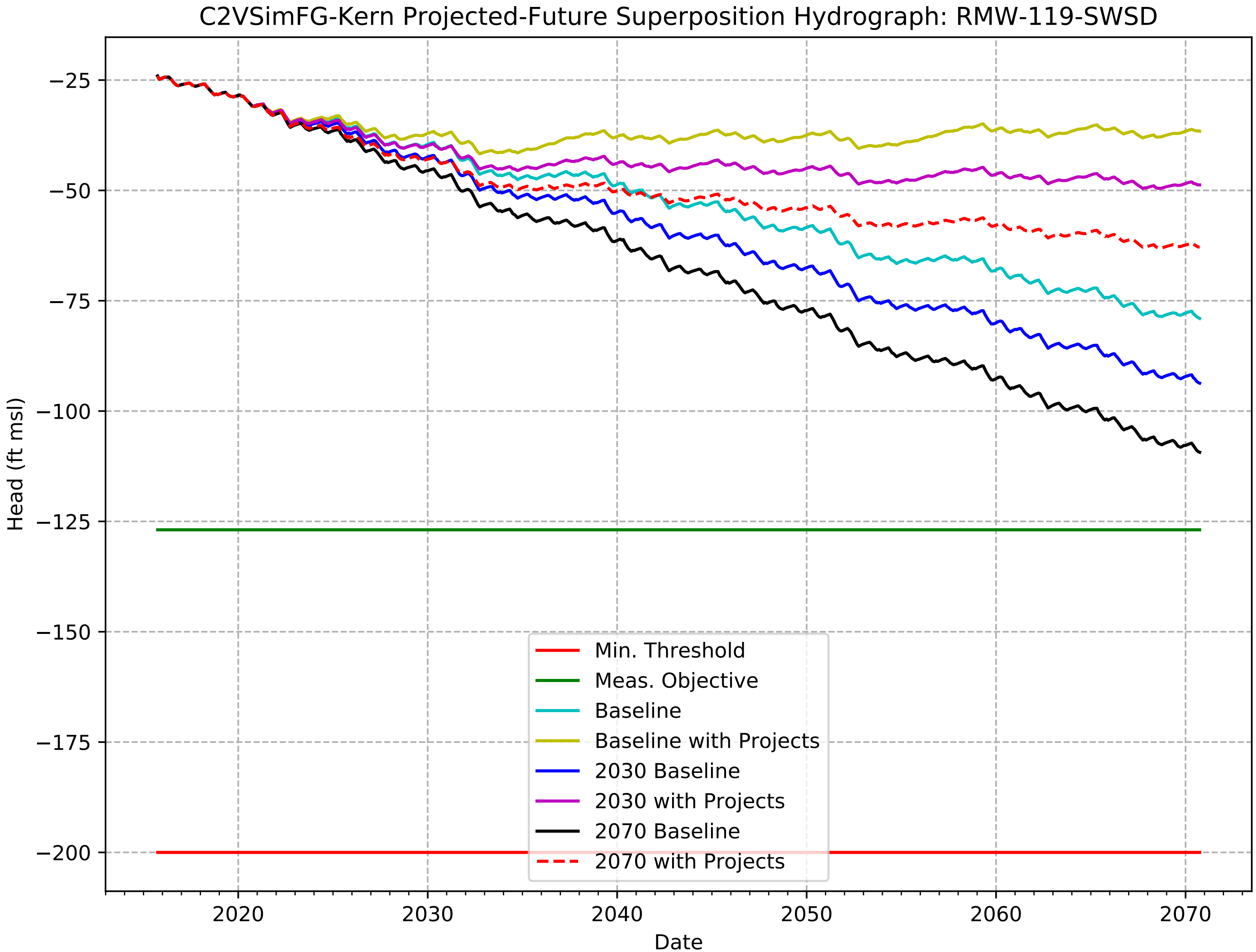
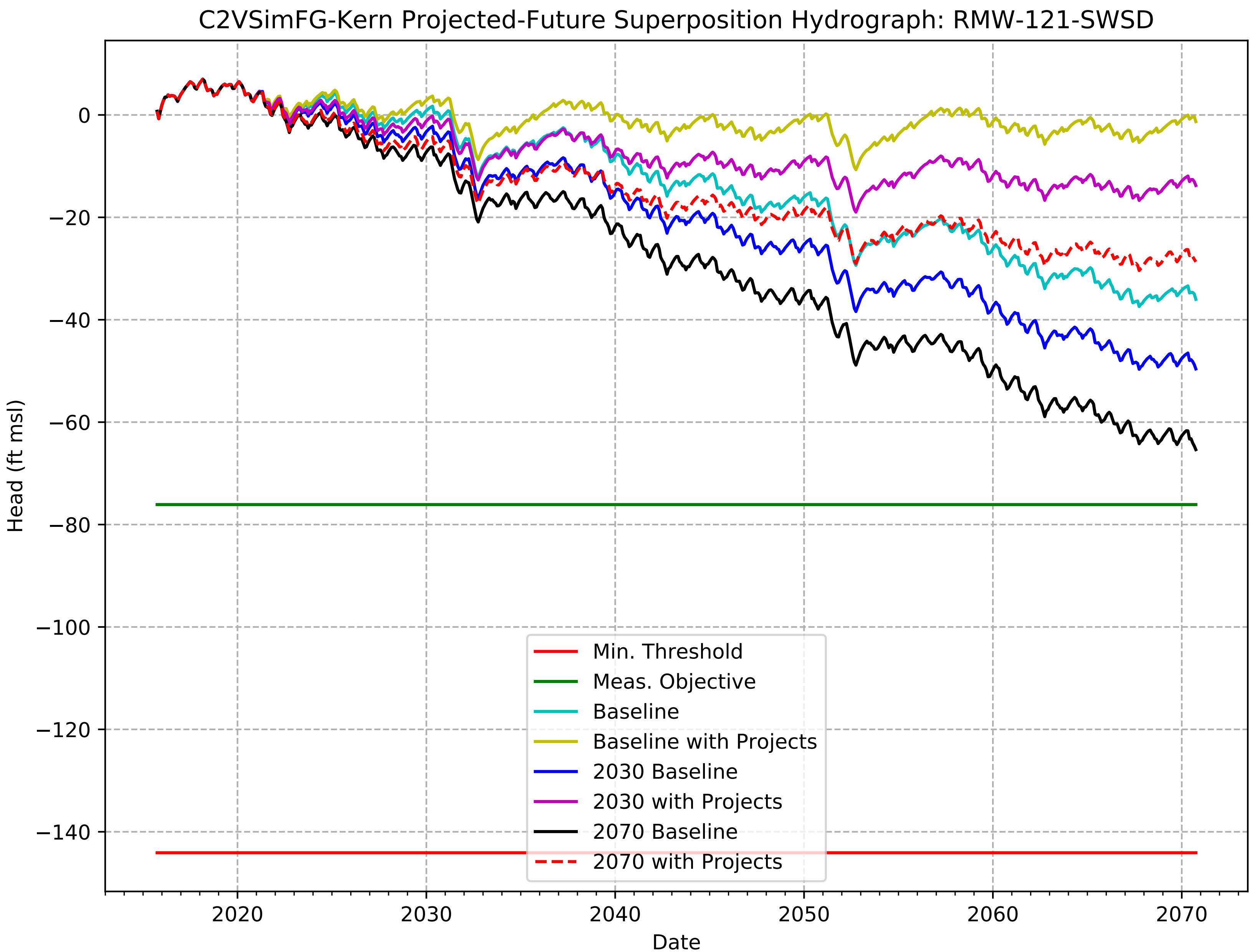
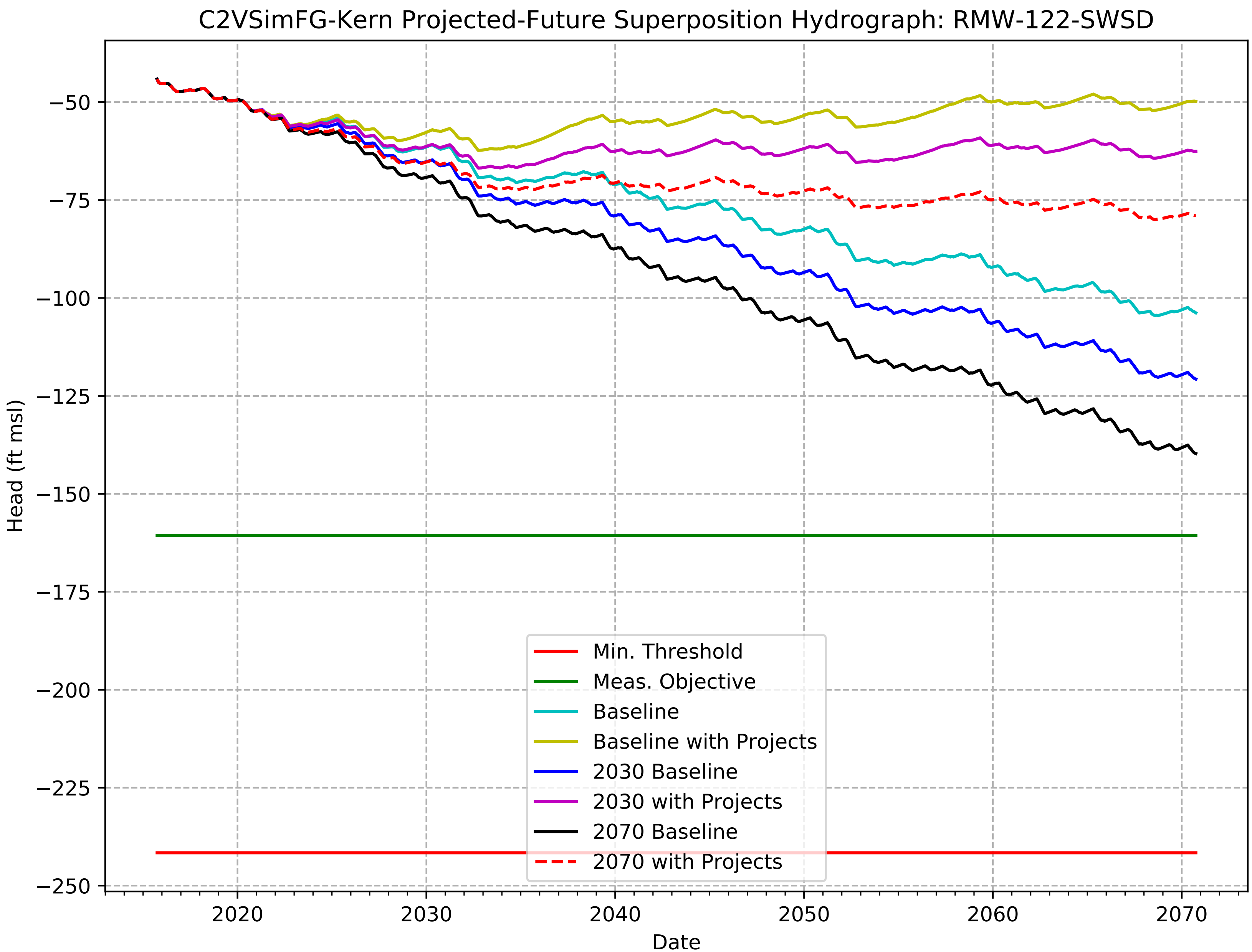
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

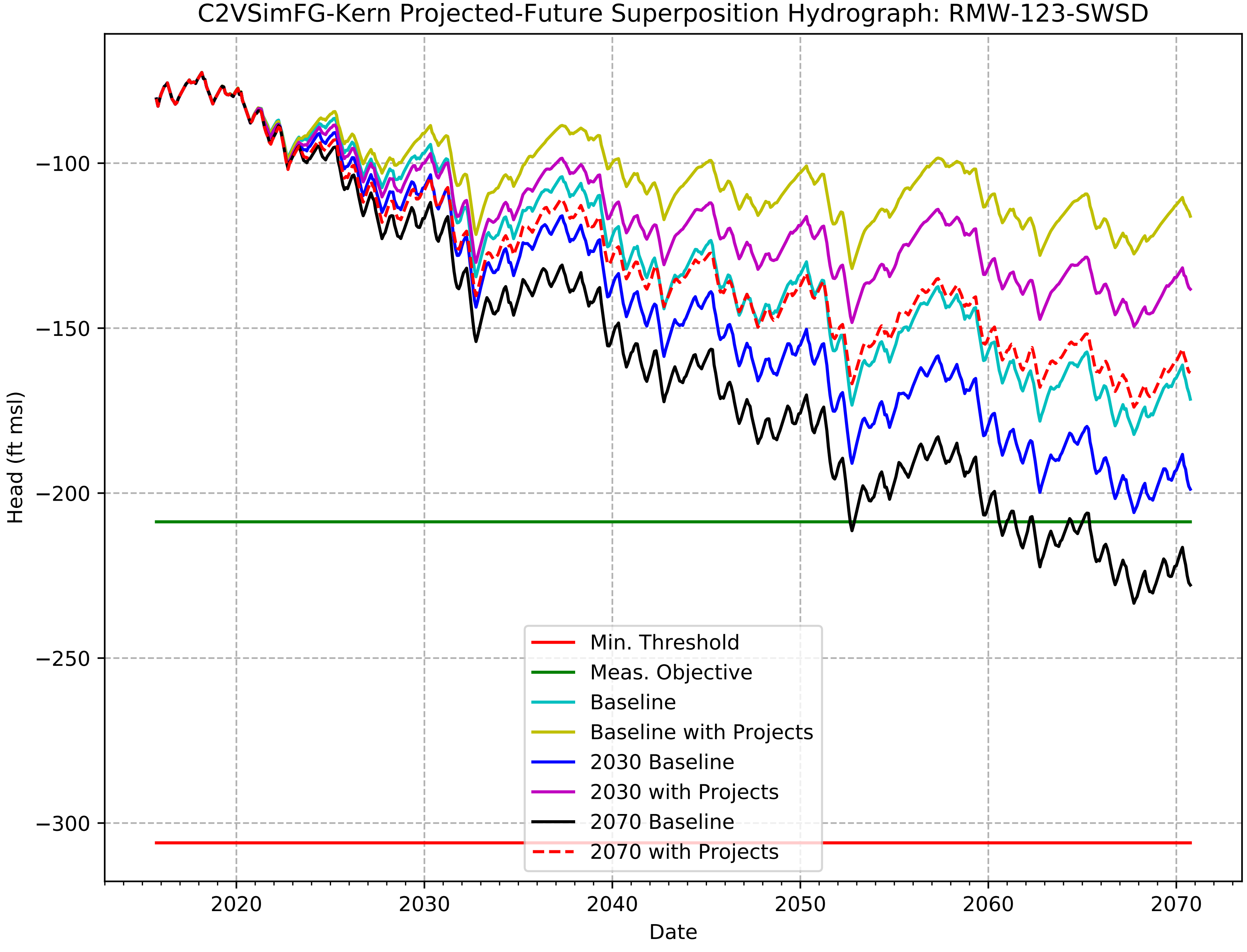

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-118-HMWD
Head (ft msl)
Date
150
100
50
0
−50
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



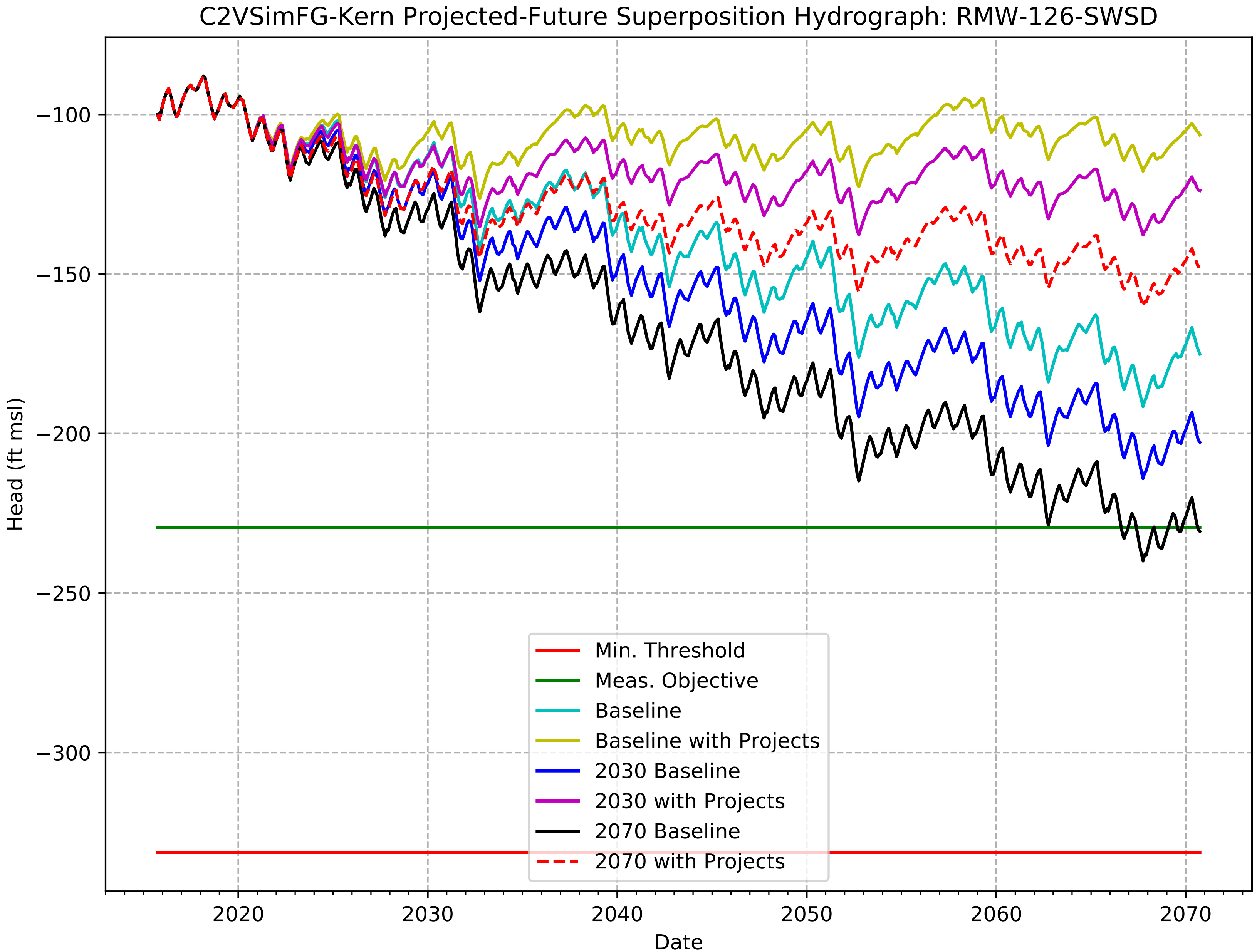
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-119-SWSD
Head (ft msl)
−25
−50
−75
−100
−125
−150
−175
−200
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

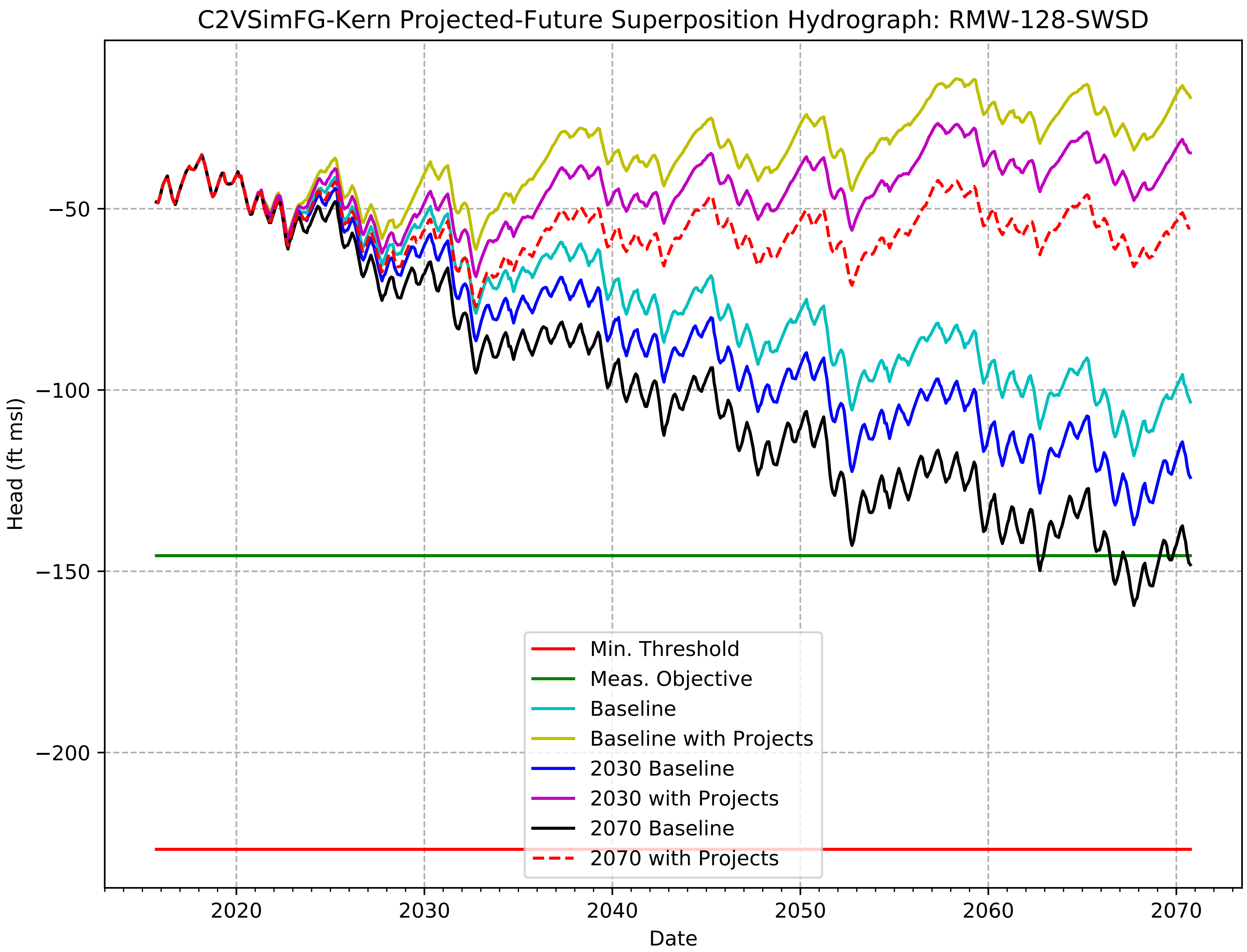

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-121-SWSD
Head (ft msl)
Date
0
−20
−40
−60
−80
−100
−120
−140
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

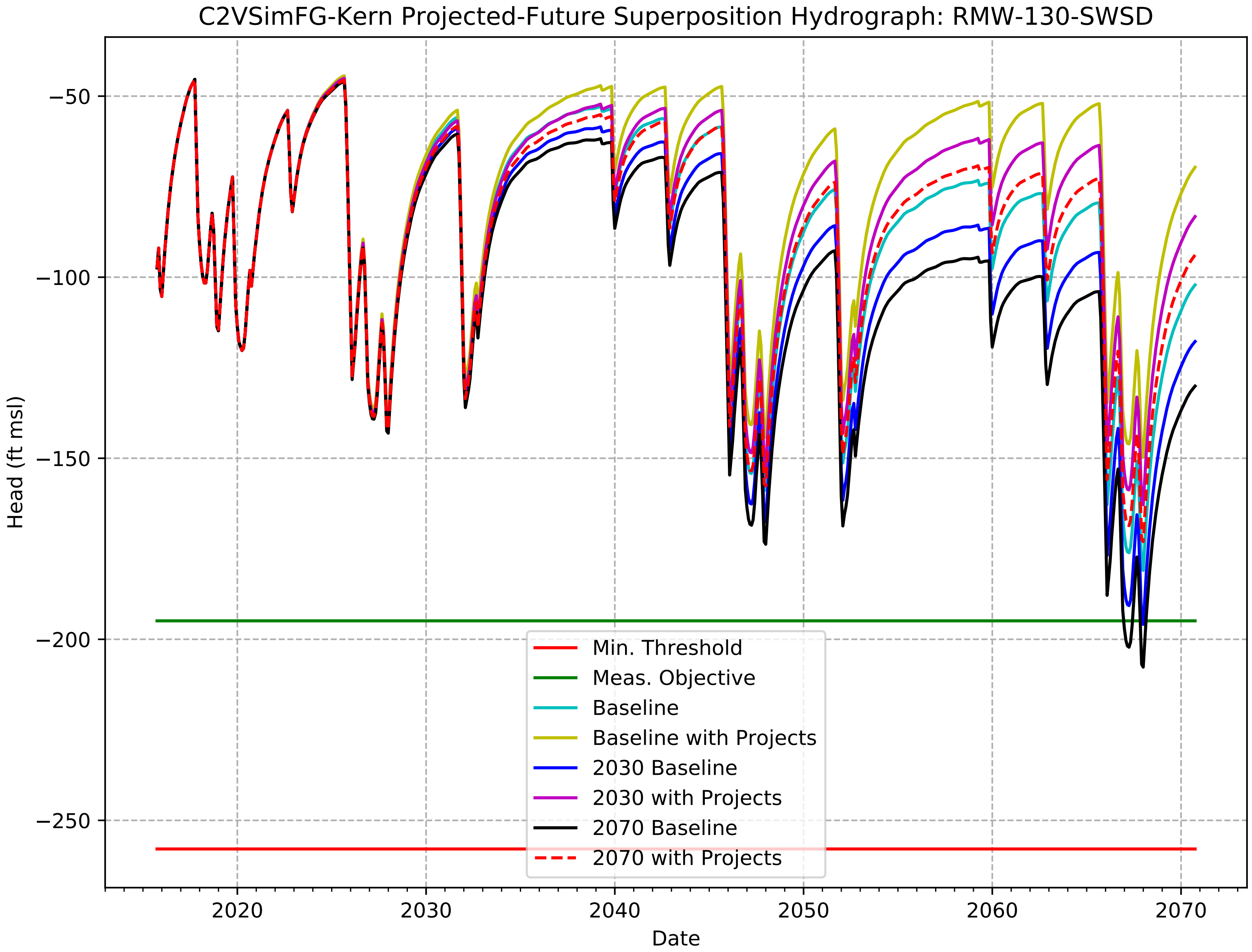

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-122-SWSD
Head (ft msl)
Date
−50
−75
−100
−125
−150
−175
−200
−225
−250
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

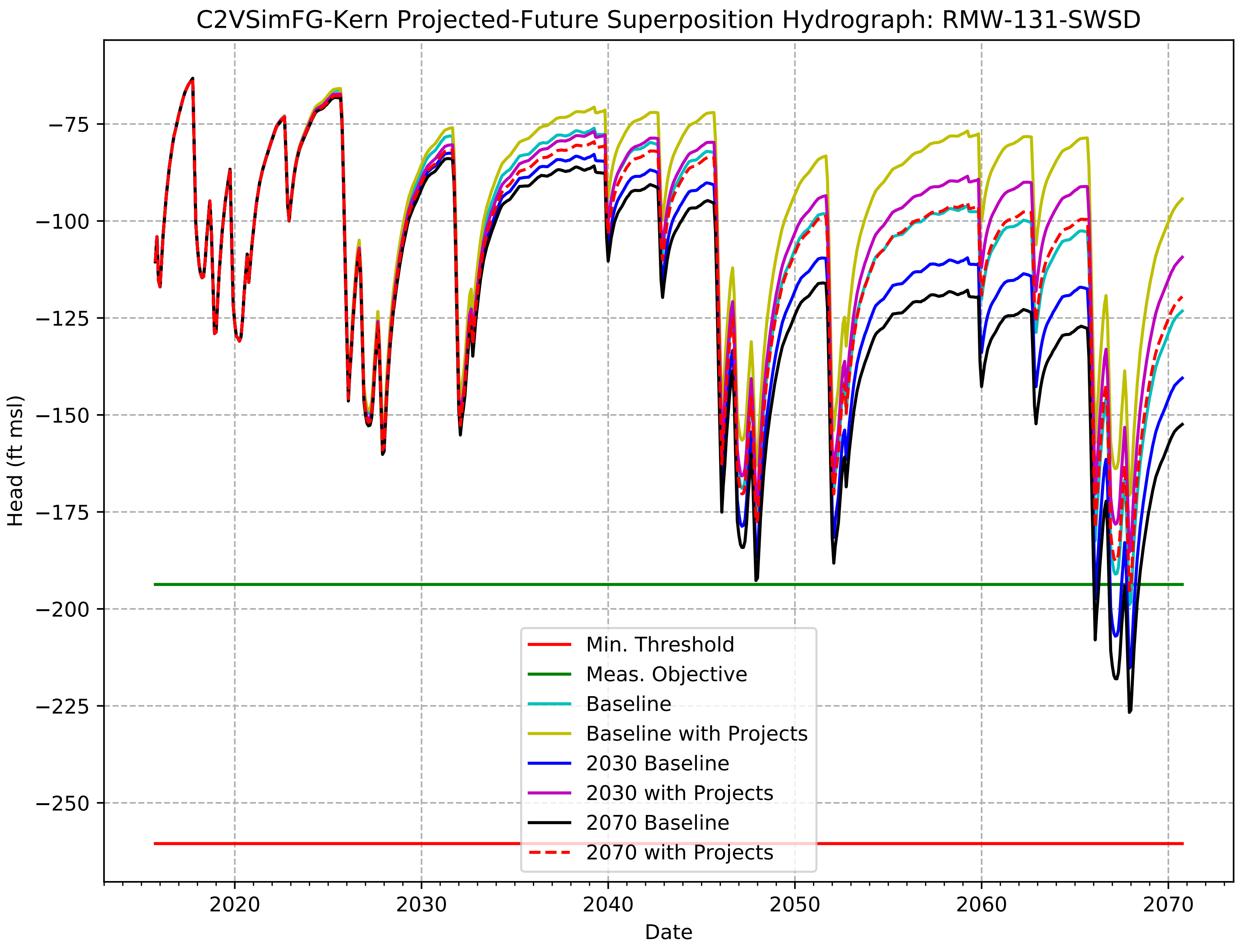


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-123-SWSD
Head (ft msl)
−100
−150
−200
−250
−300
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

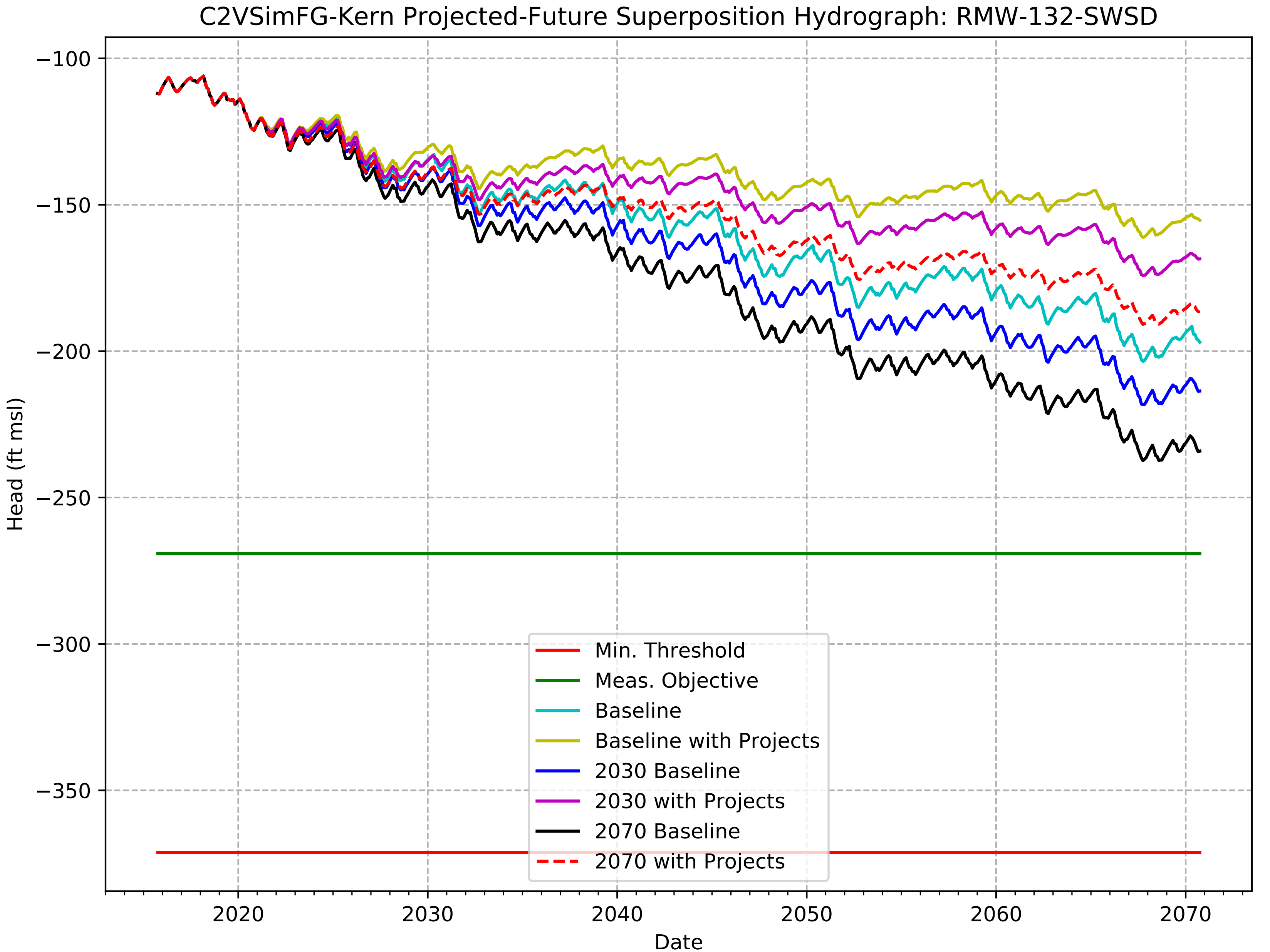

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-126-SWSD
Head (ft msl)
−100
−150
−200
−250
−300
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-128-SWSD
Head (ft msl)
−50
−100
−150
−200
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

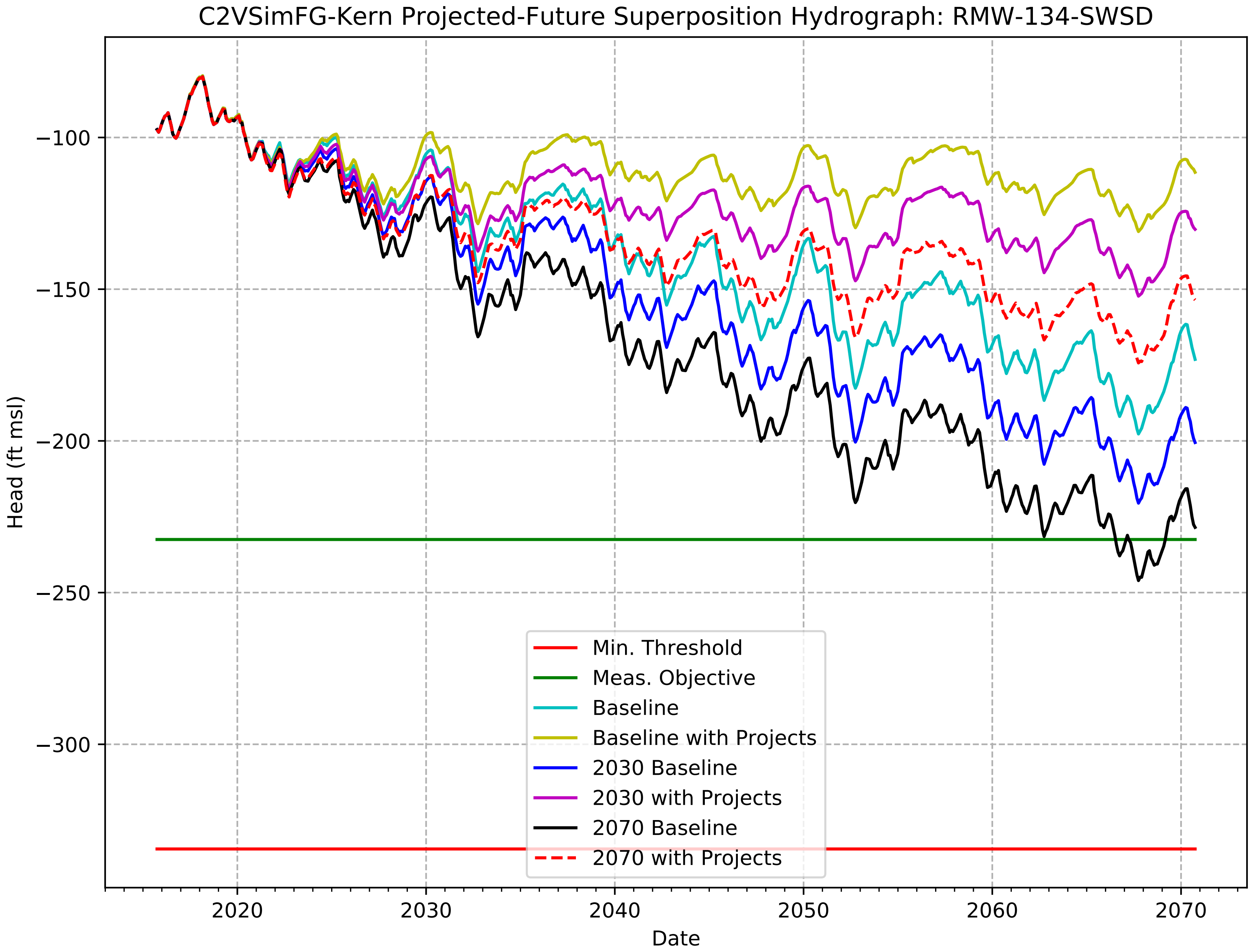

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-130-SWSD
Head (ft msl)
−50
−100
−150
−200
−250
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

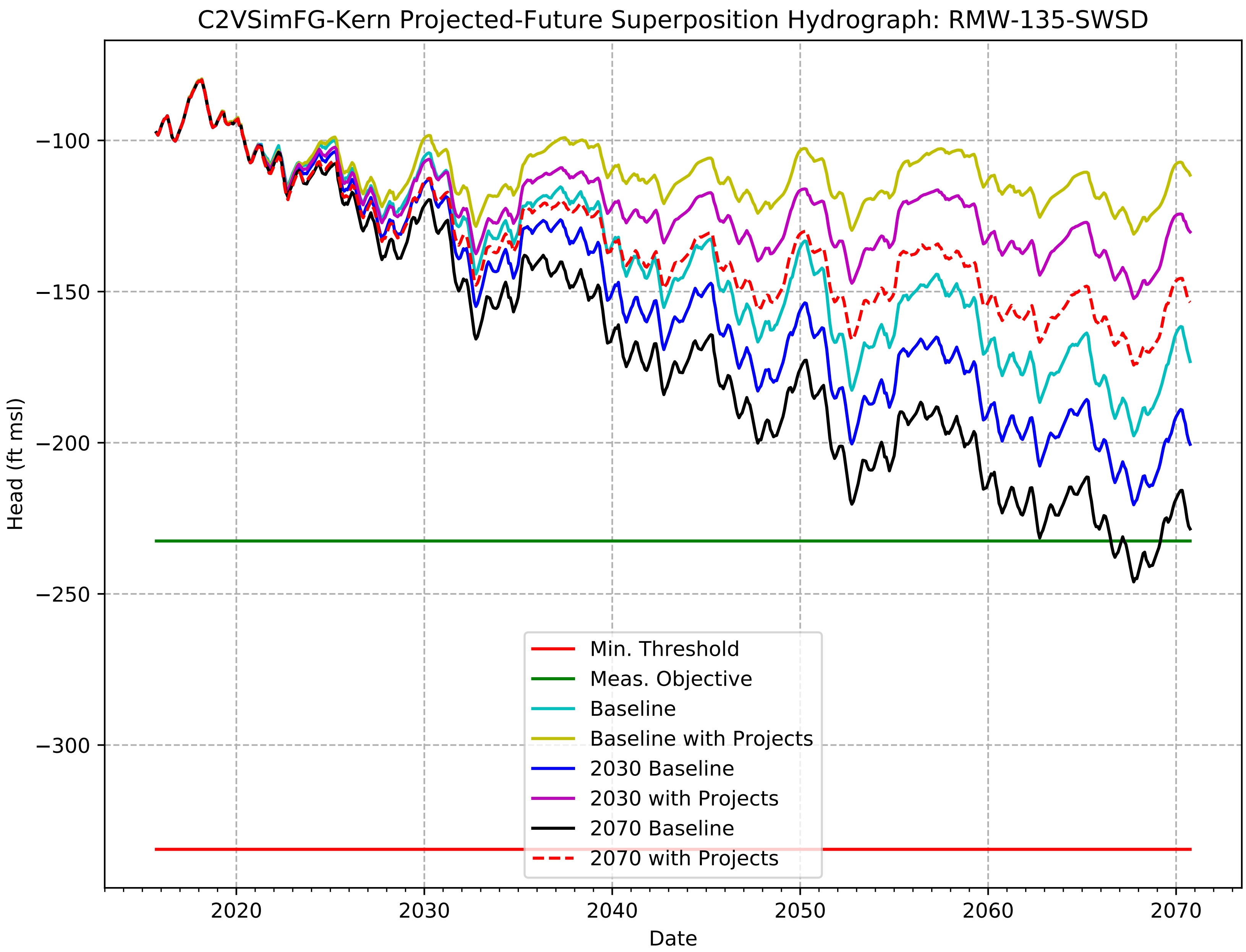


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-131-SWSD
Head (ft msl)
−75
−100
−125
−150
−175
−200
−225
−250
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

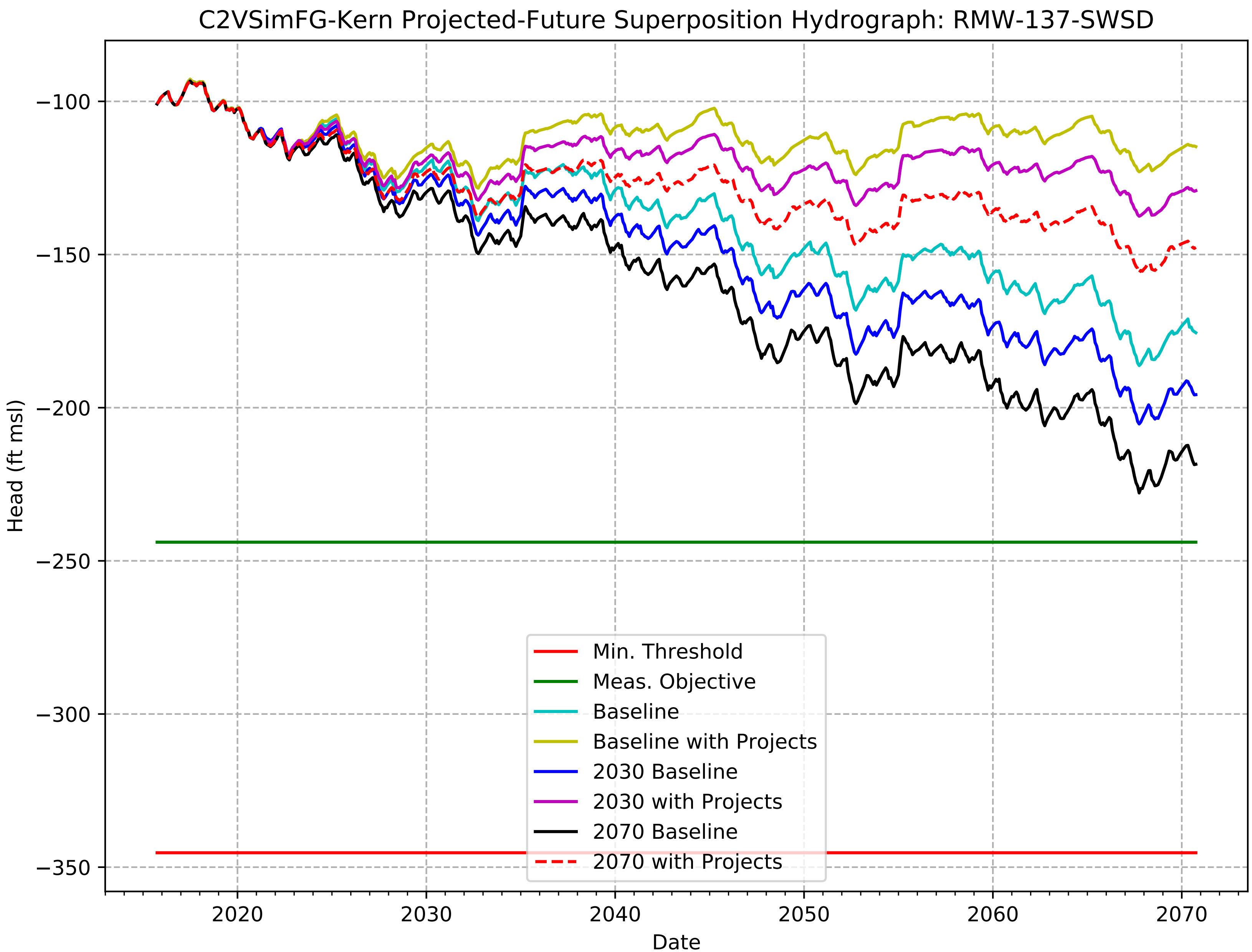


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-132-SWSD
Head (ft msl)
−100
−150
−200
−250
−300
−350
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

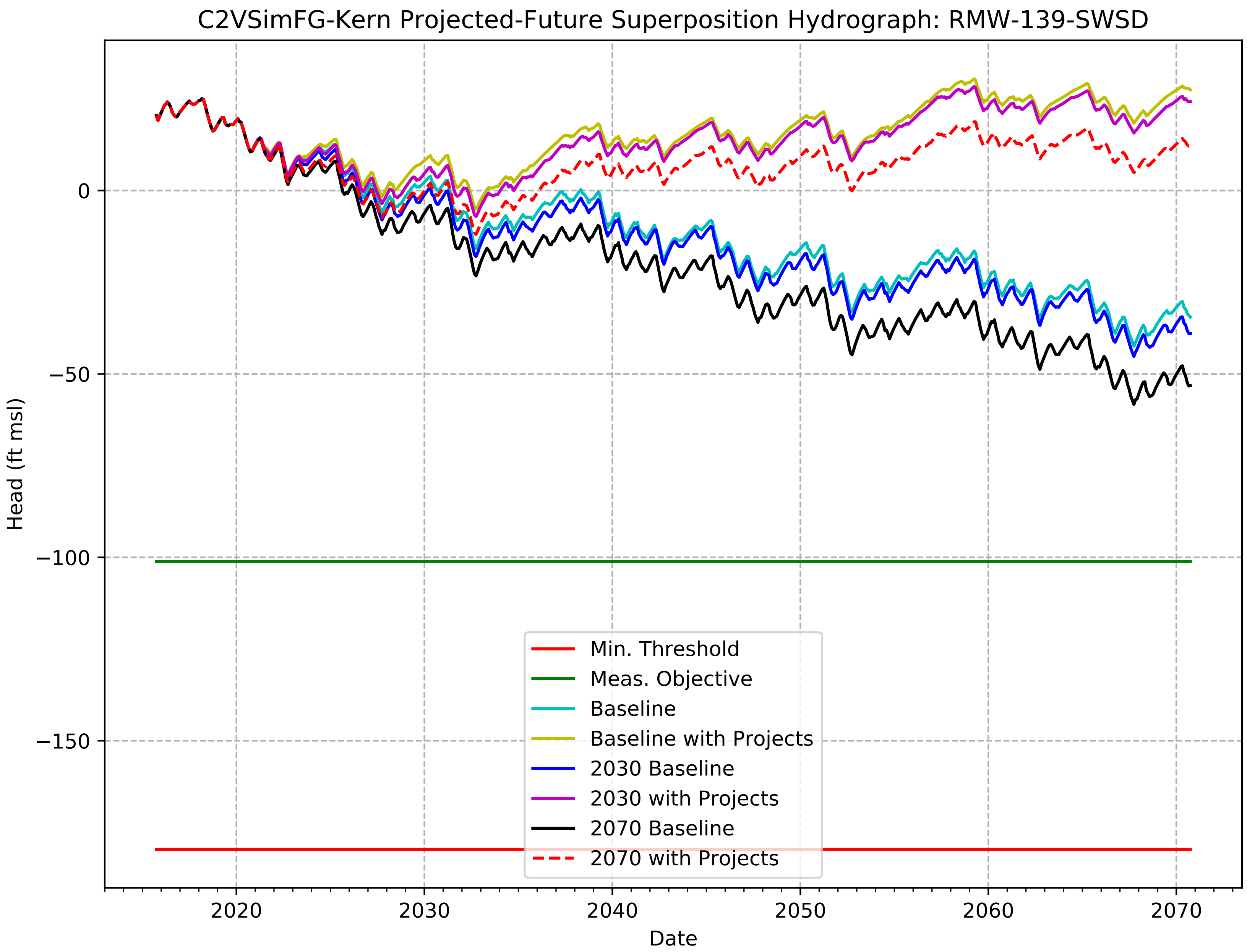

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-134-SWSD
Head (ft msl)
−100
−150
−200
−250
−300
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



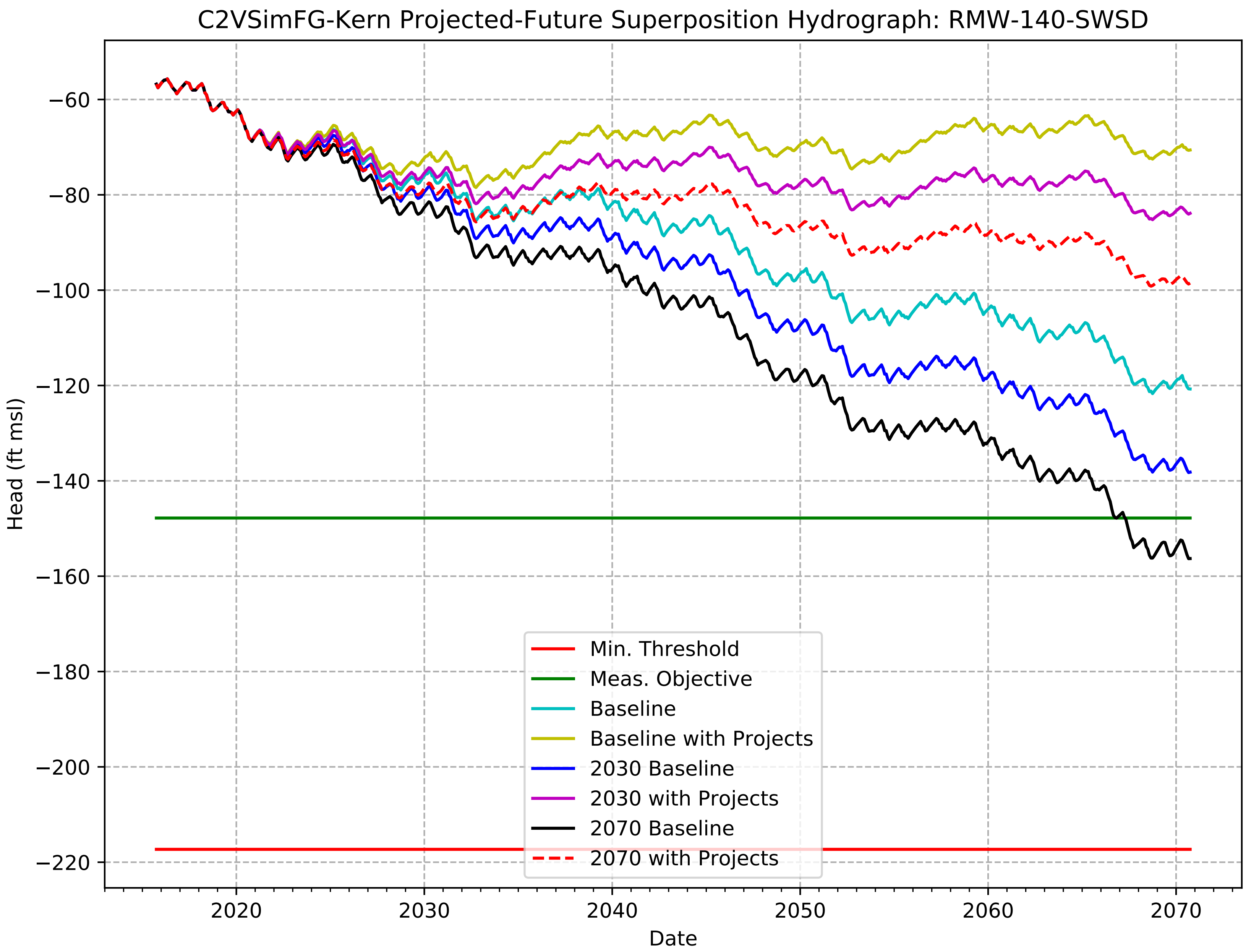
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-135-SWSD
Head (ft msl)
−100
−150
−200
−250
−300
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-137-SWSD
Head (ft msl)
−100
−150
−200
−250
−300
−350
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-139-SWSD
Head (ft msl)
Date
0
−50
−100
−150
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-140-SWSD
Head (ft msl)
−60
−80
−100
−120
−140
−160
−180
−200
−220
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
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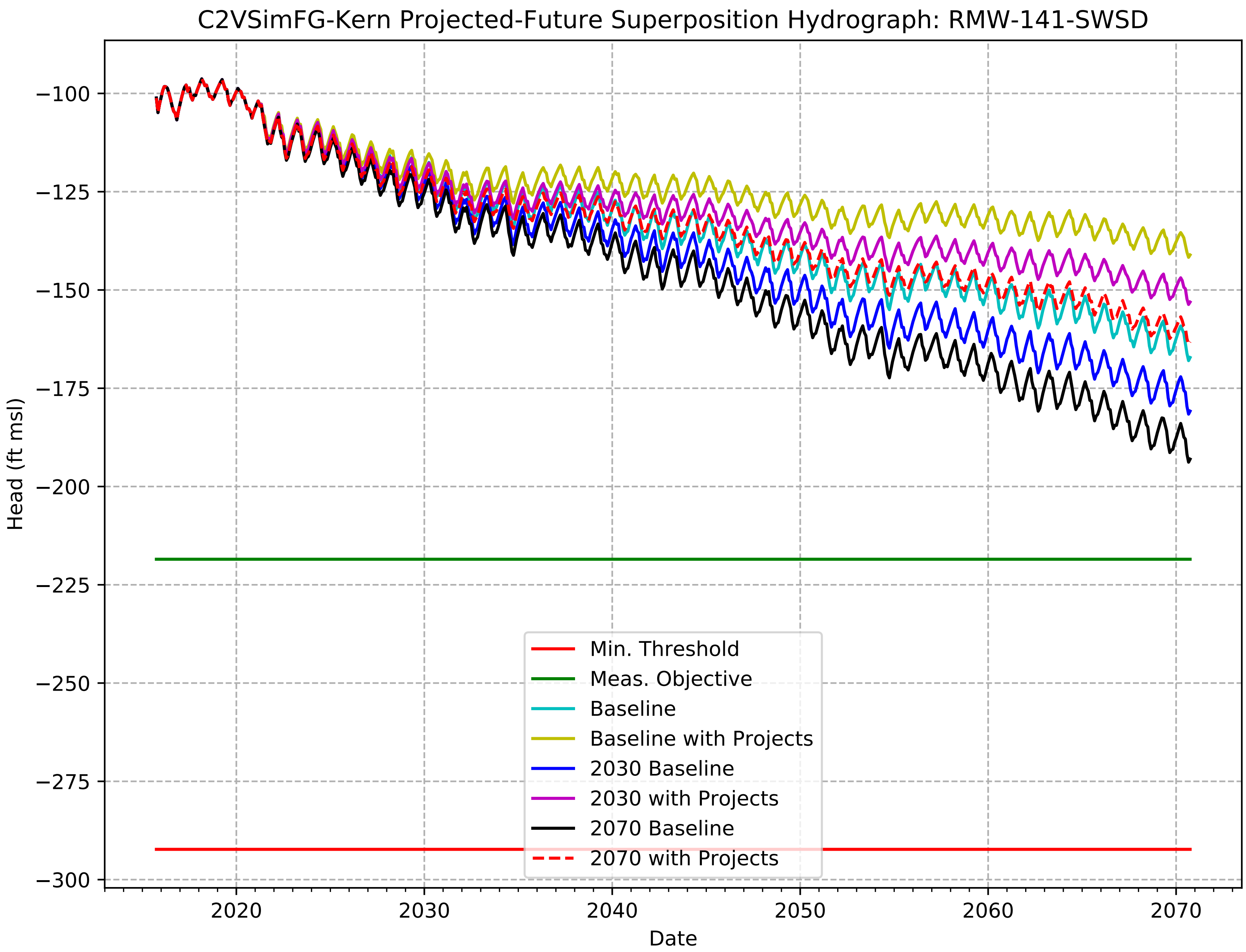
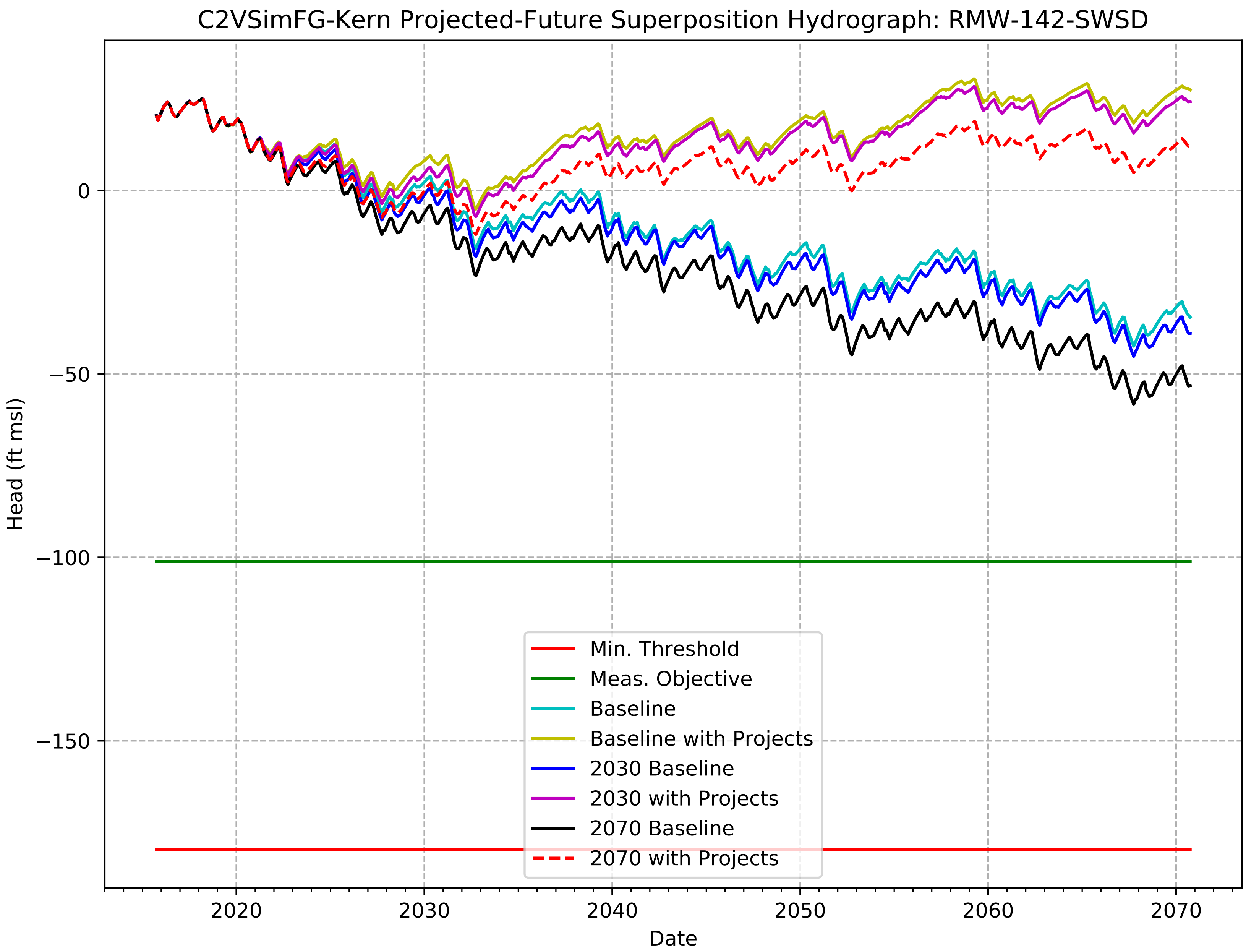
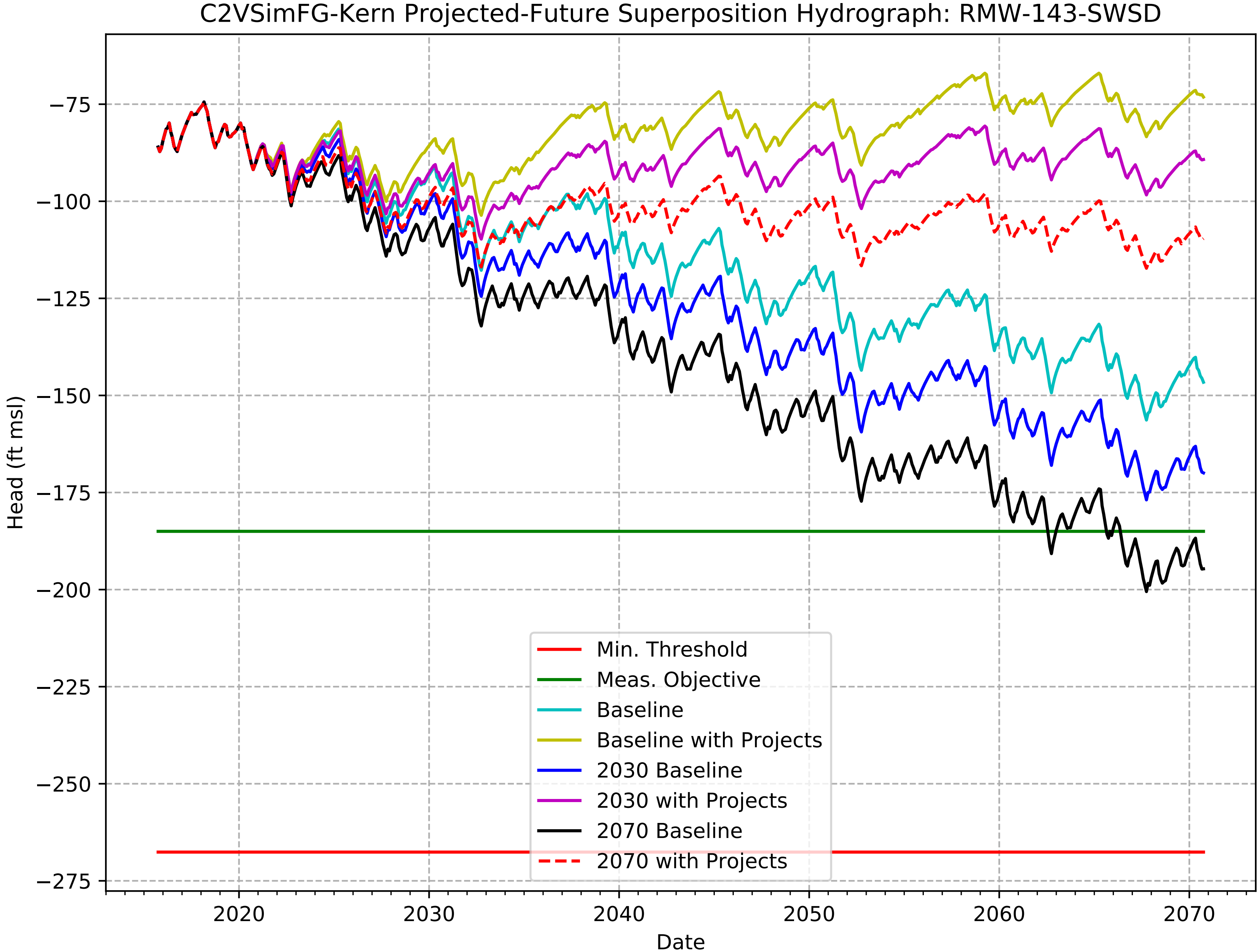
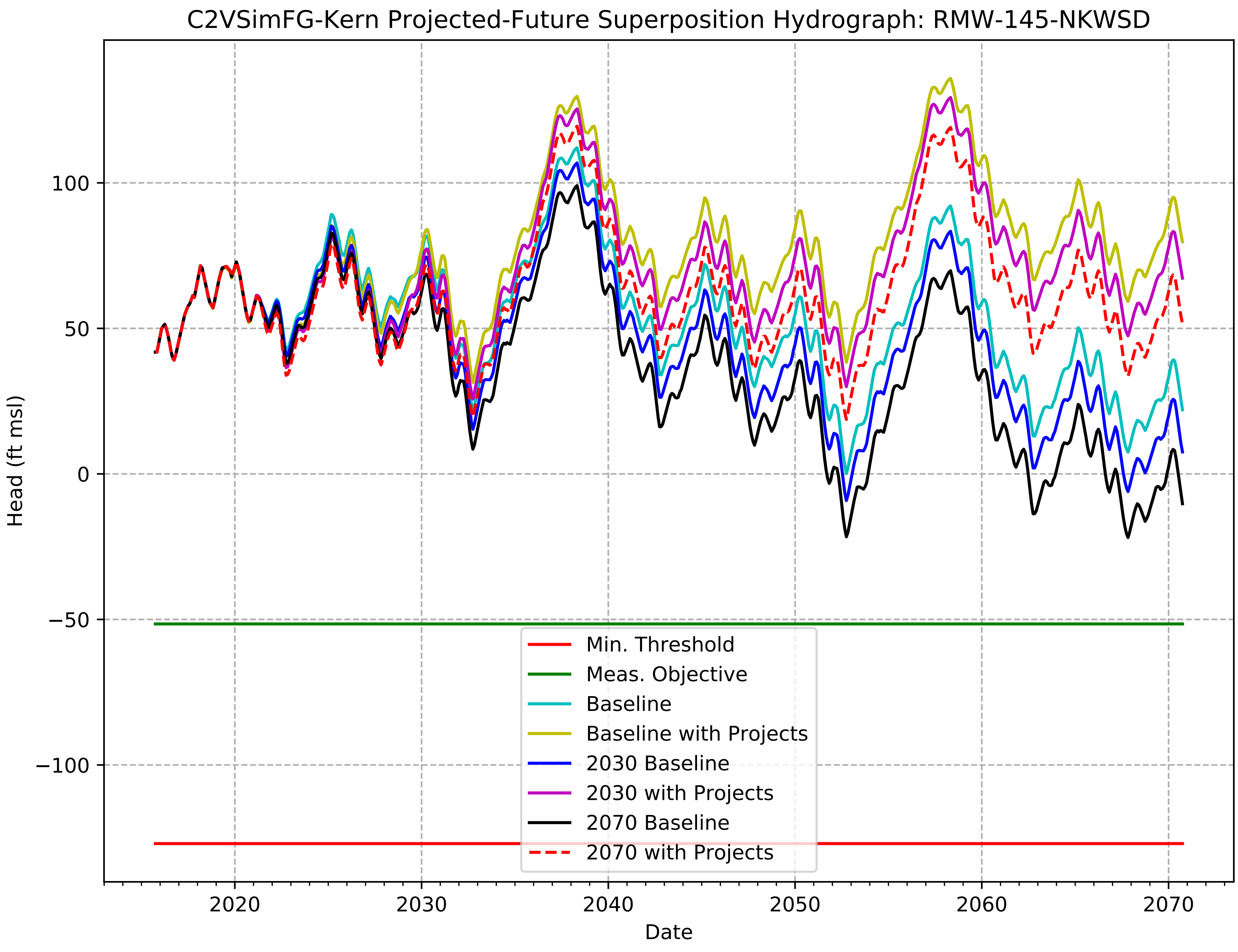
2030 with Projects
2070 Baseline
2070 with Projects

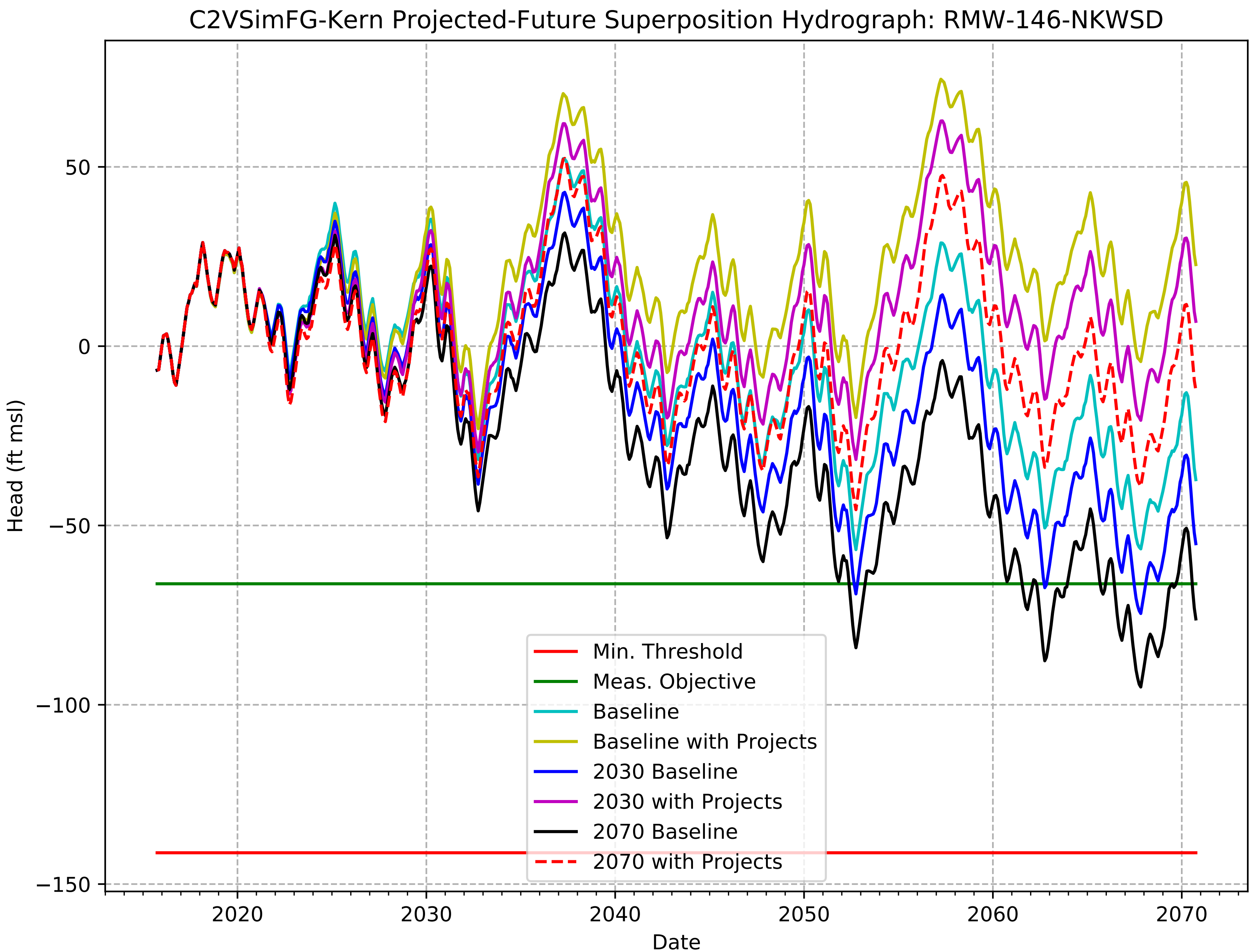

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-141-SWSD
Head (ft msl)
−100
−125
−150
−175
−200
−225
−250
−275
−300
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

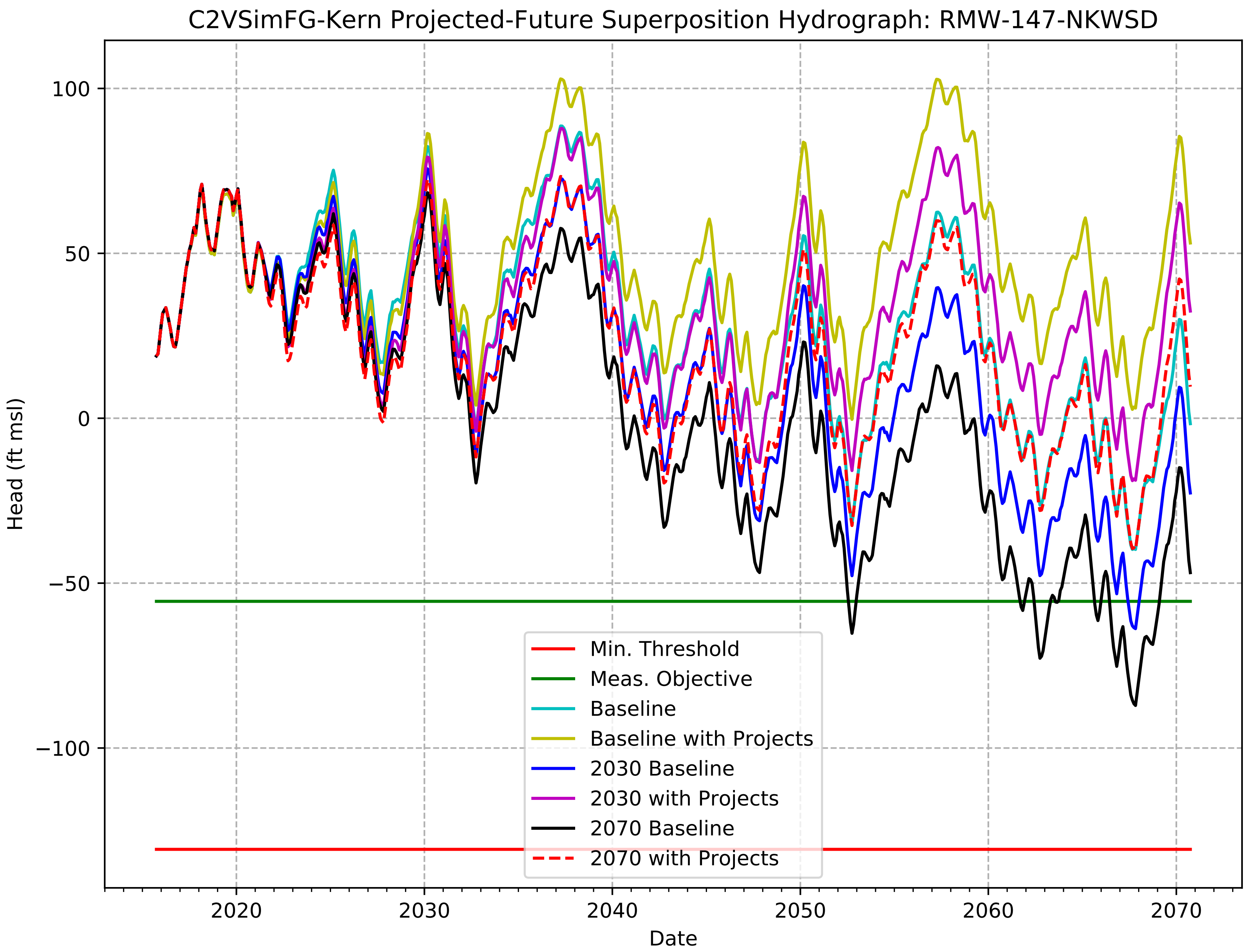


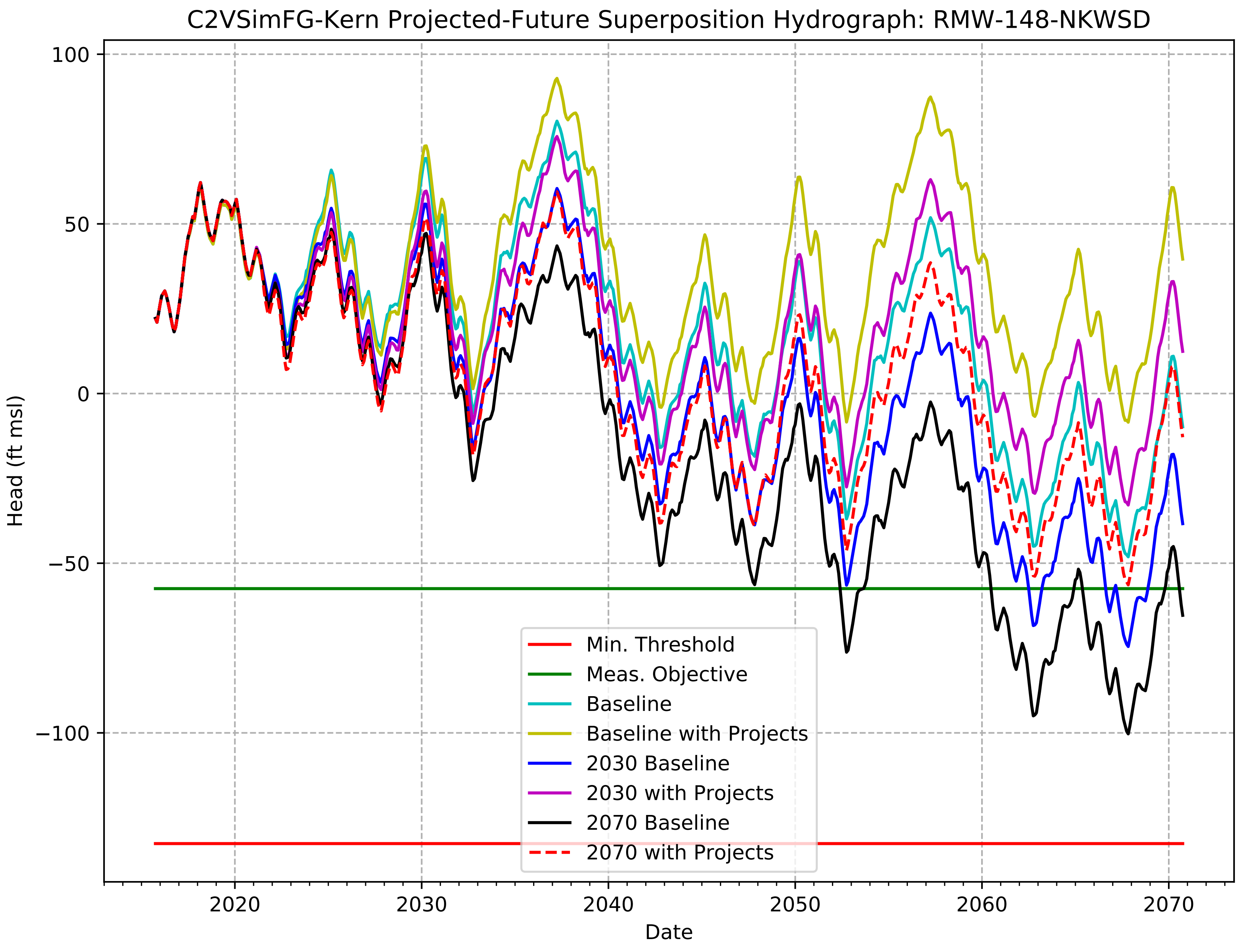
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-142-SWSD
Head (ft msl)
0
−50
−100
−150
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

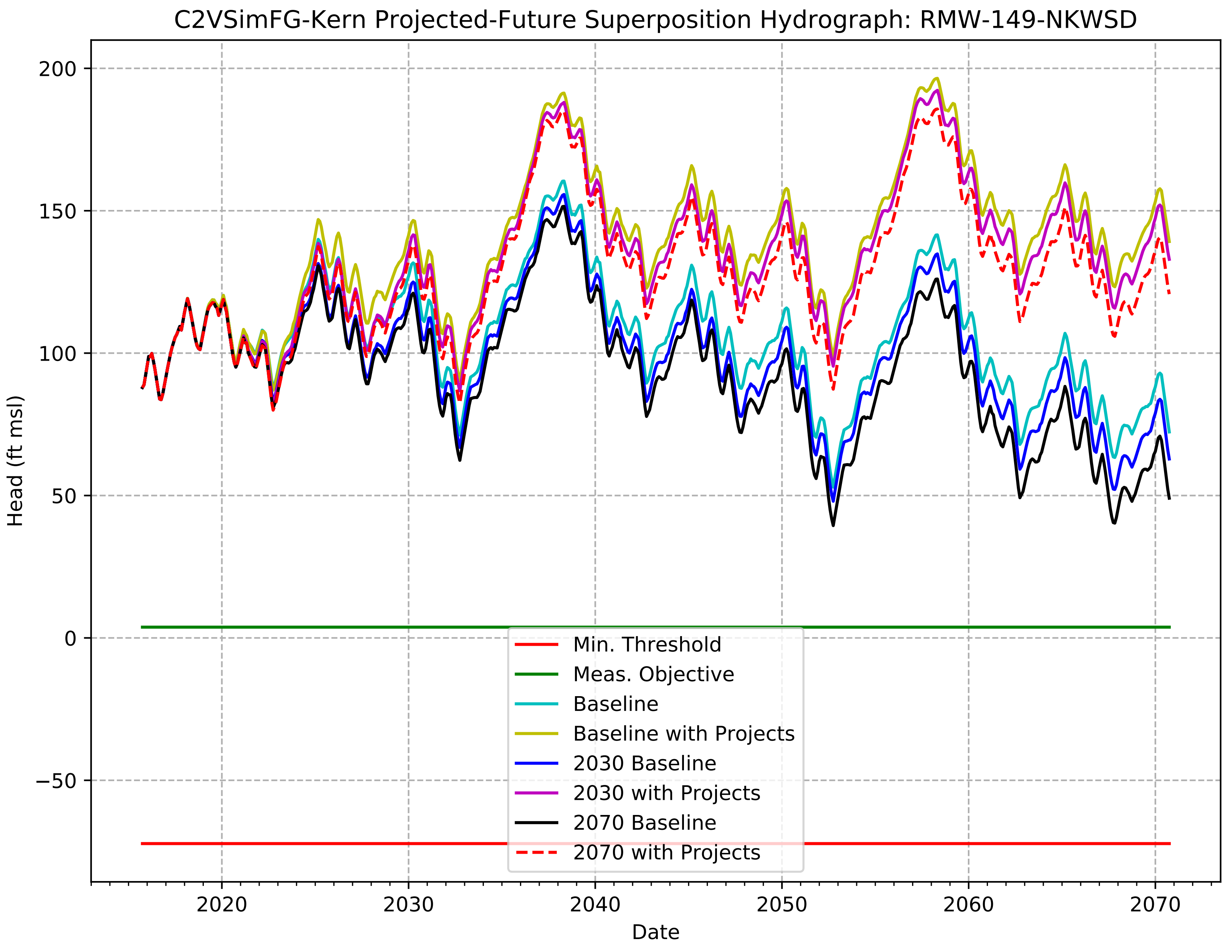

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-143-SWSD
Head (ft msl)
Date
−75
−100
−125
−150
−175
−200
−225
−250
−275
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-145-NKWSD
Head (ft msl)
100
50
0
−50
−100
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

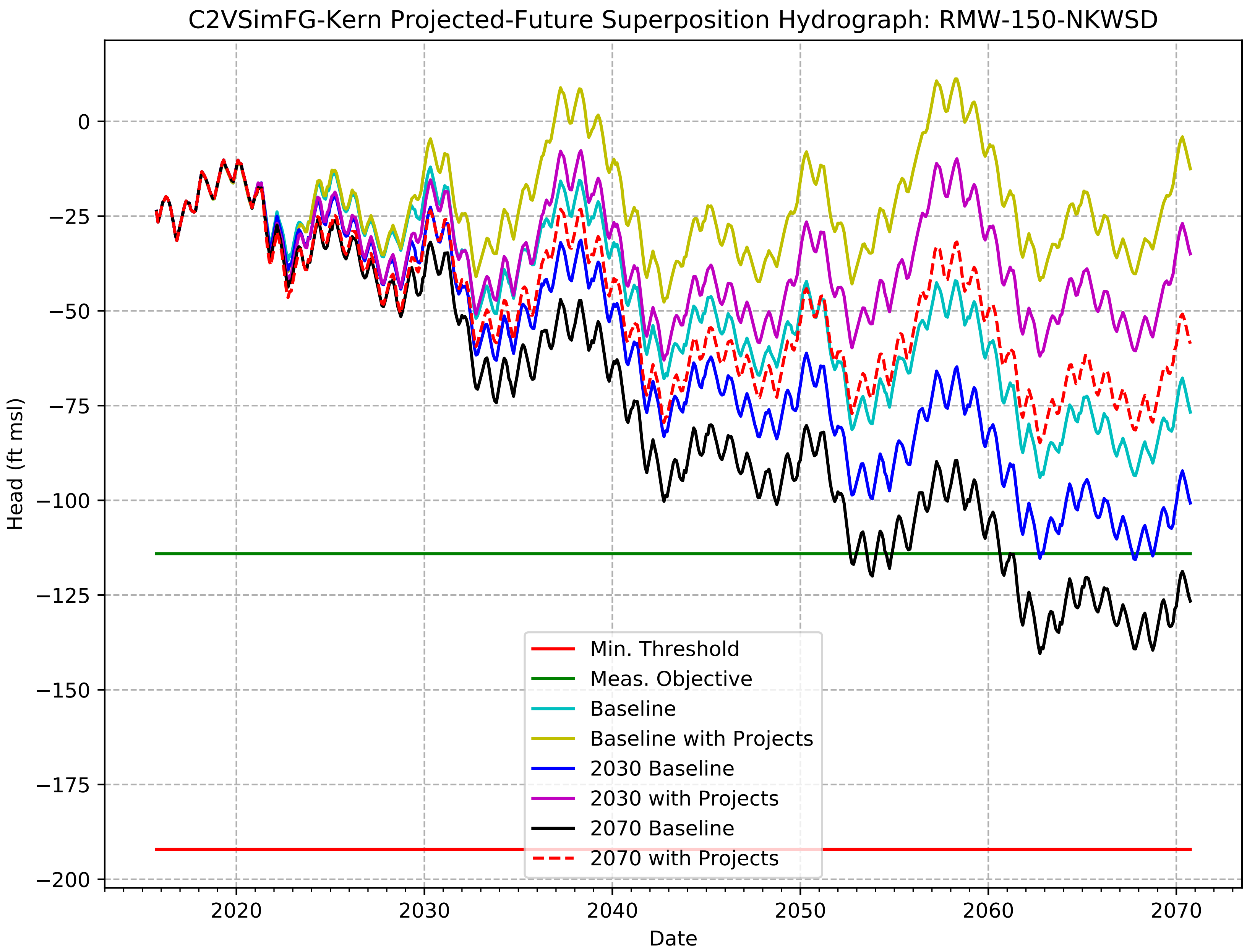

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-146-NKWSD
Head (ft msl)
50
0
−50
−100
−150
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

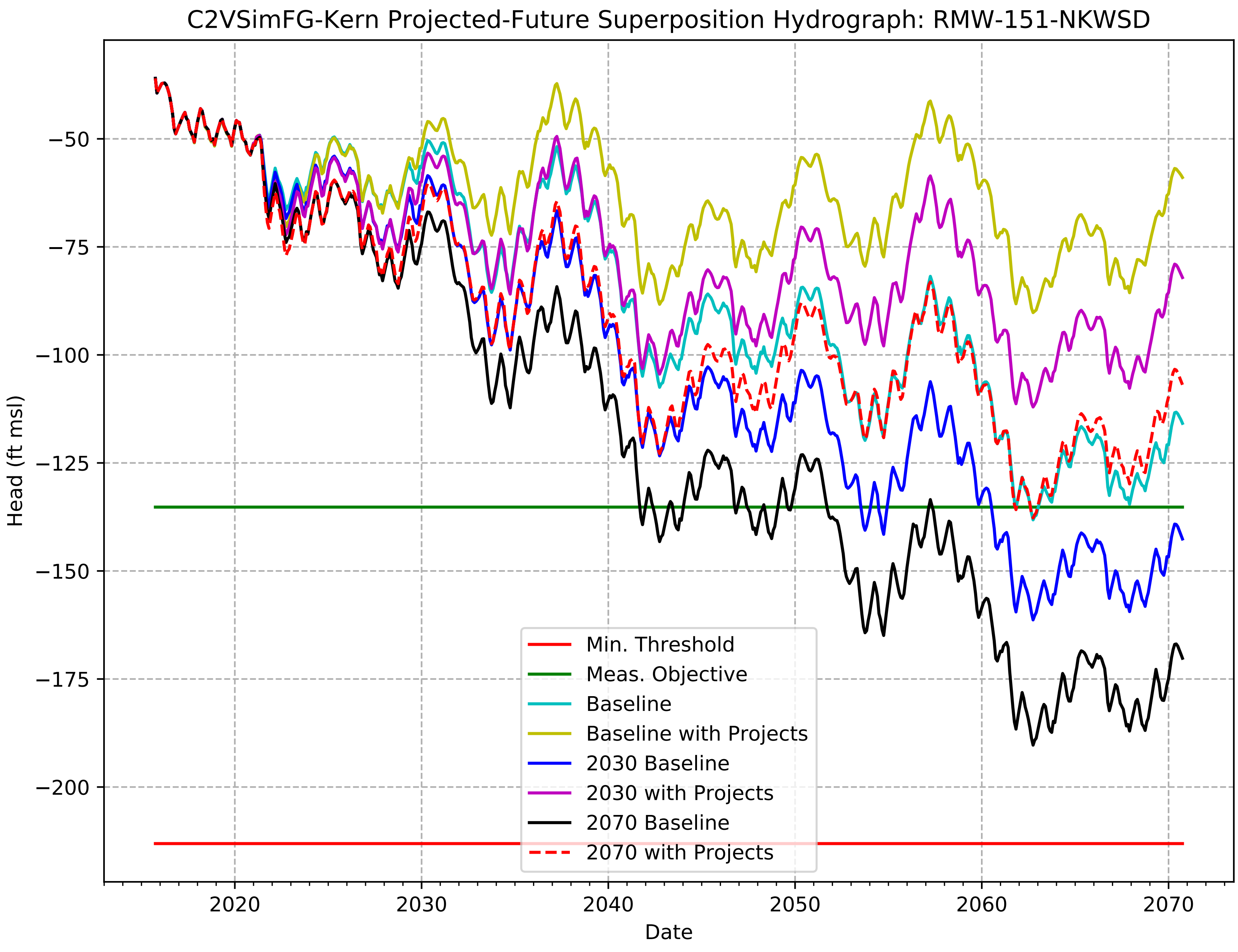

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-147-NKWSD
Head (ft msl)
Date
100
50
0
−50
−100
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-148-NKWSD
Head (ft msl)
100
50
0
−50
−100
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

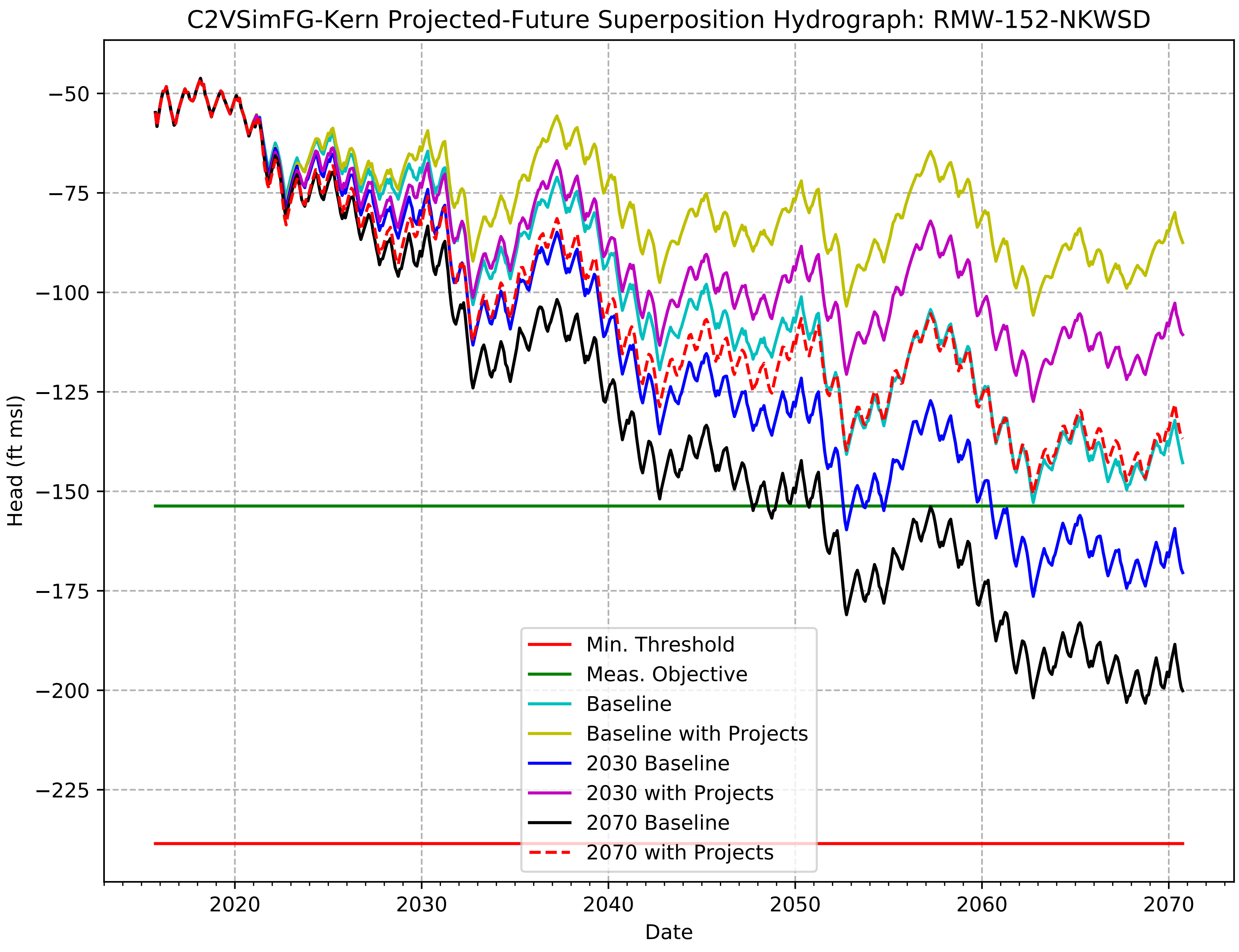


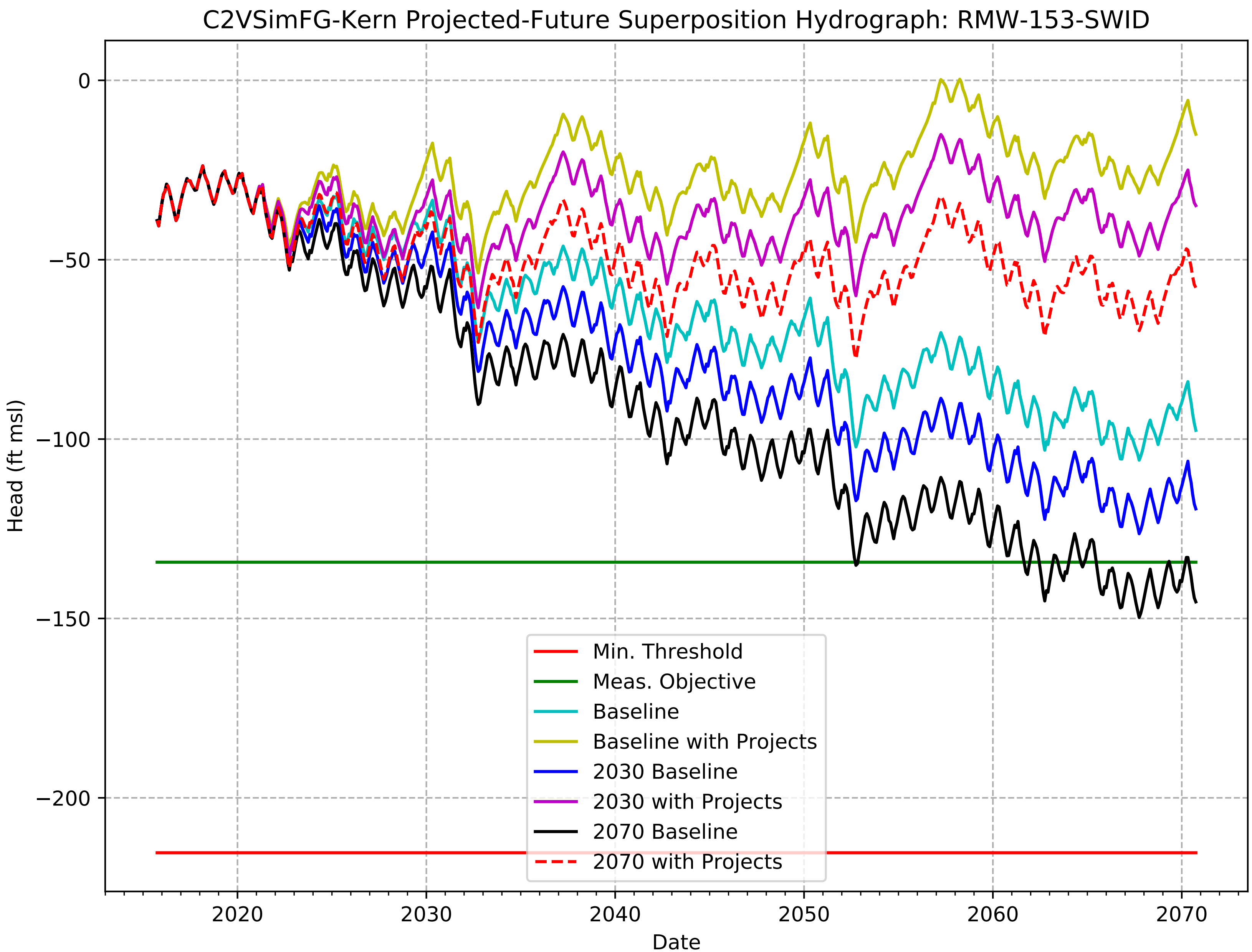
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-149-NKWSD
Head (ft msl)
200
150
100
50
0
−50
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

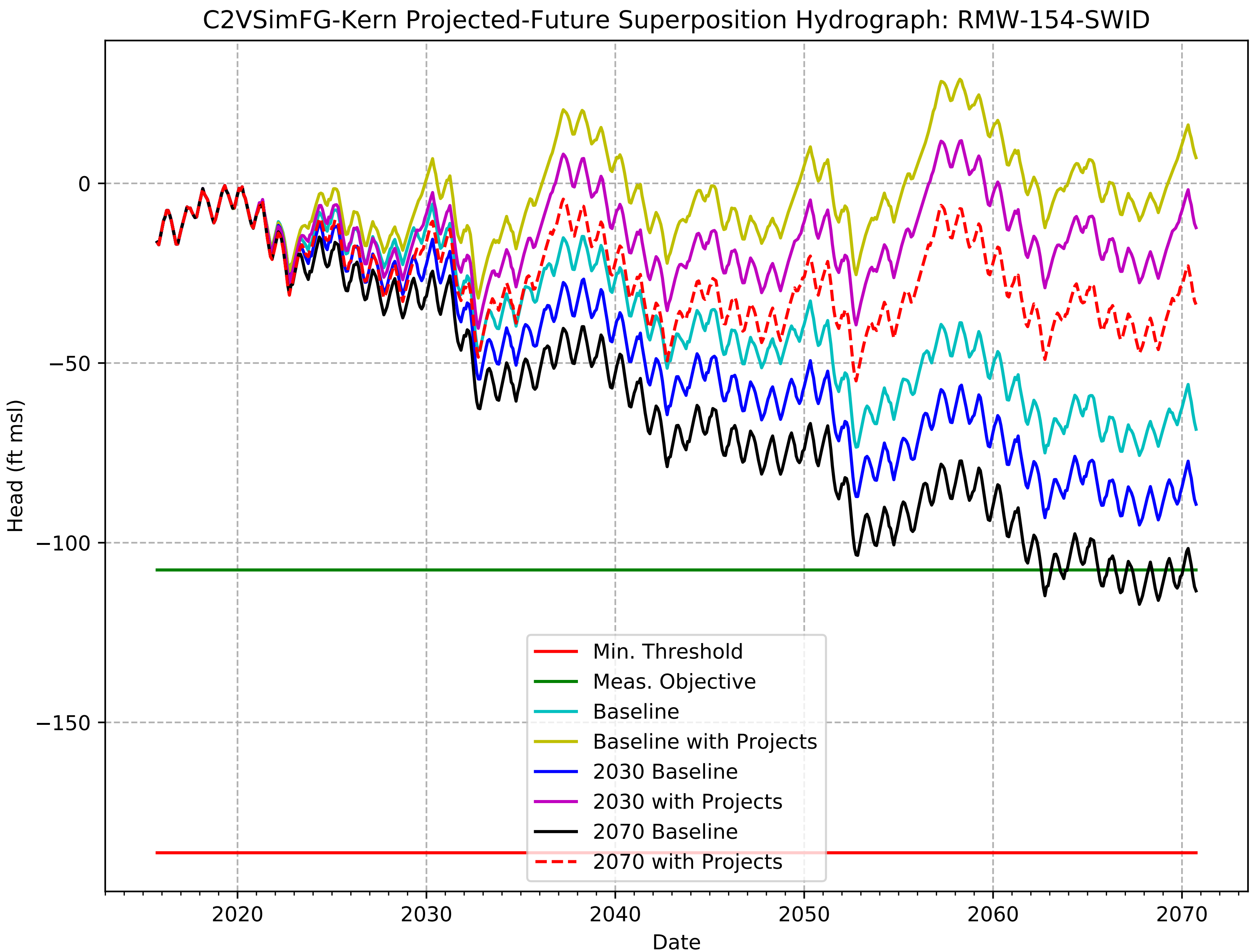

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-150-NKWSD
Head (ft msl)
0
−25
−50
−75
−100
−125
−150
−175
−200
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

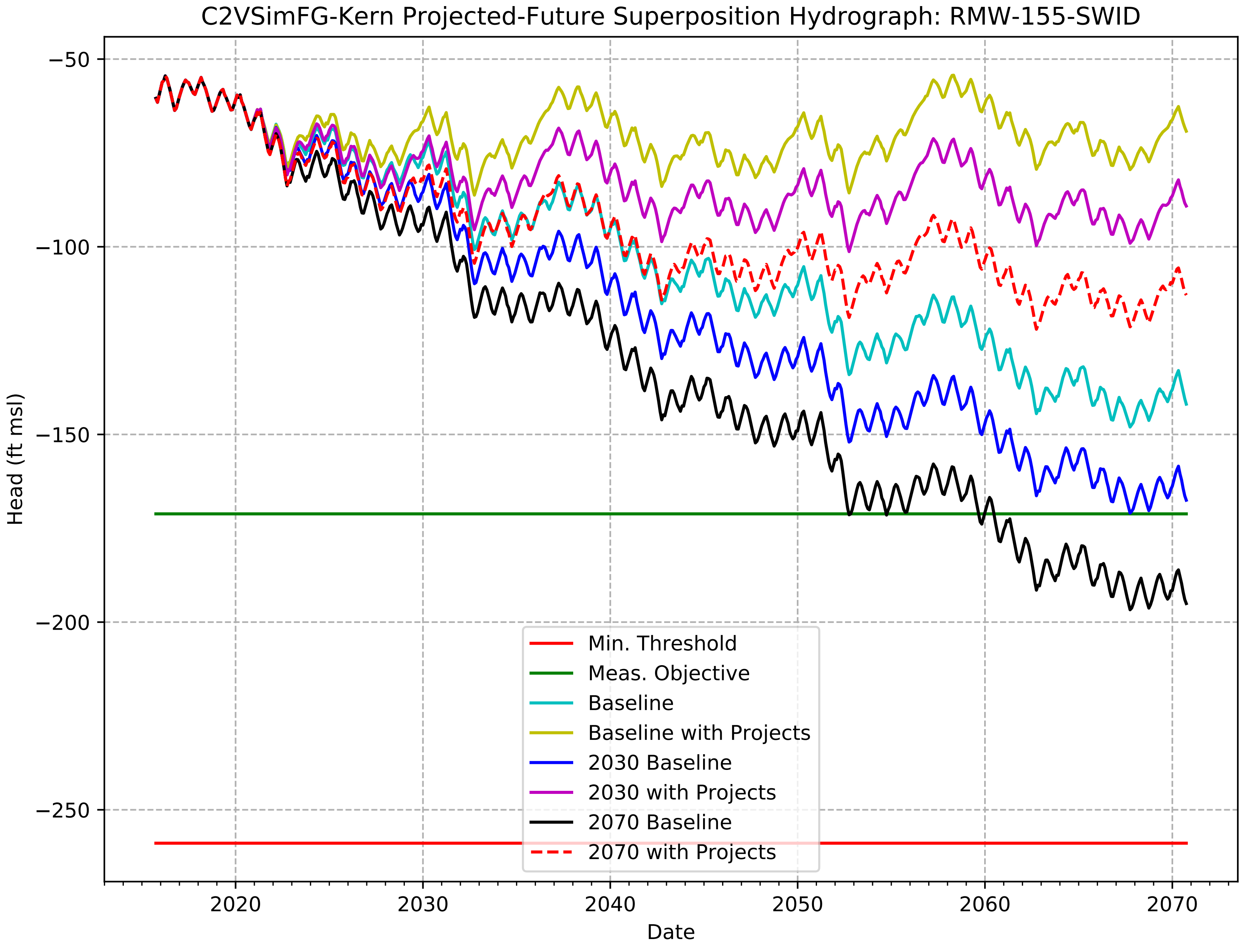


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-151-NKWSD
Head (ft msl)
−50
−75
−100
−125
−150
−175
−200
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

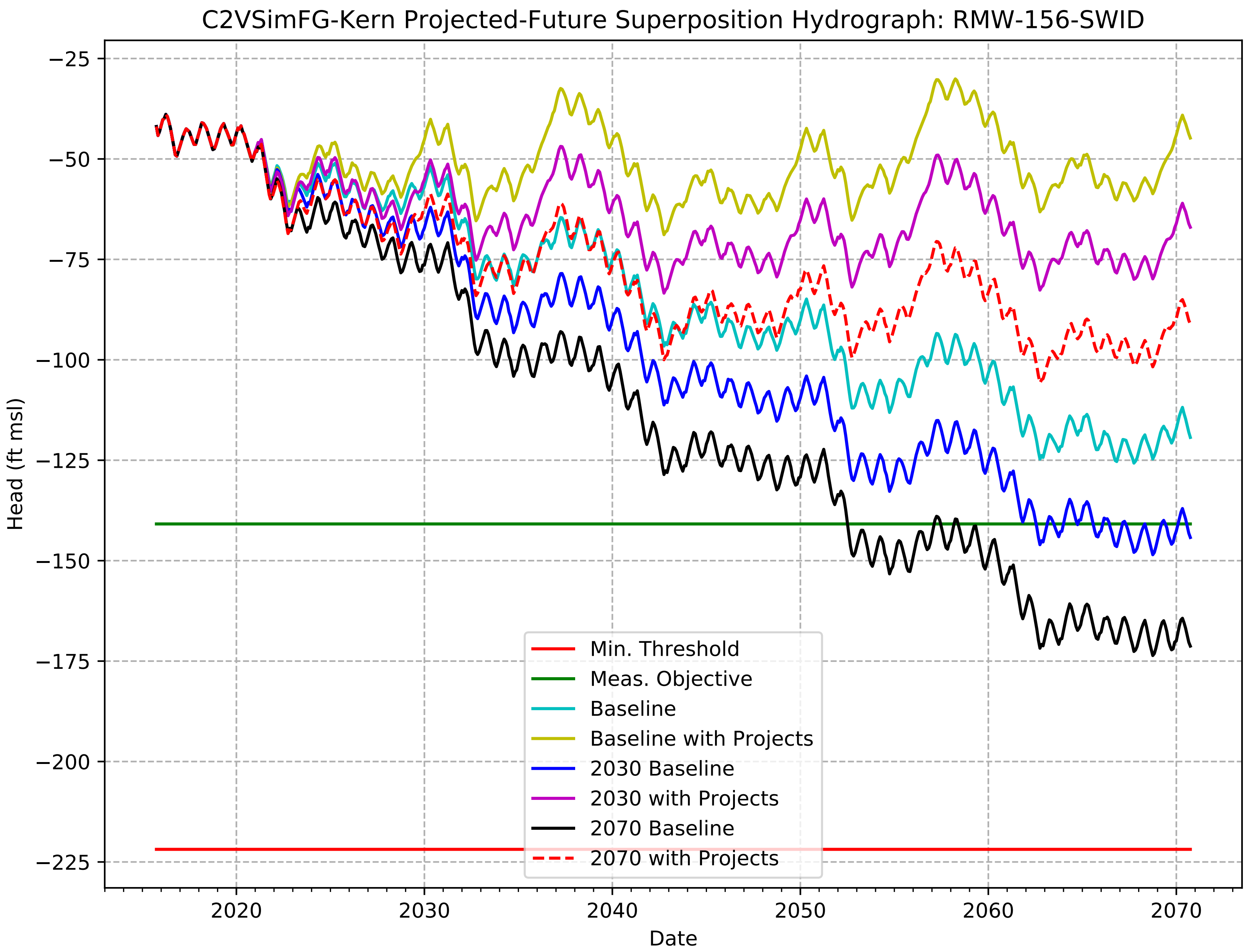

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-152-NKWSD
Head (ft msl)
−50
−75
−100
−125
−150
−175
−200
−225
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-153-SWID
Head (ft msl)
0
−50
−100
−150
−200
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

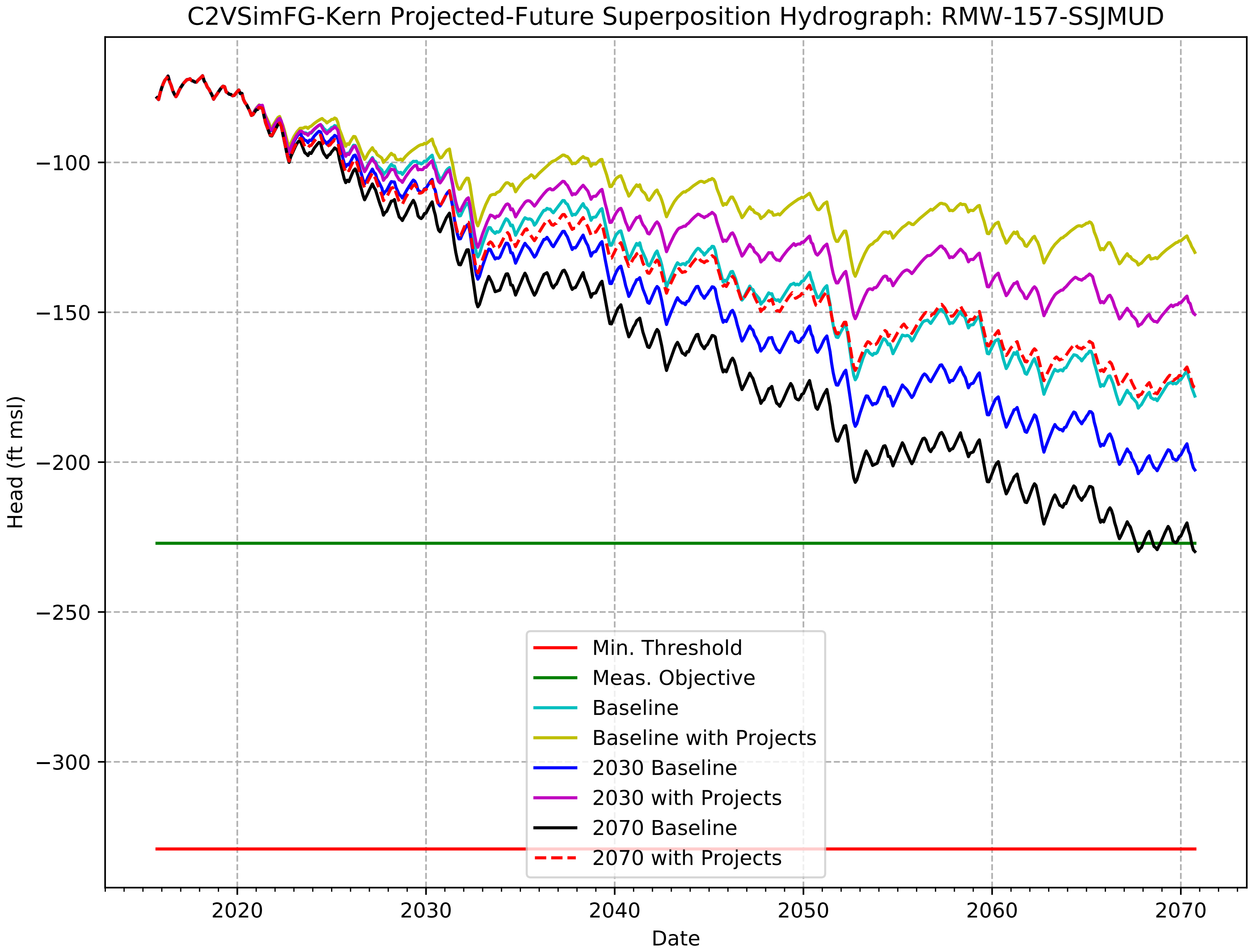

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-154-SWID
Head (ft msl)
0
−50
−100
−150
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



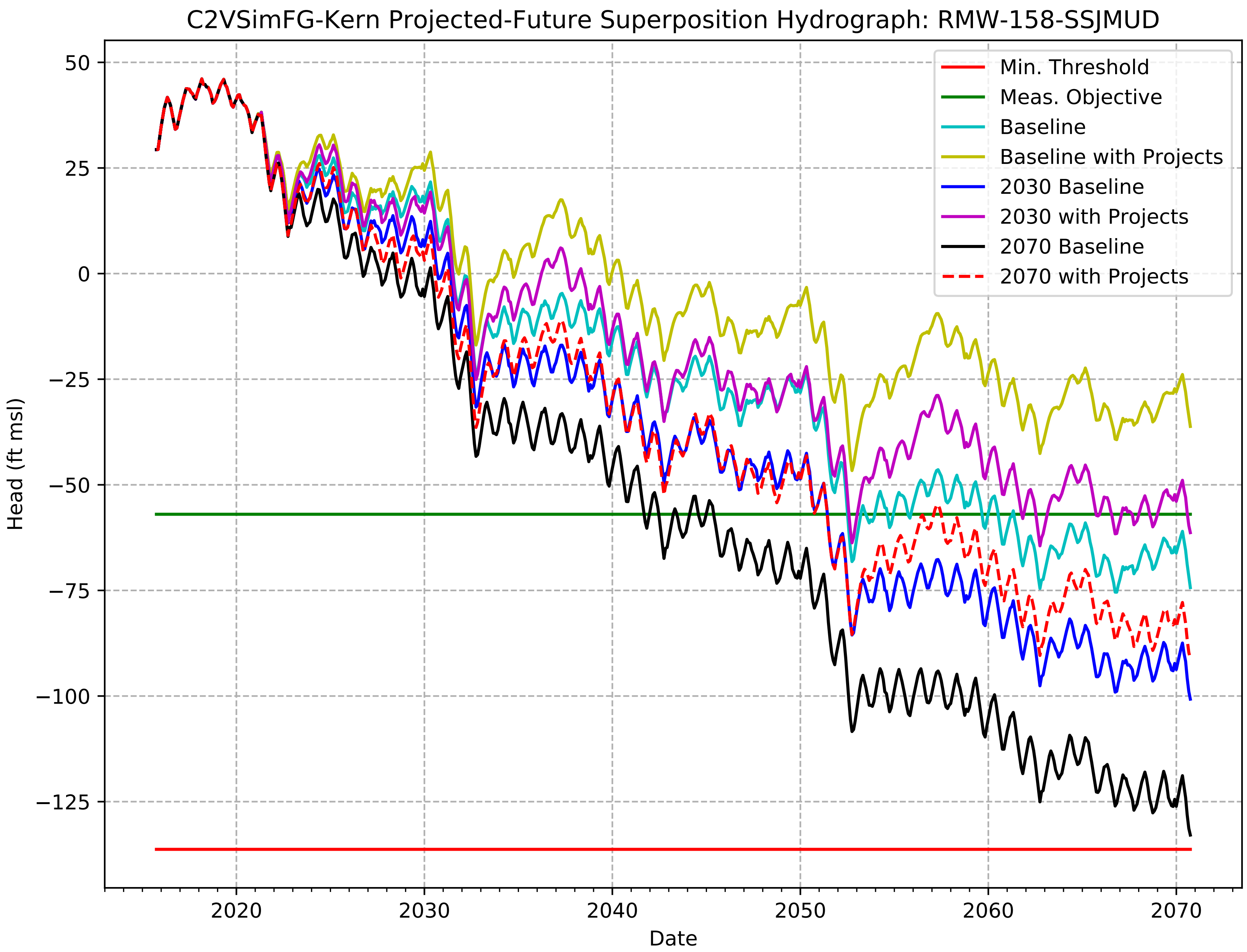
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-155-SWID
Head (ft msl)
−50
−100
−150
−200
−250
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



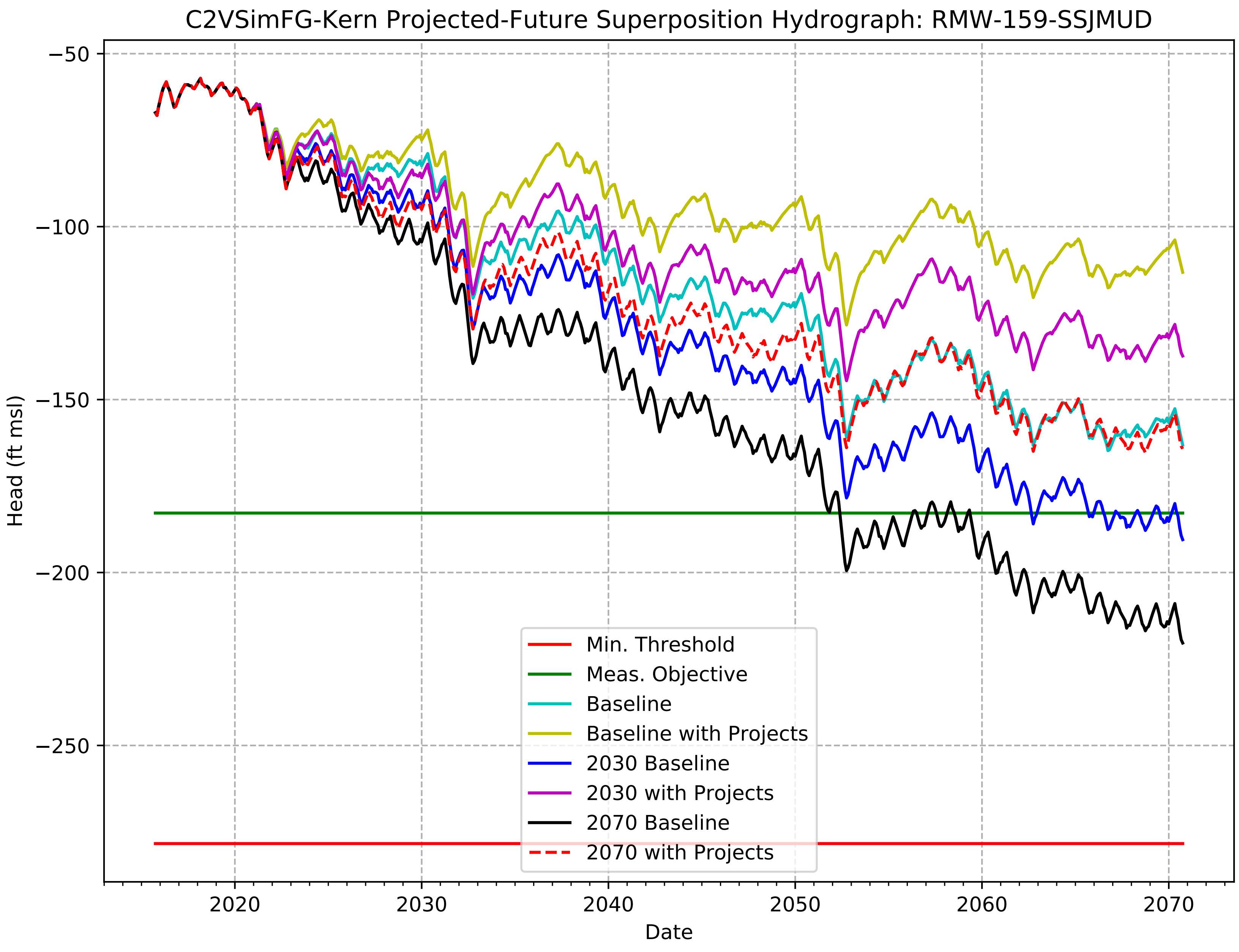
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-156-SWID
Head (ft msl)
Date
−25
−50
−75
−100
−125
−150
−175
−200
−225
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

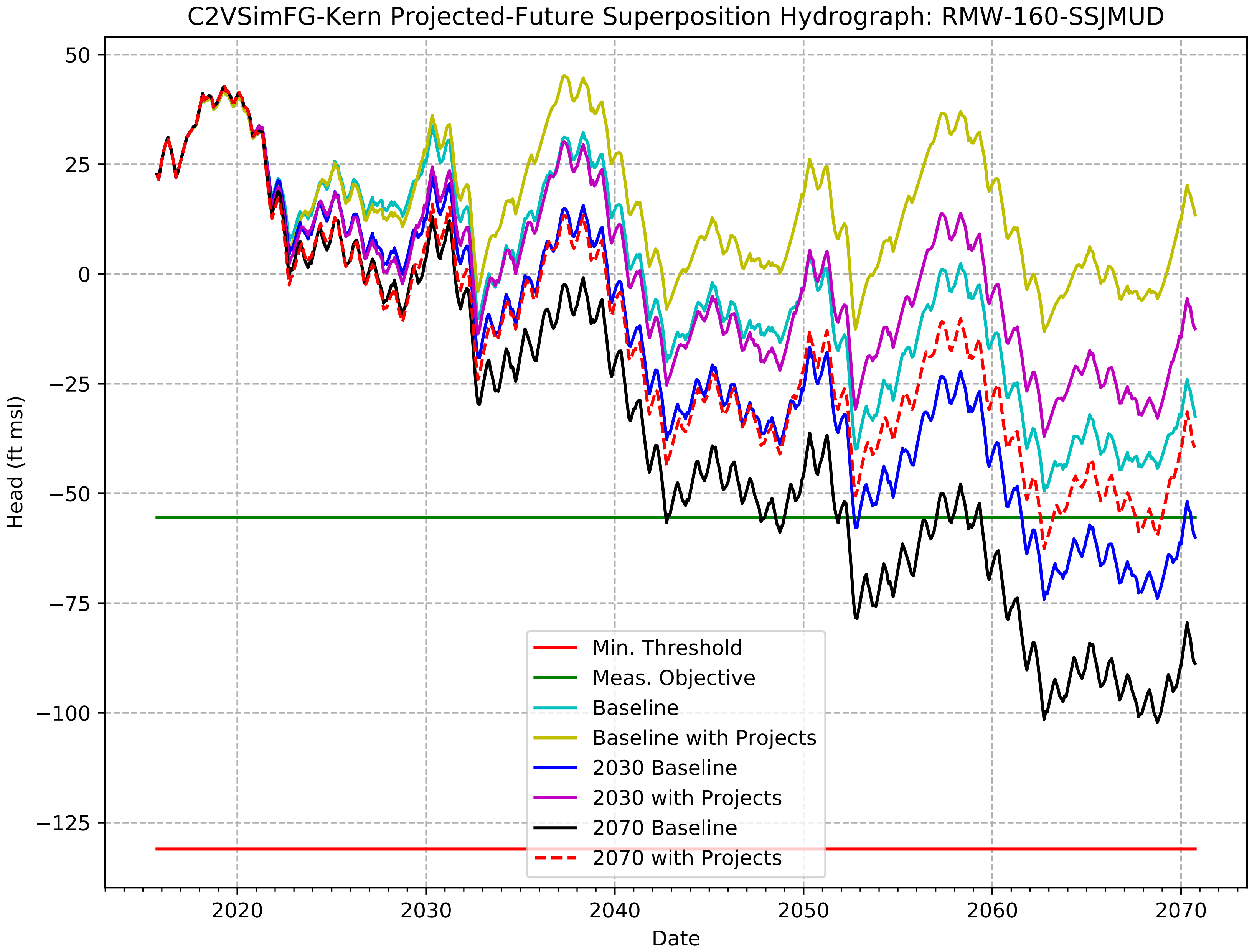


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-157-SSJMUD
Head (ft msl)
−100
−150
−200
−250
−300
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

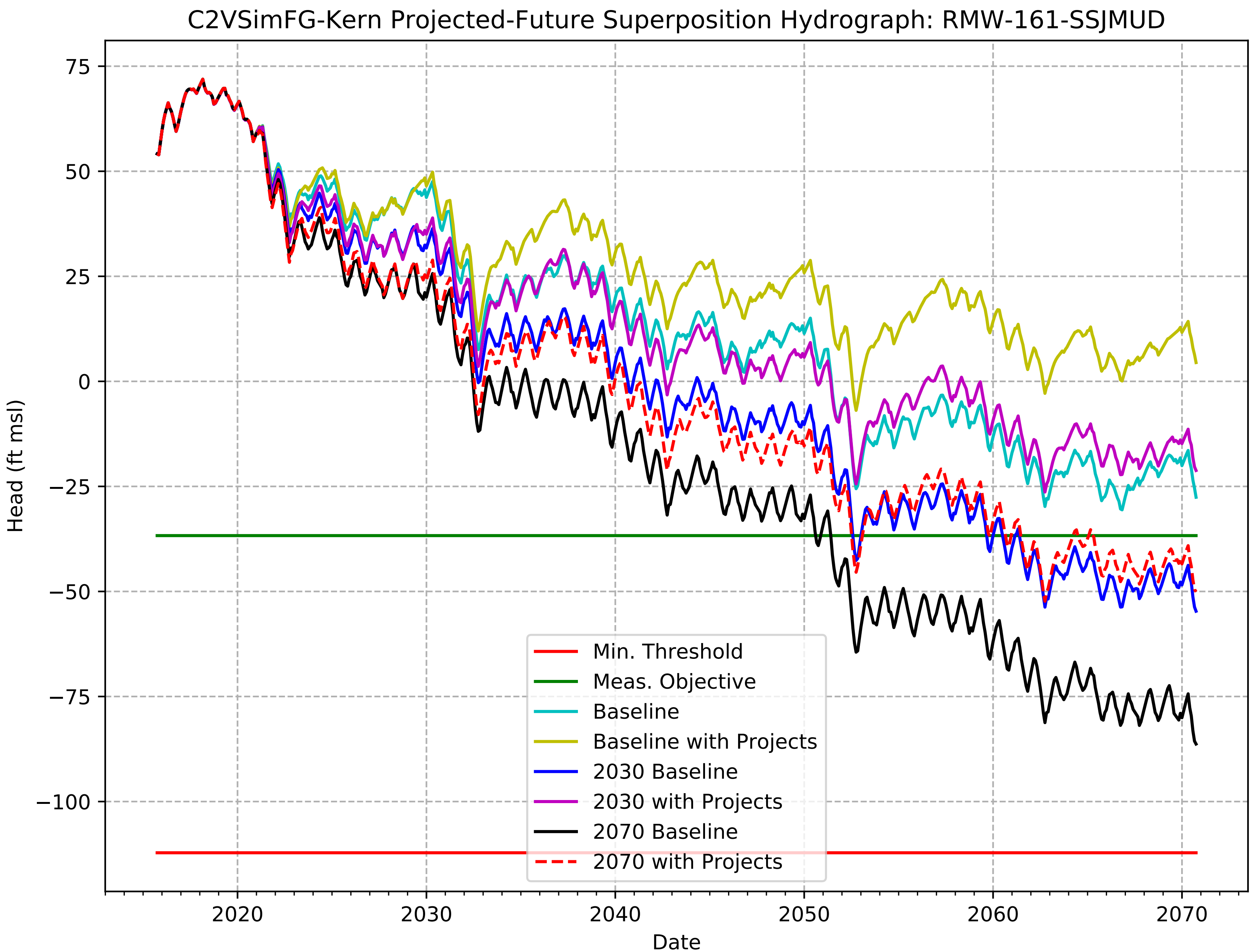


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-158-SSJMUD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
50
25
0
−25
−50
−75
−100
−125
2020
2030
2040
2050
2060
2070
Date

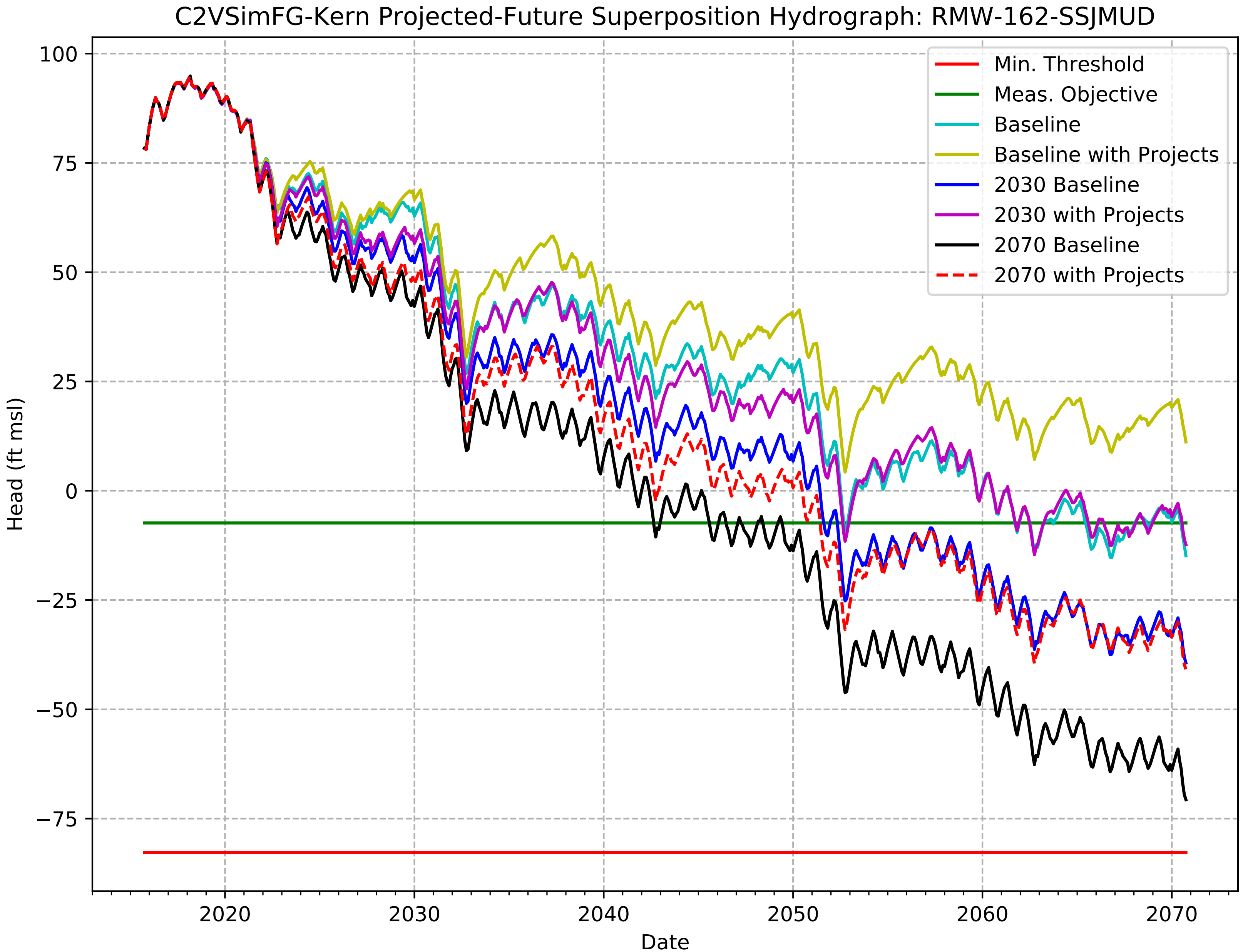

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-159-SSJMUD
Head (ft msl)
−50
−100
−150
−200
−250
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

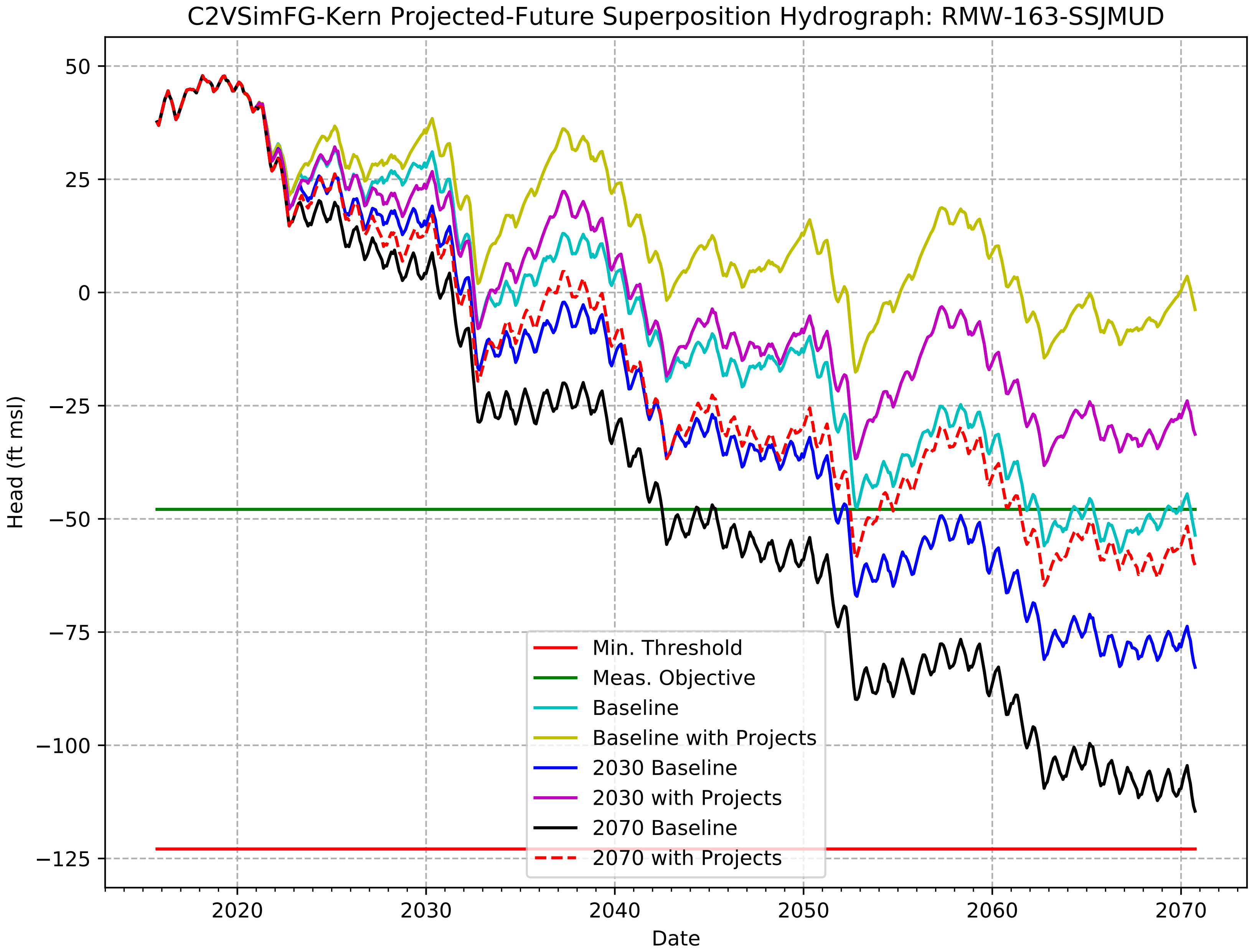


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-160-SSJMUD
Head (ft msl)
50
25
0
−25
−50
−75
−100
−125
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

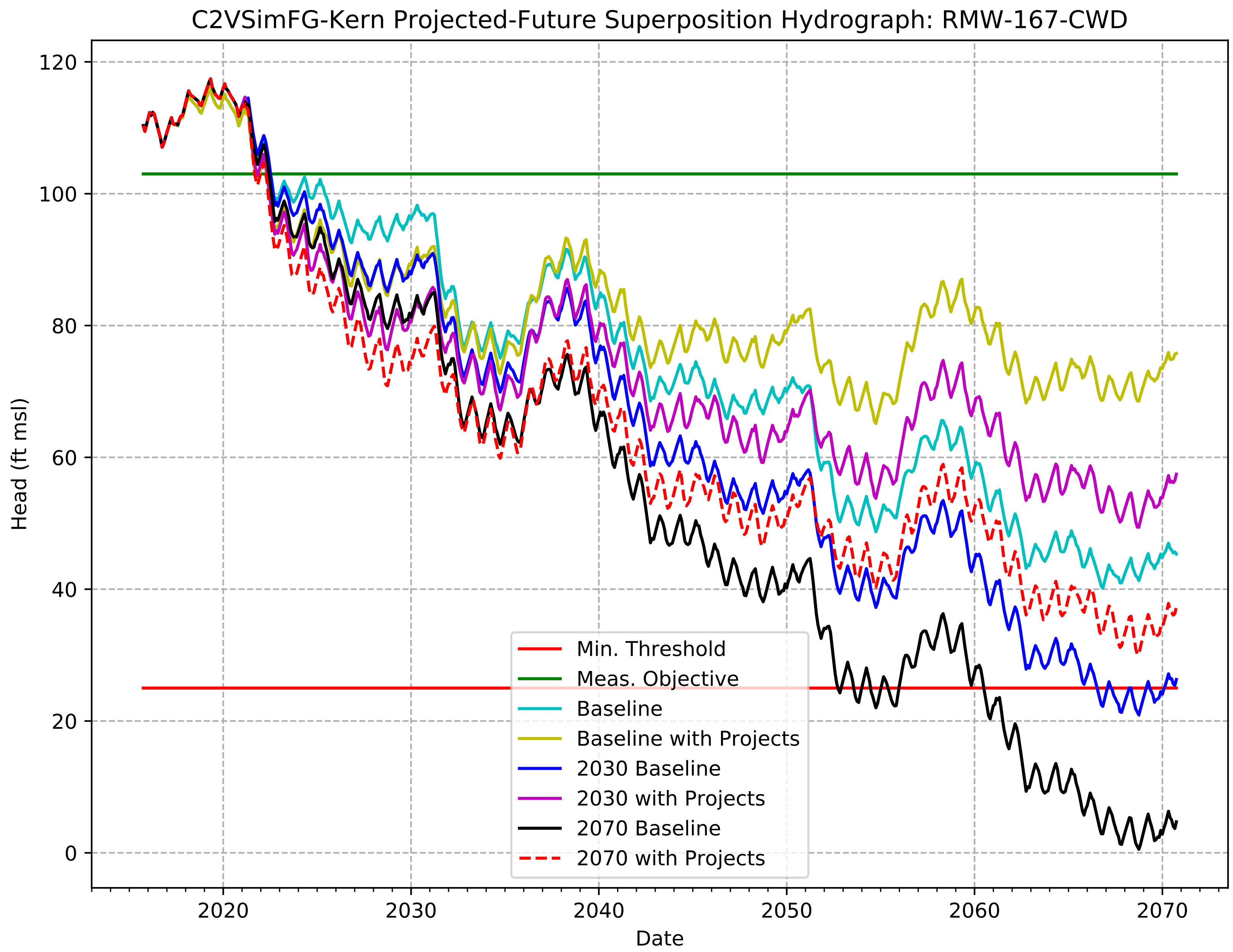


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-161-SSJMUD
Head (ft msl)
75
50
25
0
−25
−50
−75
−100
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

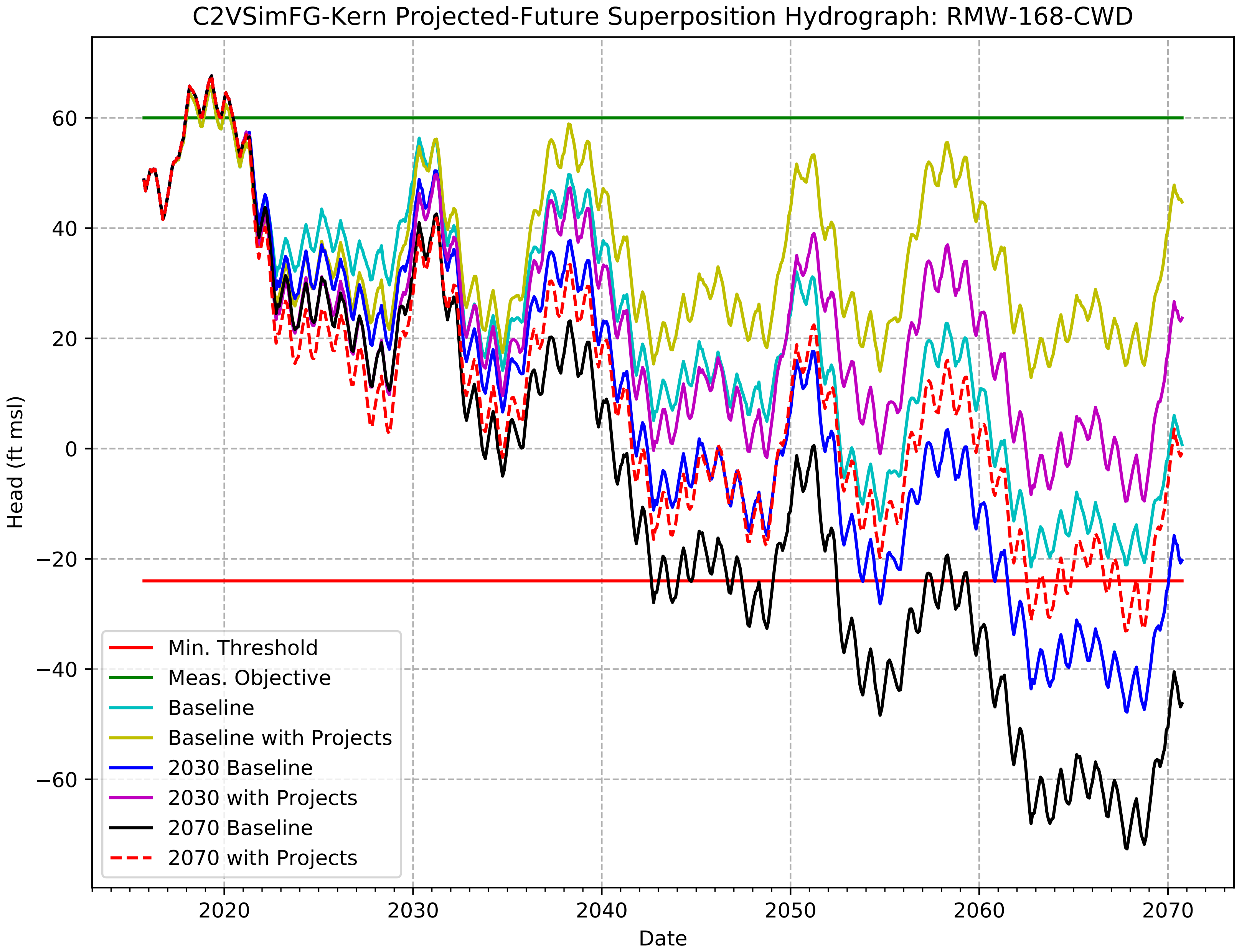

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-162-SSJMUD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
100
75
50
25
0
−25
−50
−75
Date
2020
2030
2040
2050
2060
2070



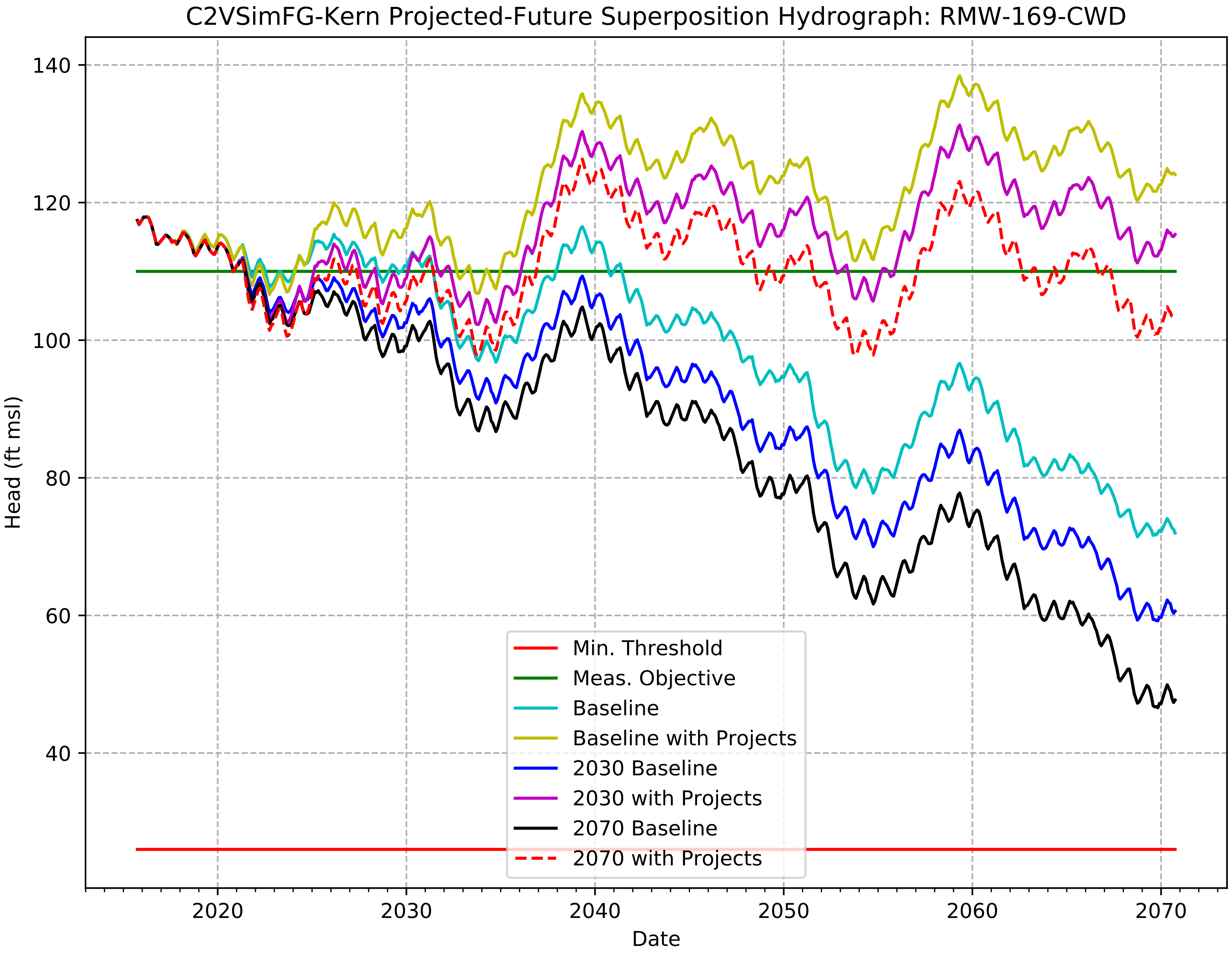
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-163-SSJMUD
Head (ft msl)
50
25
0
−25
−50
−75
−100
−125
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



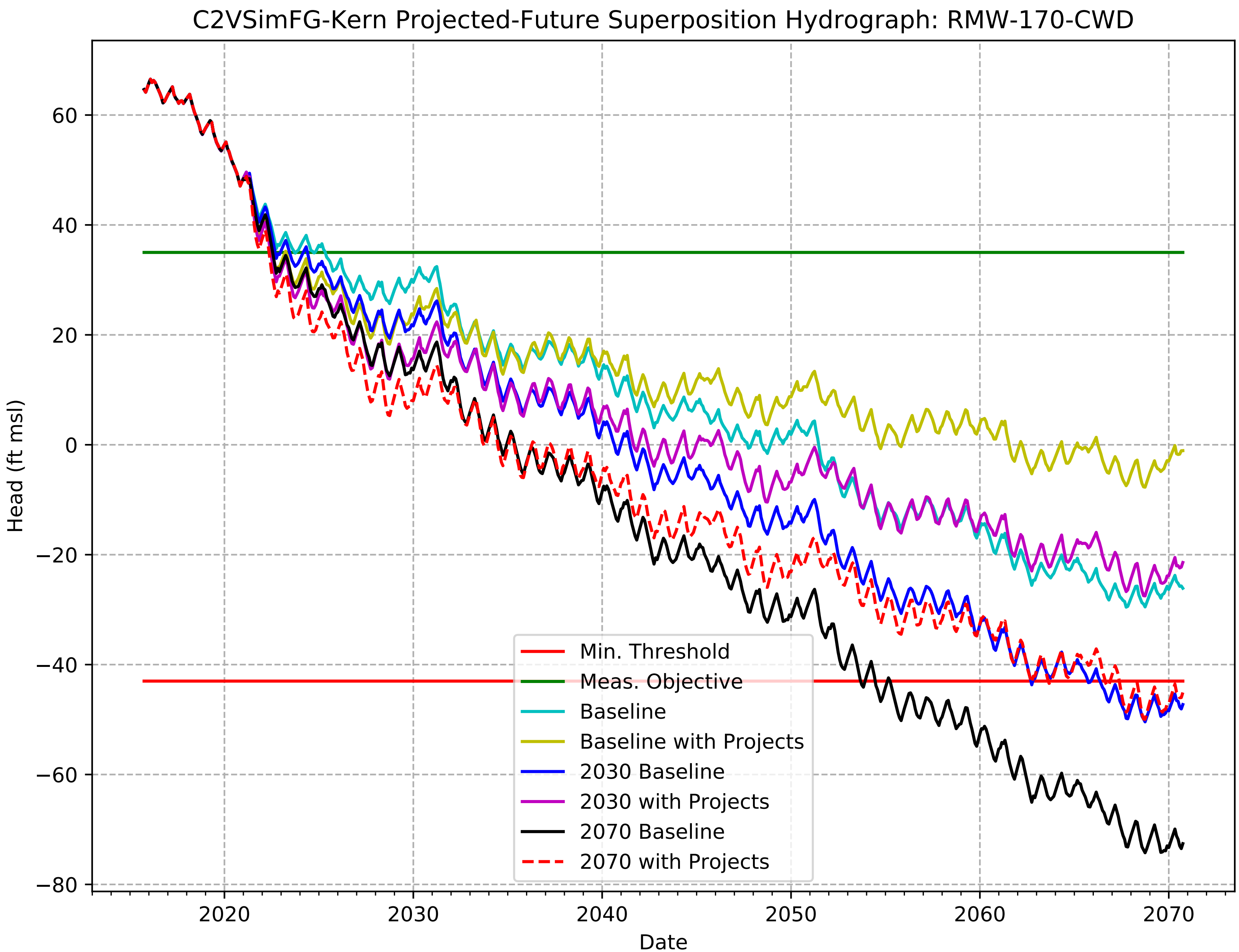
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-167-CWD
Head (ft msl)
120
100
80
60
40
20
0
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

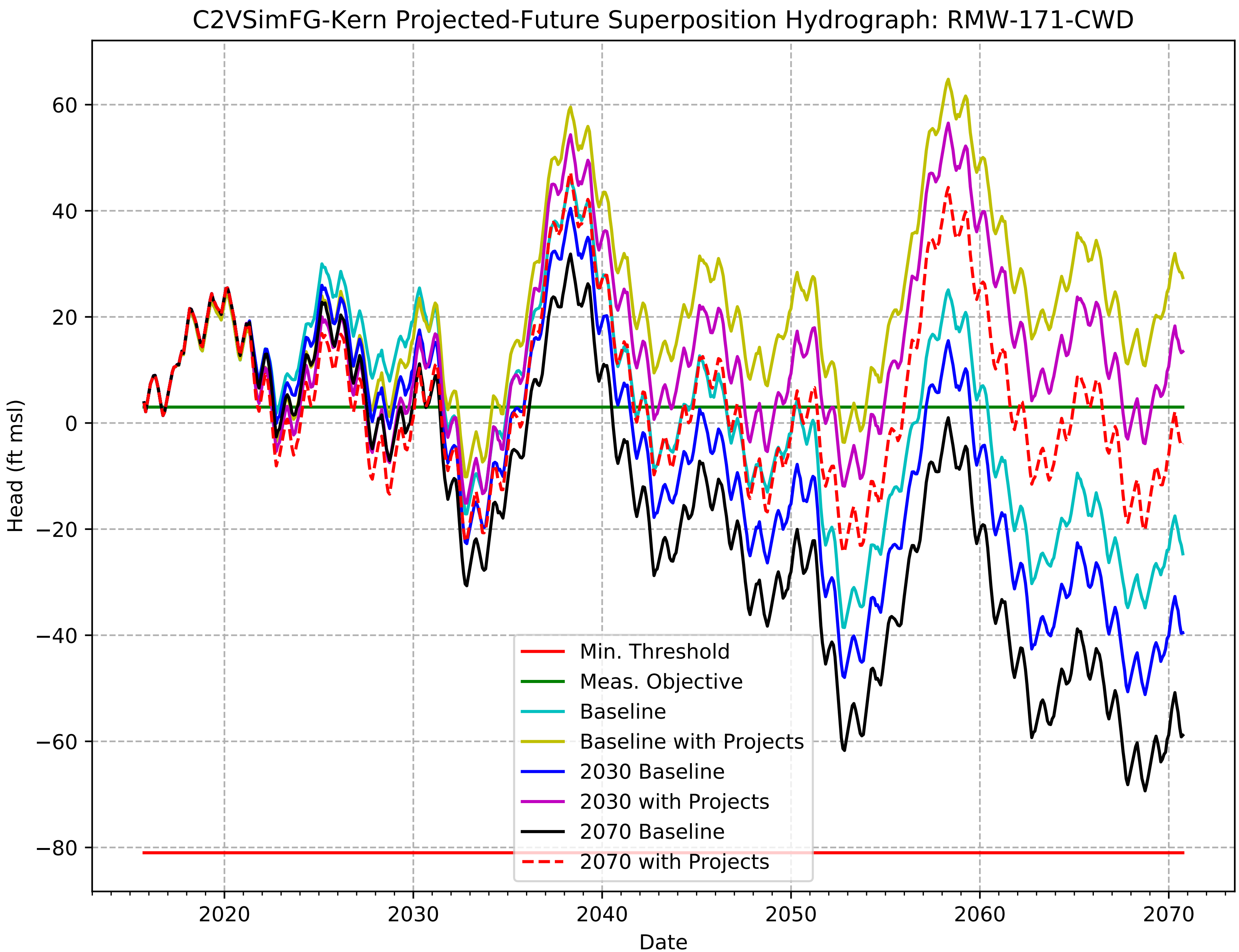


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-168-CWD
Head (ft msl)
60
40
20
0
−20
−40
−60
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

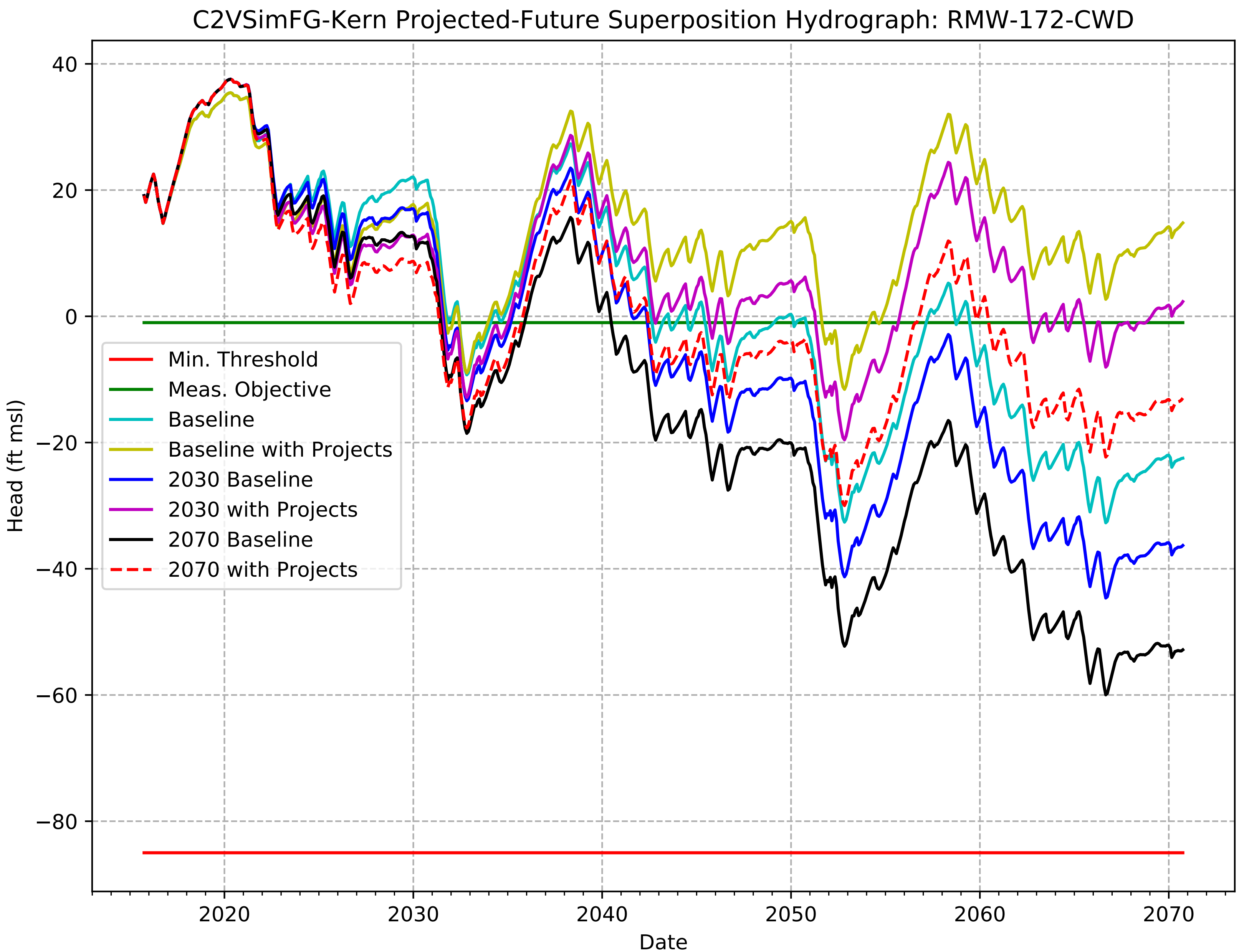


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-169-CWD
Head (ft msl)
140
120
100
80
60
40
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

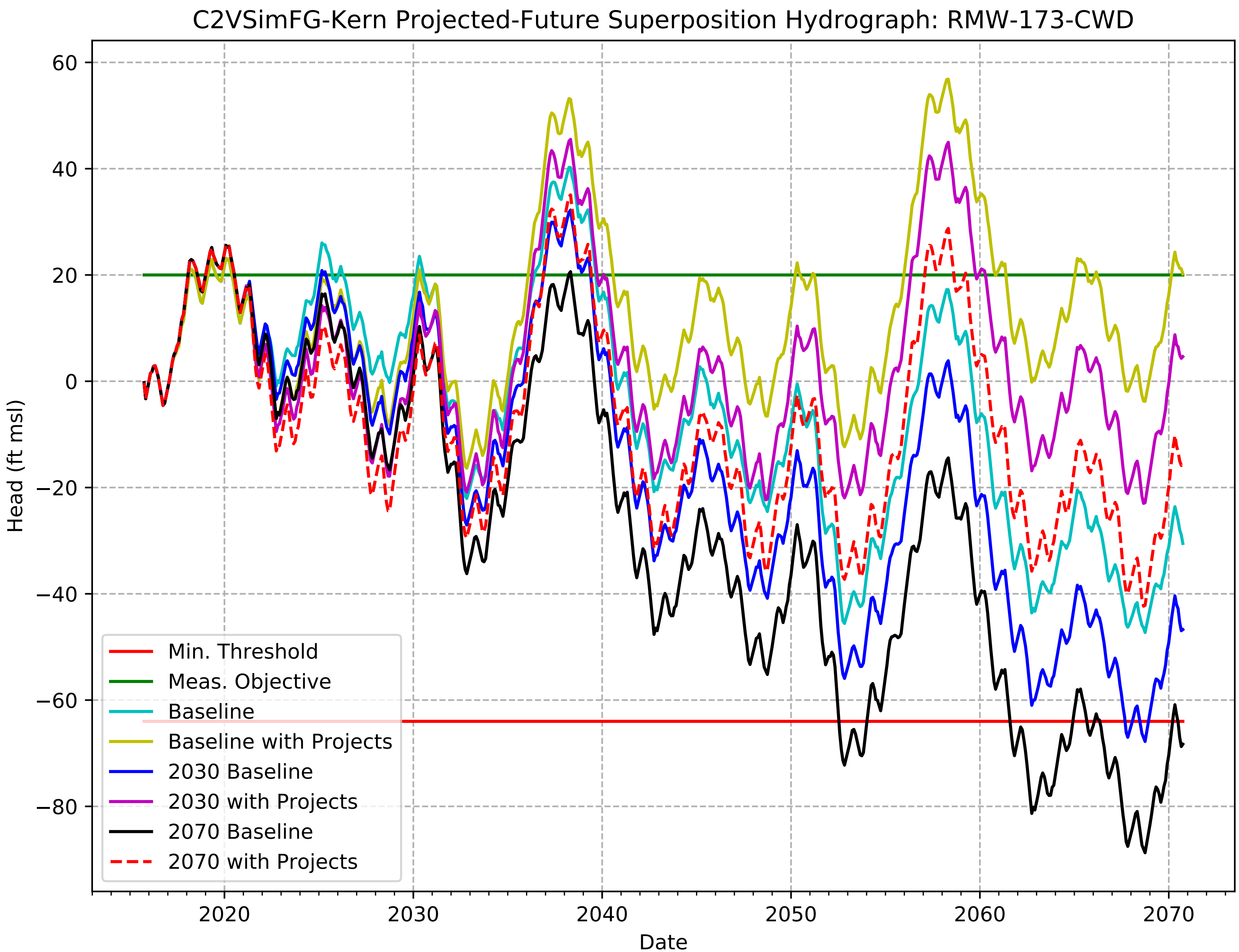

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-170-CWD
Head (ft msl)
Date
60
40
20
0
−20
−40
−60
−80
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



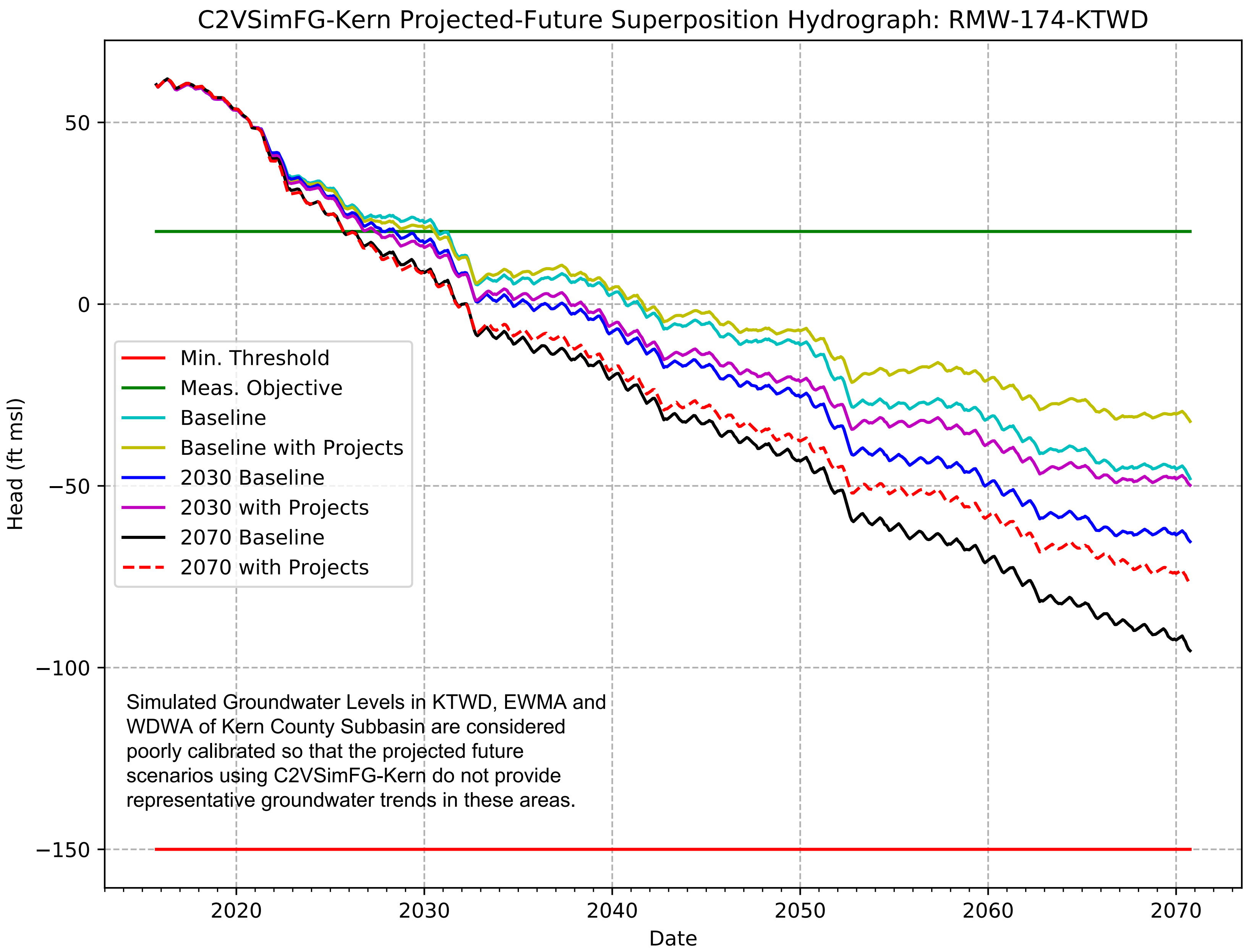
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-171-CWD
Head (ft msl)
60
40
20
0
−20
−40
−60
−80
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

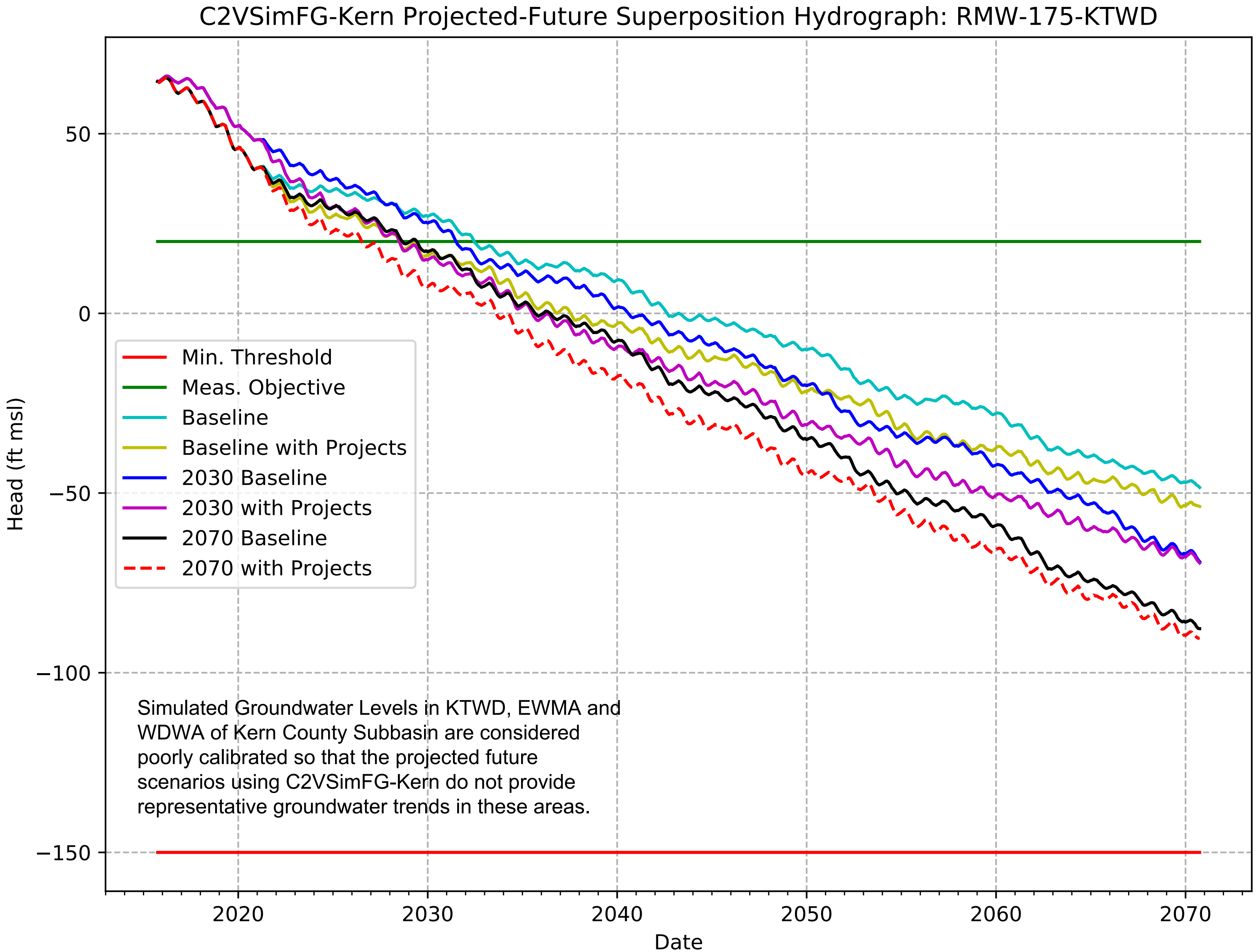


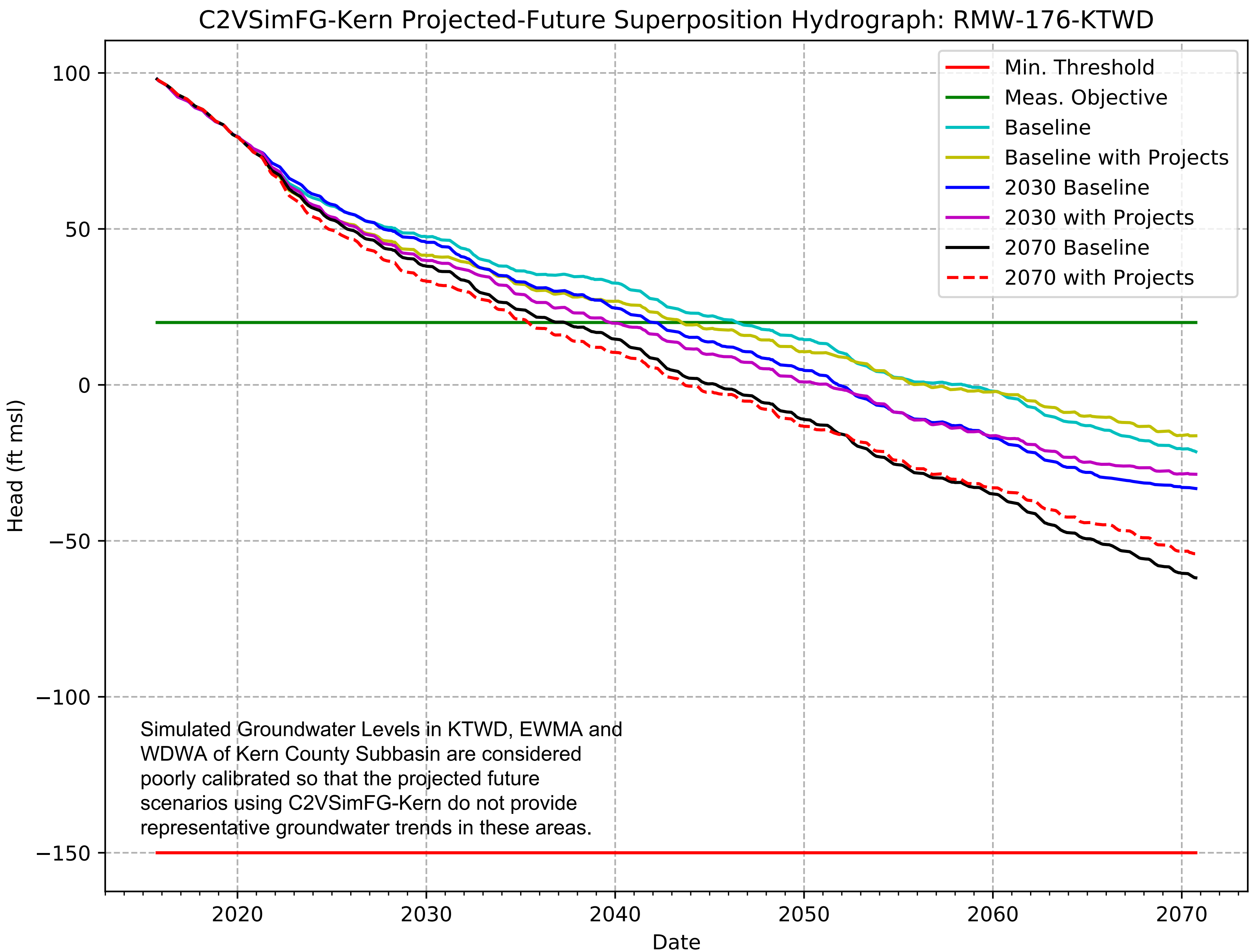
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-172-CWD
Head (ft msl)
Date
40
20
0
−20
−40
−60
−80
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



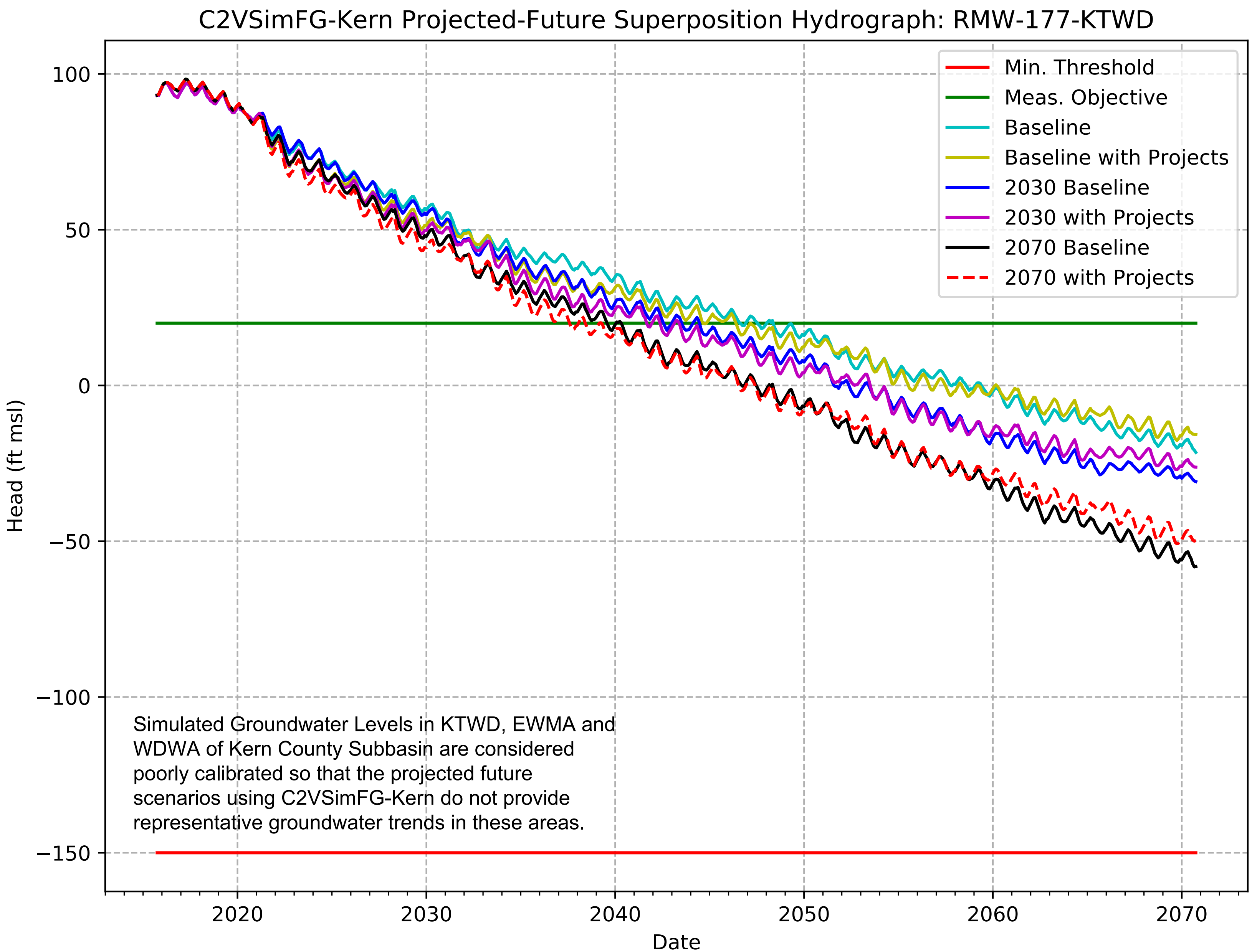
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-173-CWD
Head (ft msl)
Date
60
40
20
0
−20
−40
−60
−80
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-174-KTWD
Head (ft msl)
50
0
−50
−100
−150
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.

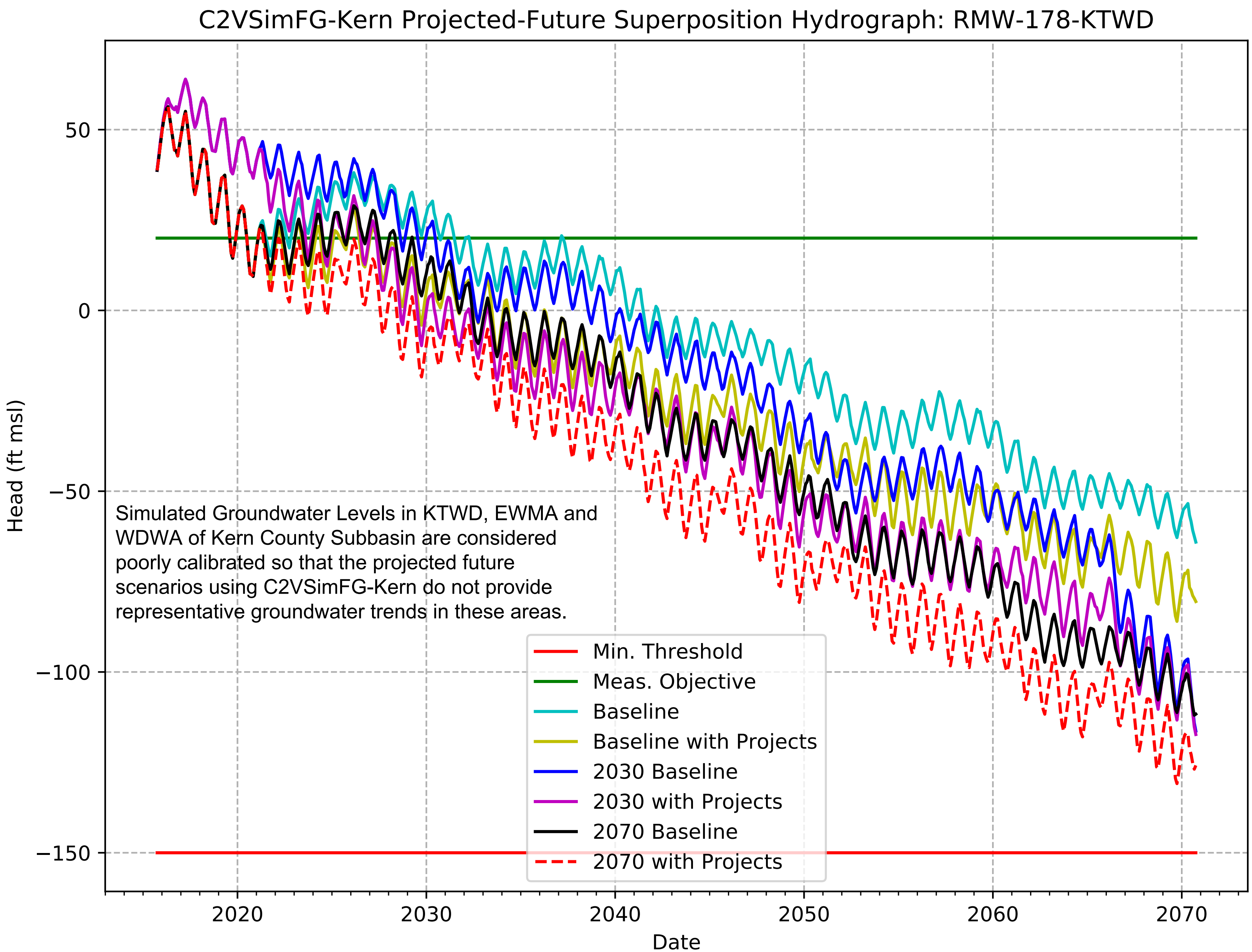

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-175-KTWD
Head (ft msl)
50
0
−50
−100
−150
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.

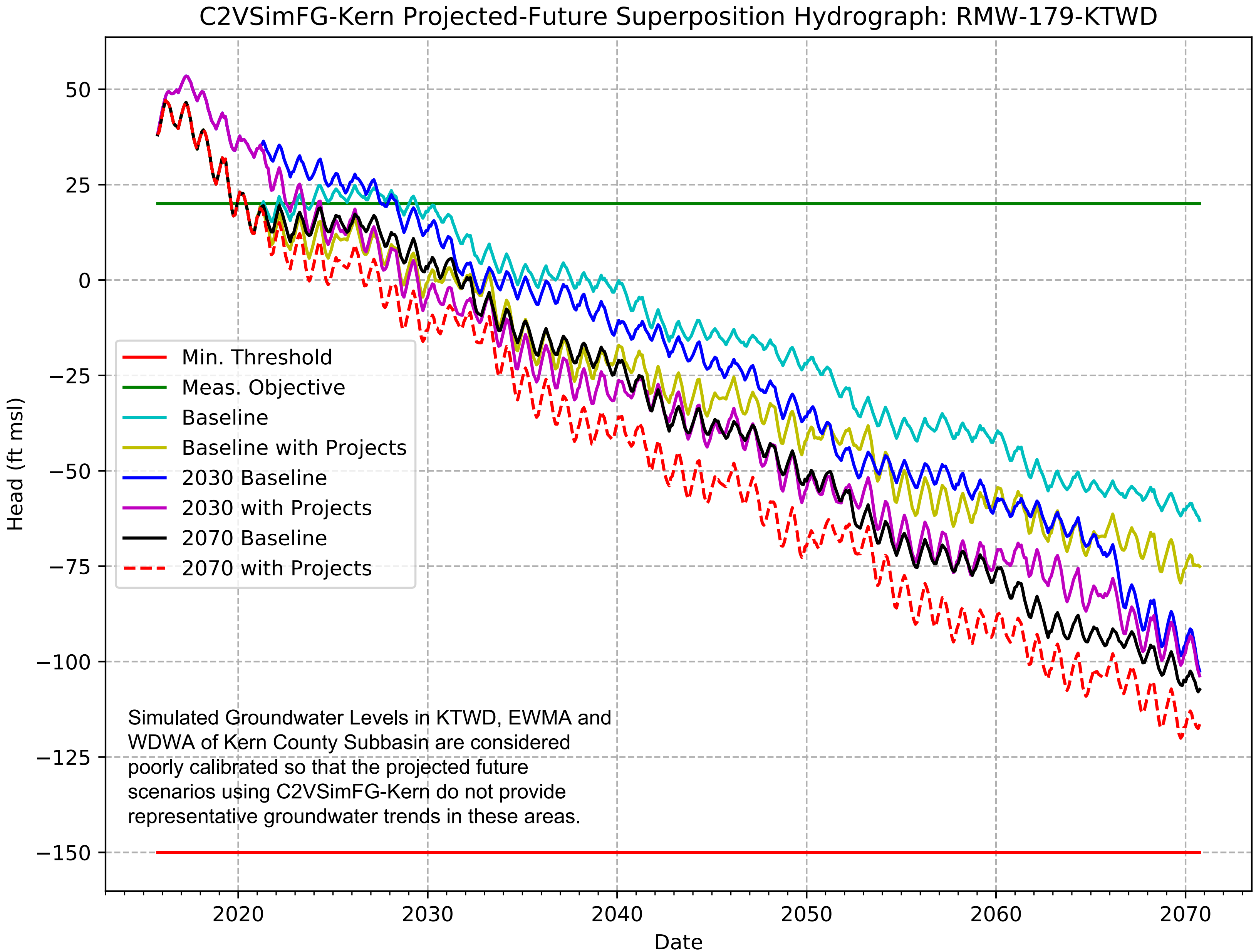


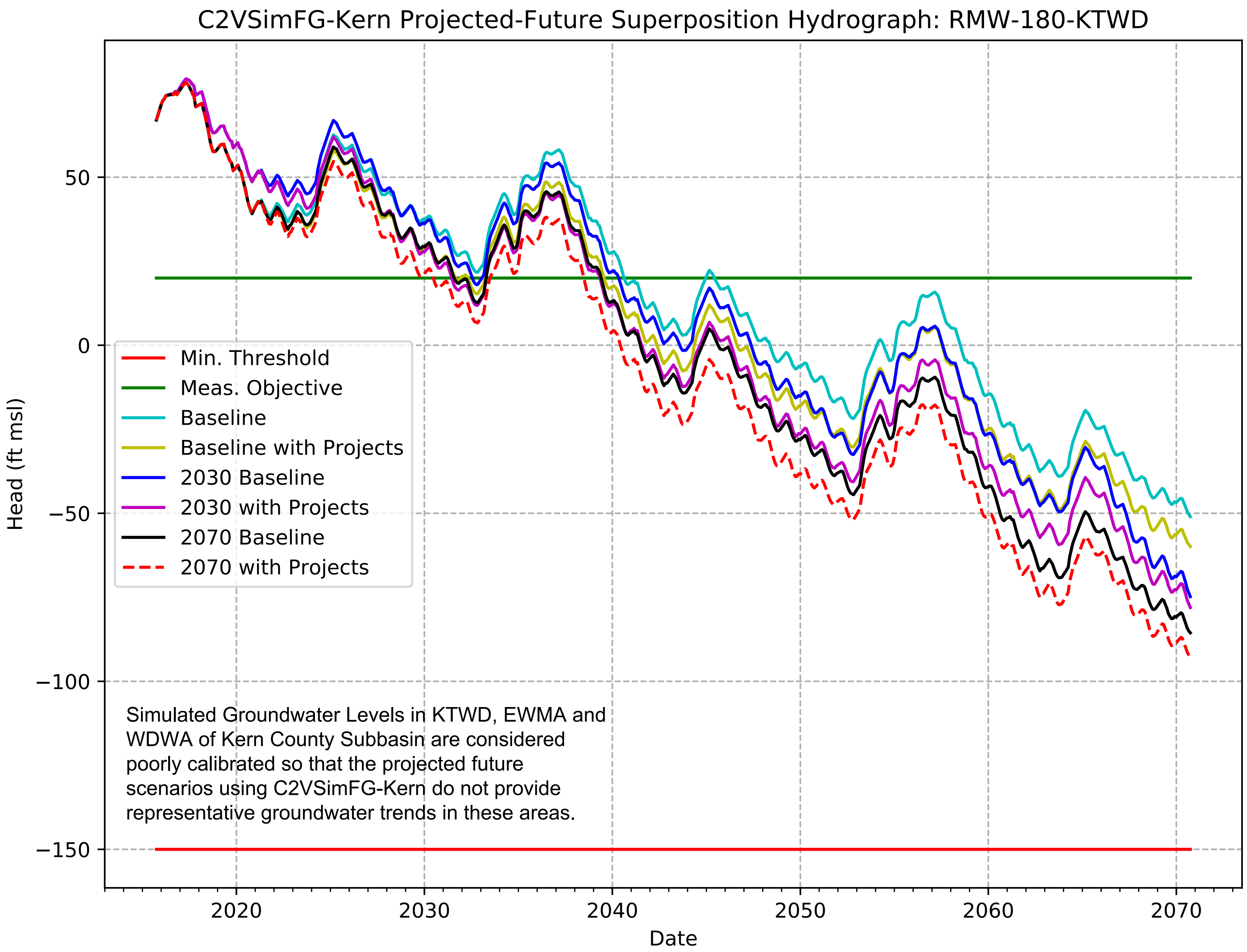
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-176-KTWD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
100
50
0
−50
−100
−150
2020
2030
2040
2050
2060
2070
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.



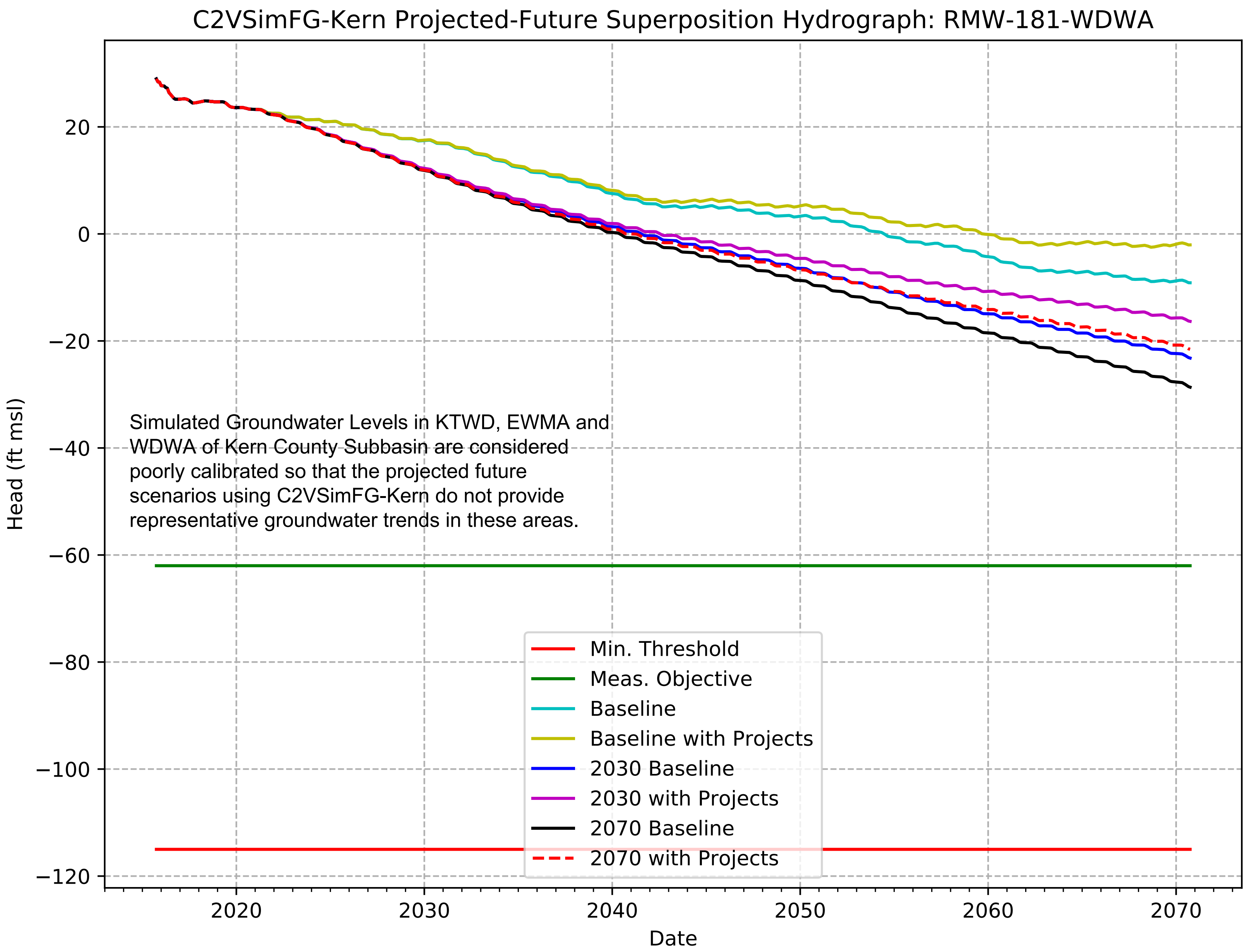
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-177-KTWD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
100
50
0
−50
−100
−150
2020
2030
2040
2050
2060
2070
Date
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.

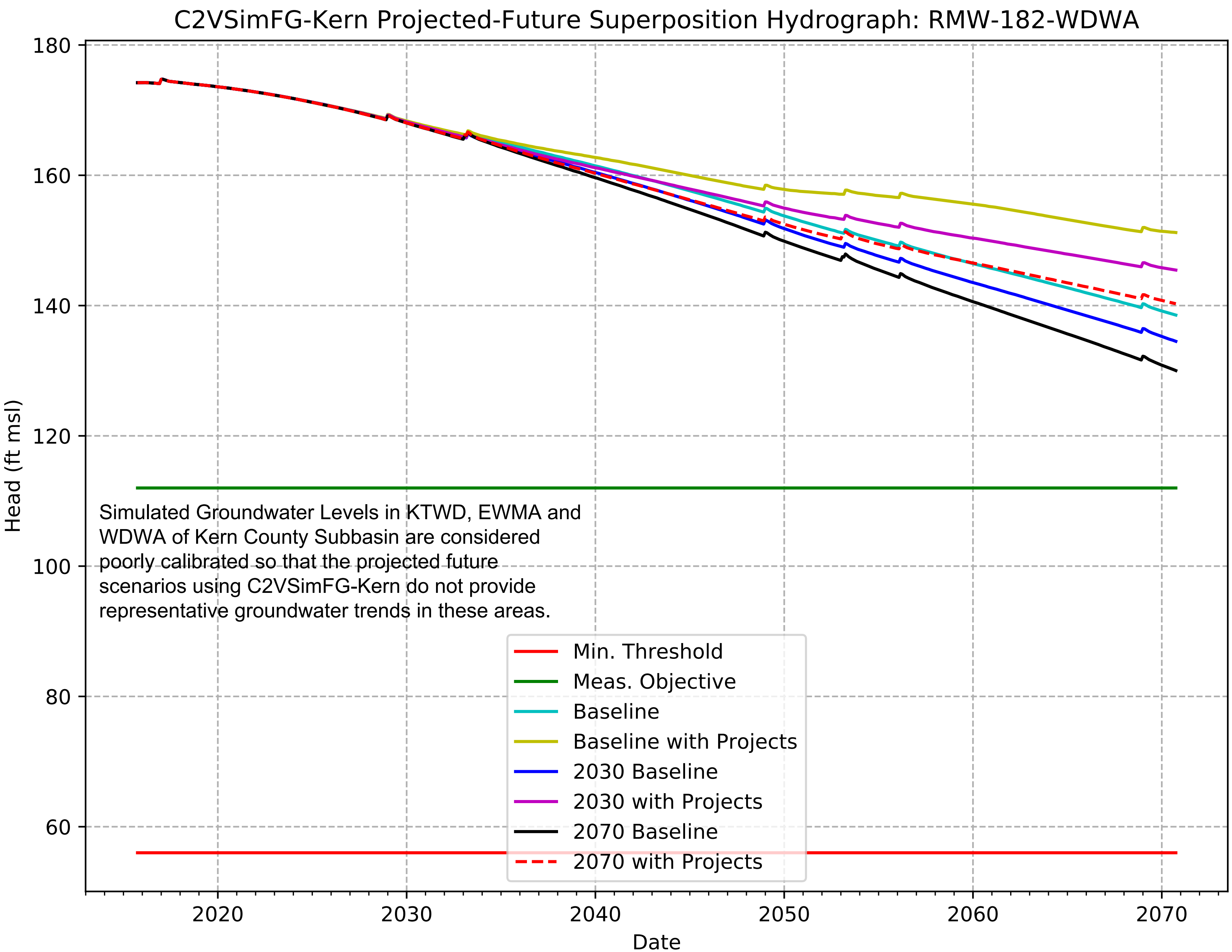

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-178-KTWD
Head (ft msl)
50
0
−50
−100
−150
2020
2030
2040
2050
2060
2070
Date
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

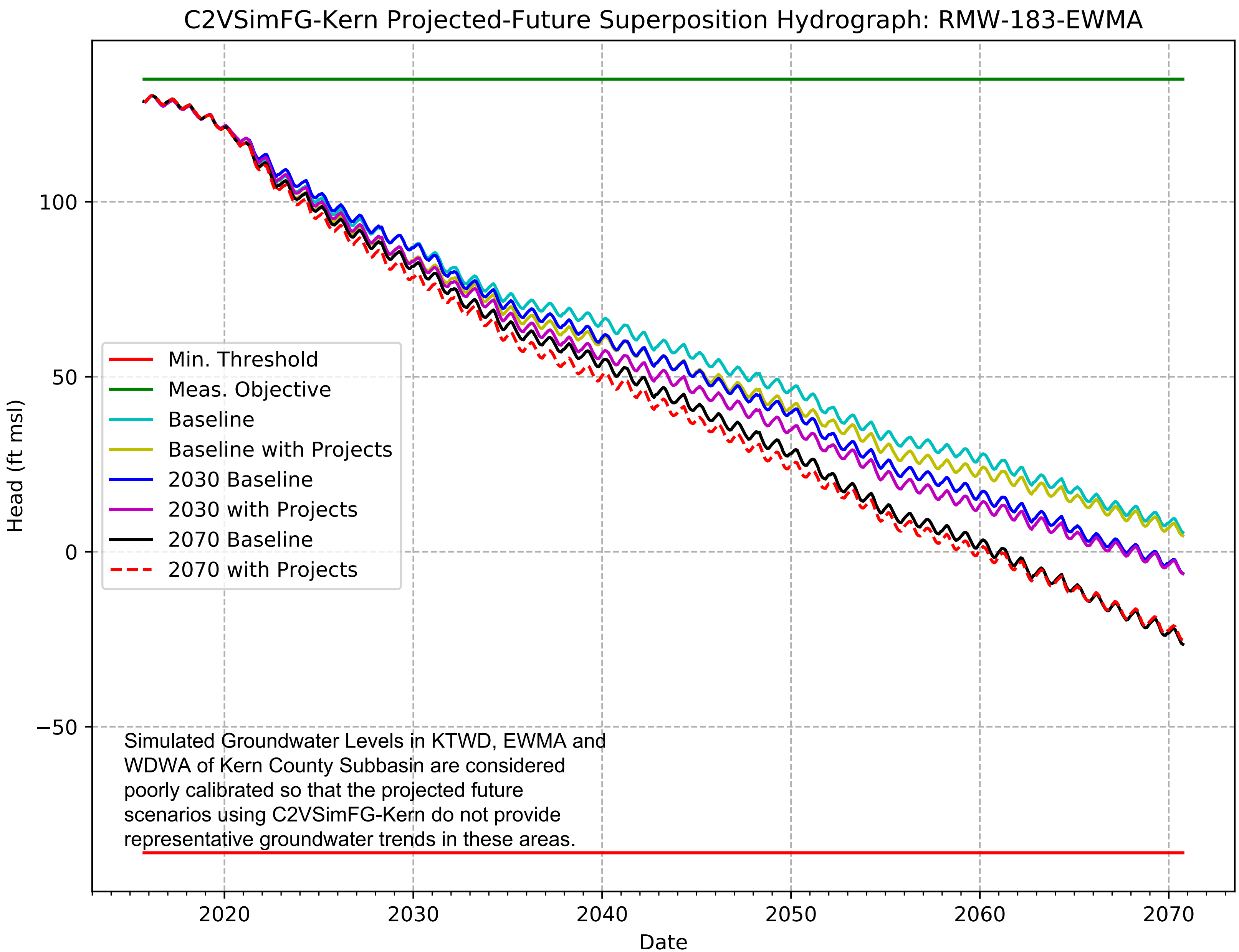

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-179-KTWD
Head (ft msl)
50
25
0
−25
−50
−75
−100
−125
−150
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.

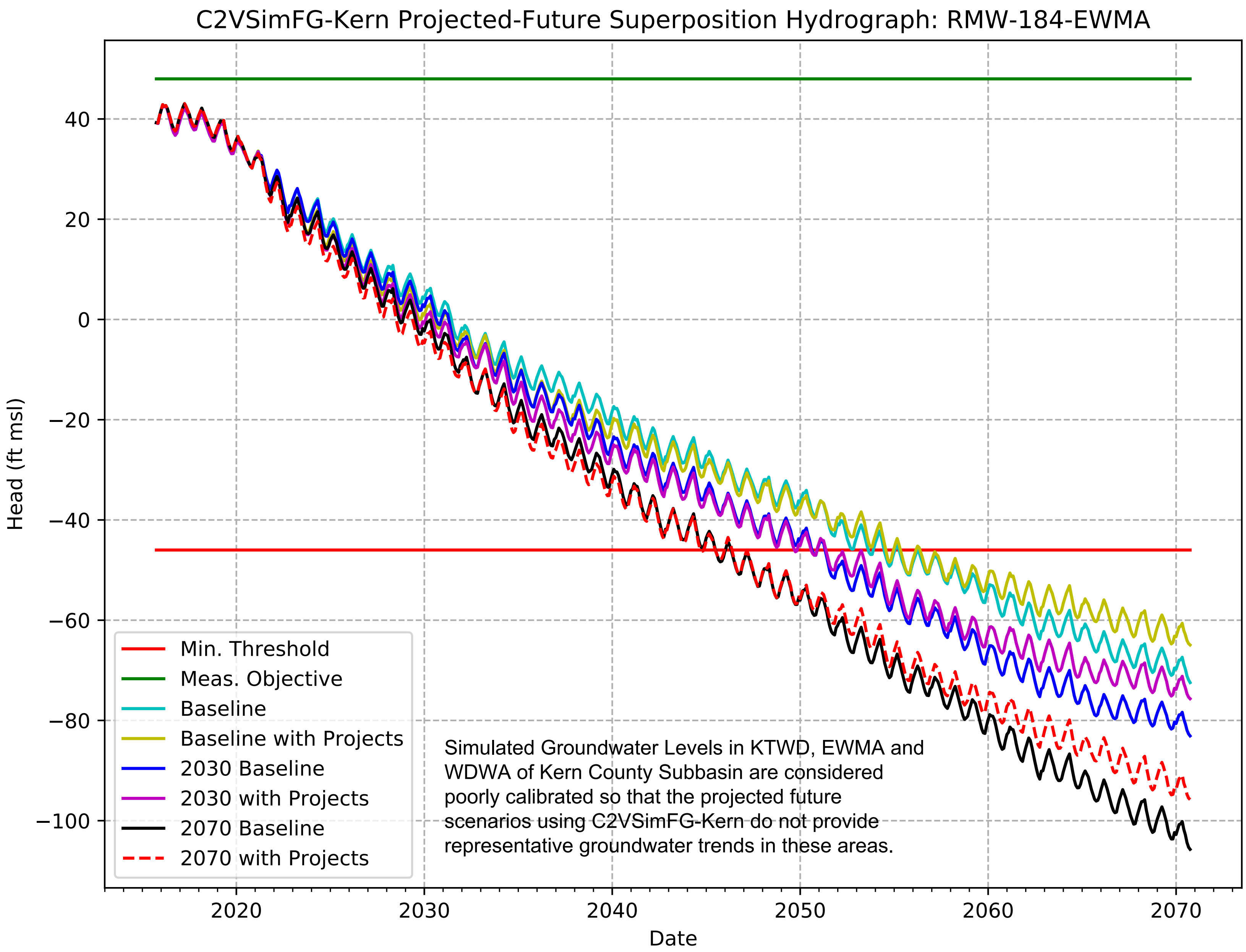


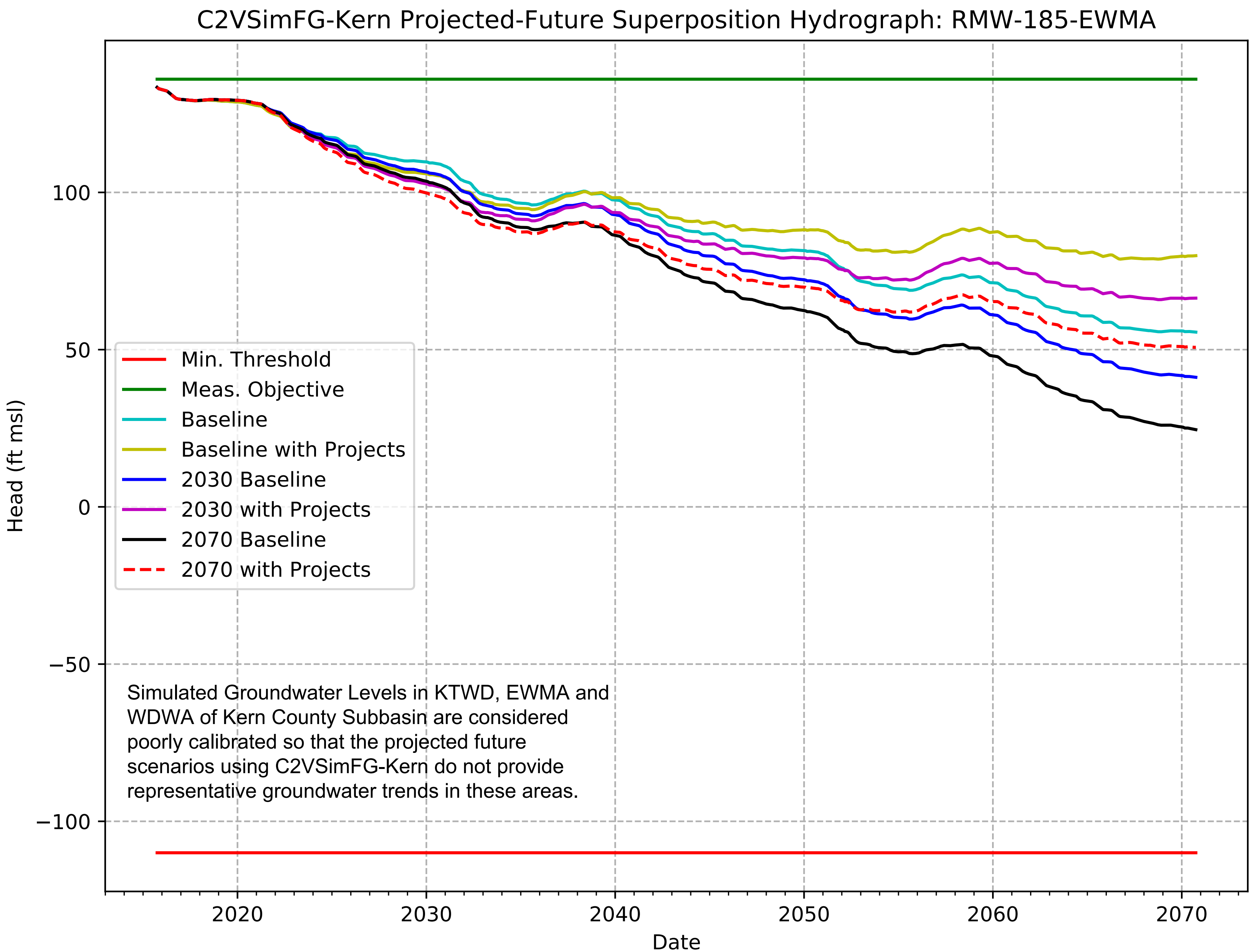
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-180-KTWD
Head (ft msl)
50
0
−50
−100
−150
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.

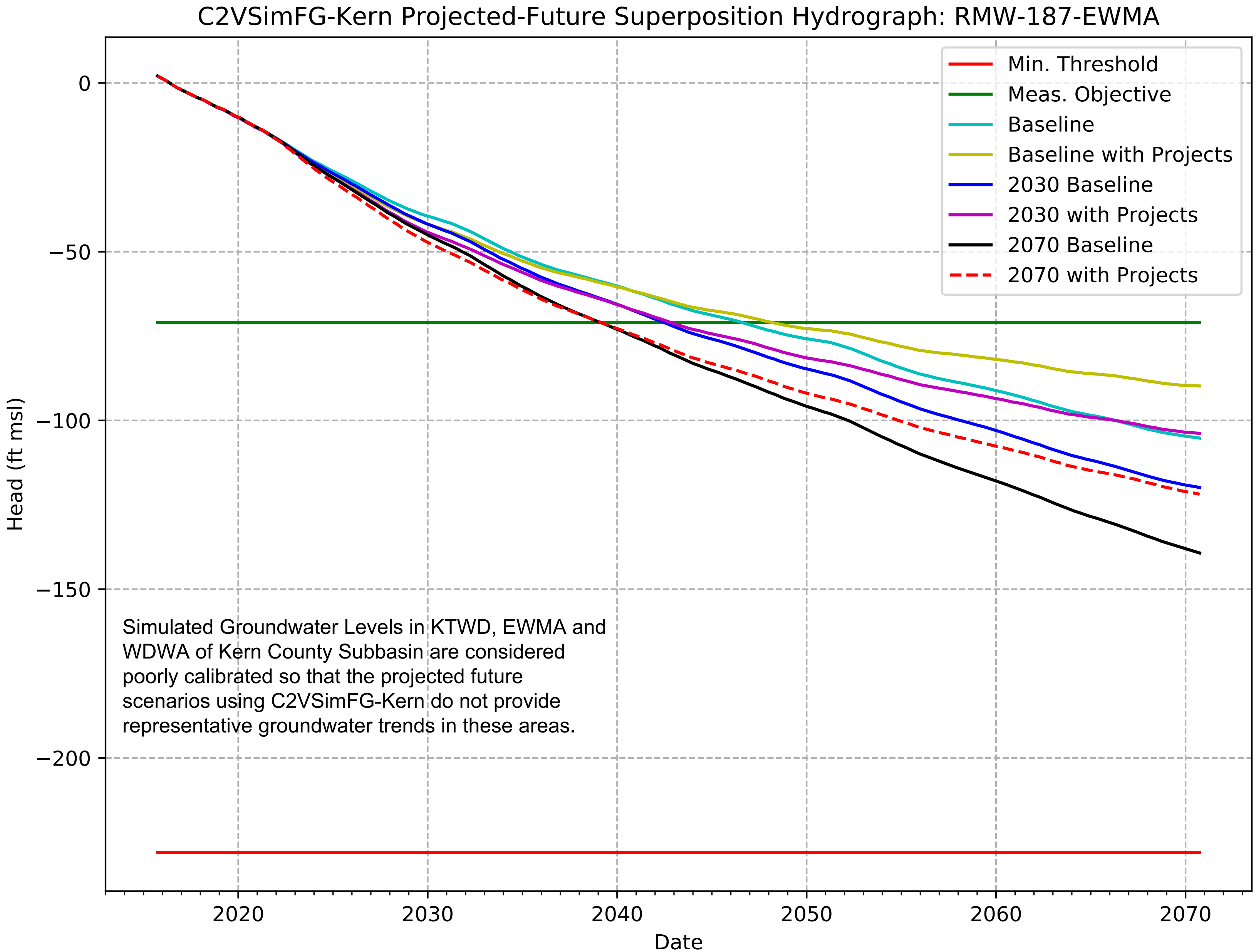

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-181-WDWA
Head (ft msl)
Date
20
0
−20
−40
−60
−80
−100
−120
2020
2030
2040
2050
2060
2070
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

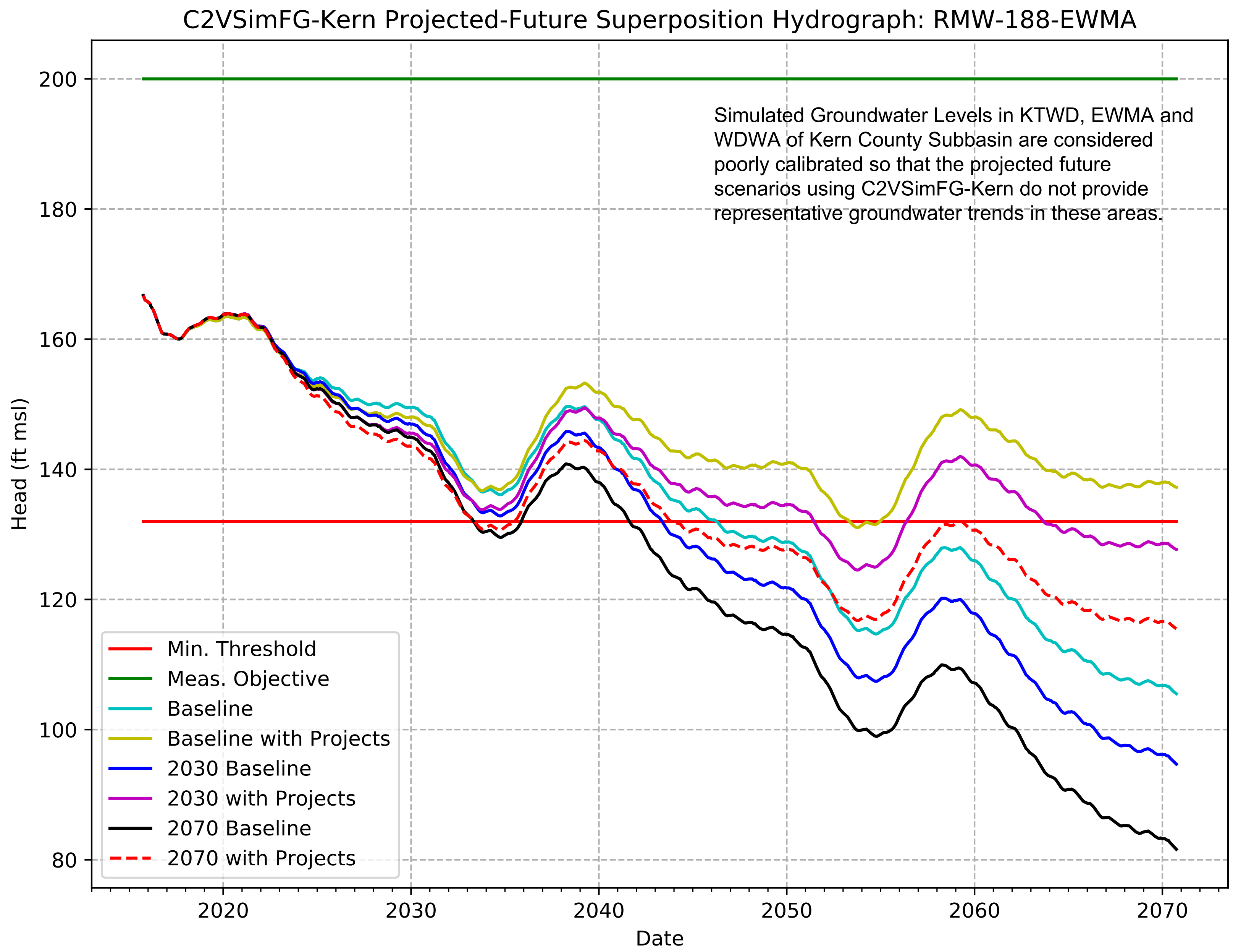

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-182-WDWA
Head (ft msl)
180
160
140
120
100
80
60
2020
2030
2040
2050
2060
2070
Date
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-183-EWMA
Head (ft msl)
100
50
0
−50
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.

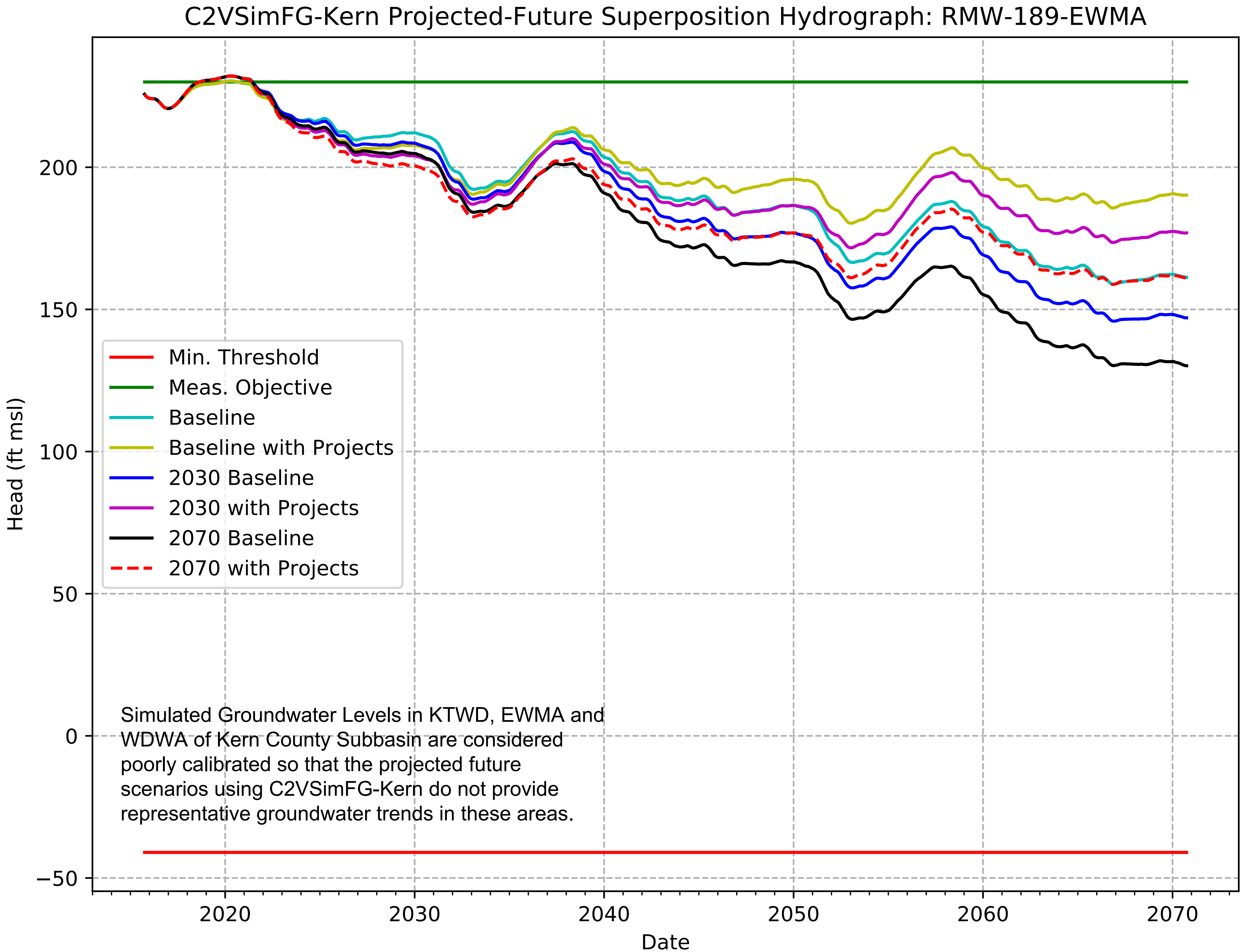

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-184-EWMA
Head (ft msl)
Date
40
20
0
−20
−40
−60
−80
−100
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.

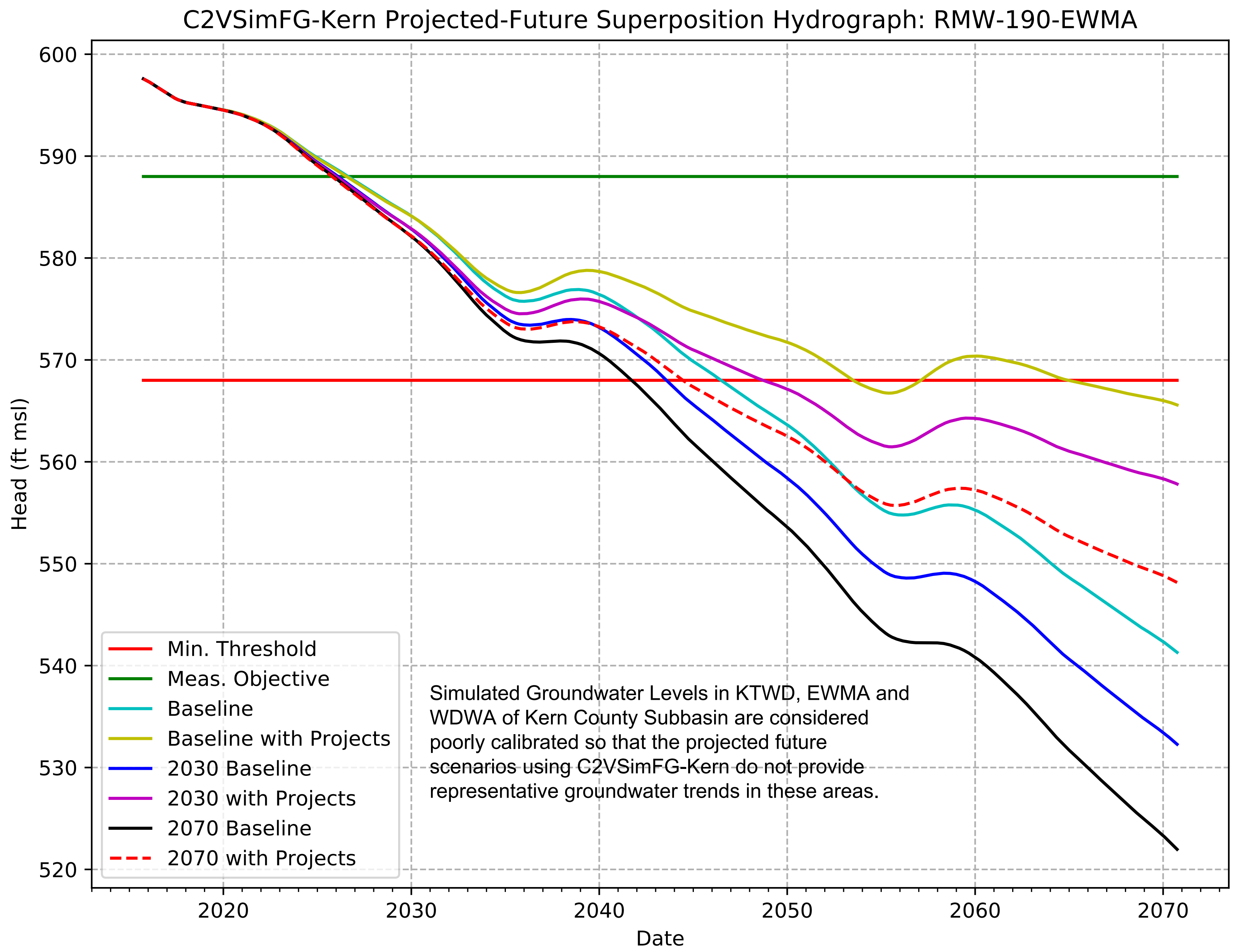

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-185-EWMA
Head (ft msl)
100
50
0
−50
−100
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Simulated Groundwater Levels in KTWD, EWMA and
WDWA of Kern County Subbasin are considered
poorly calibrated so that the projected future
scenarios using C2VSimFG-Kern do not provide
representative groundwater trends in these areas.

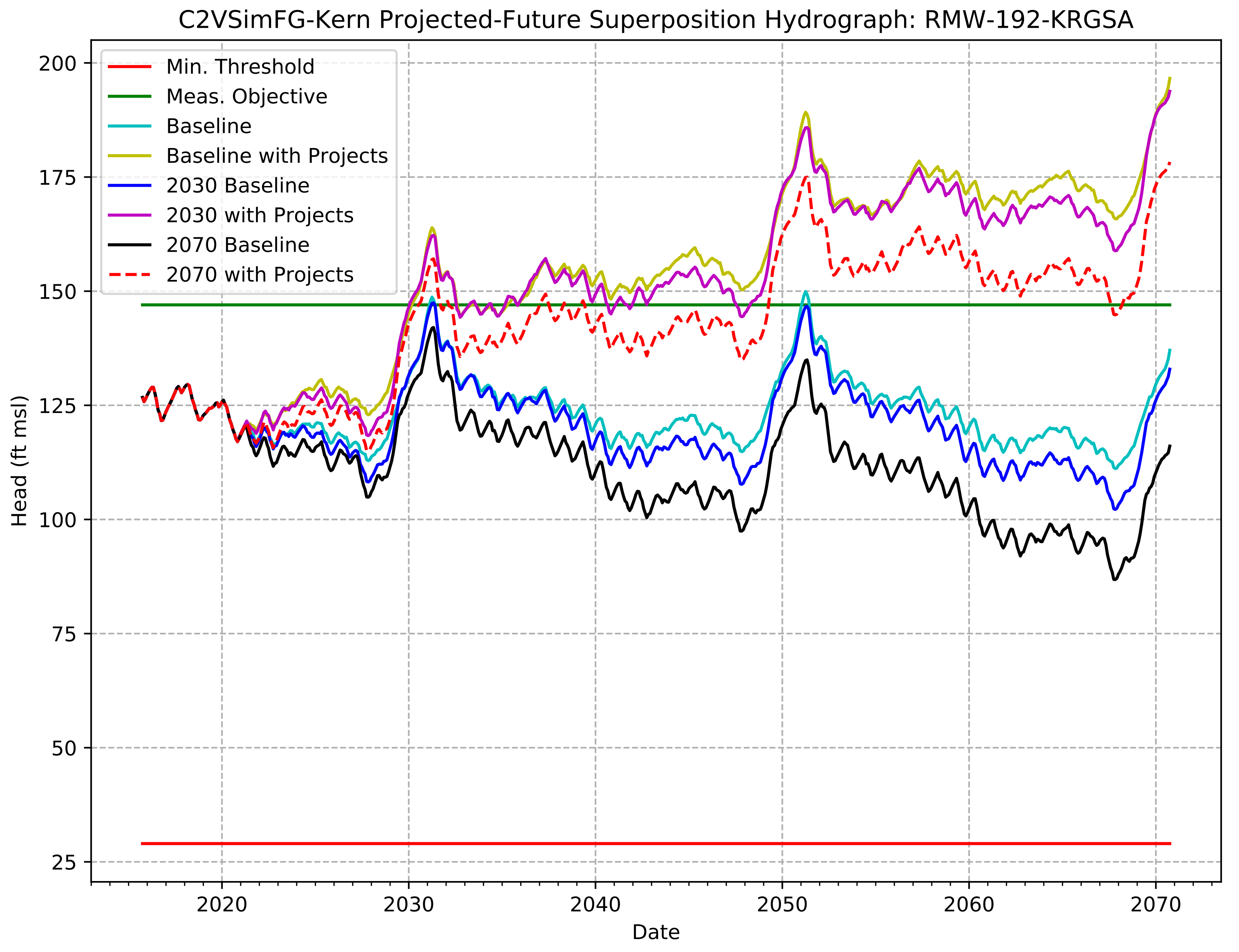

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-187-EWMA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
0
−50
−100
−150
−200
Head (ft msl)
2020
2030
2040
2050
2060
2070
Date
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.

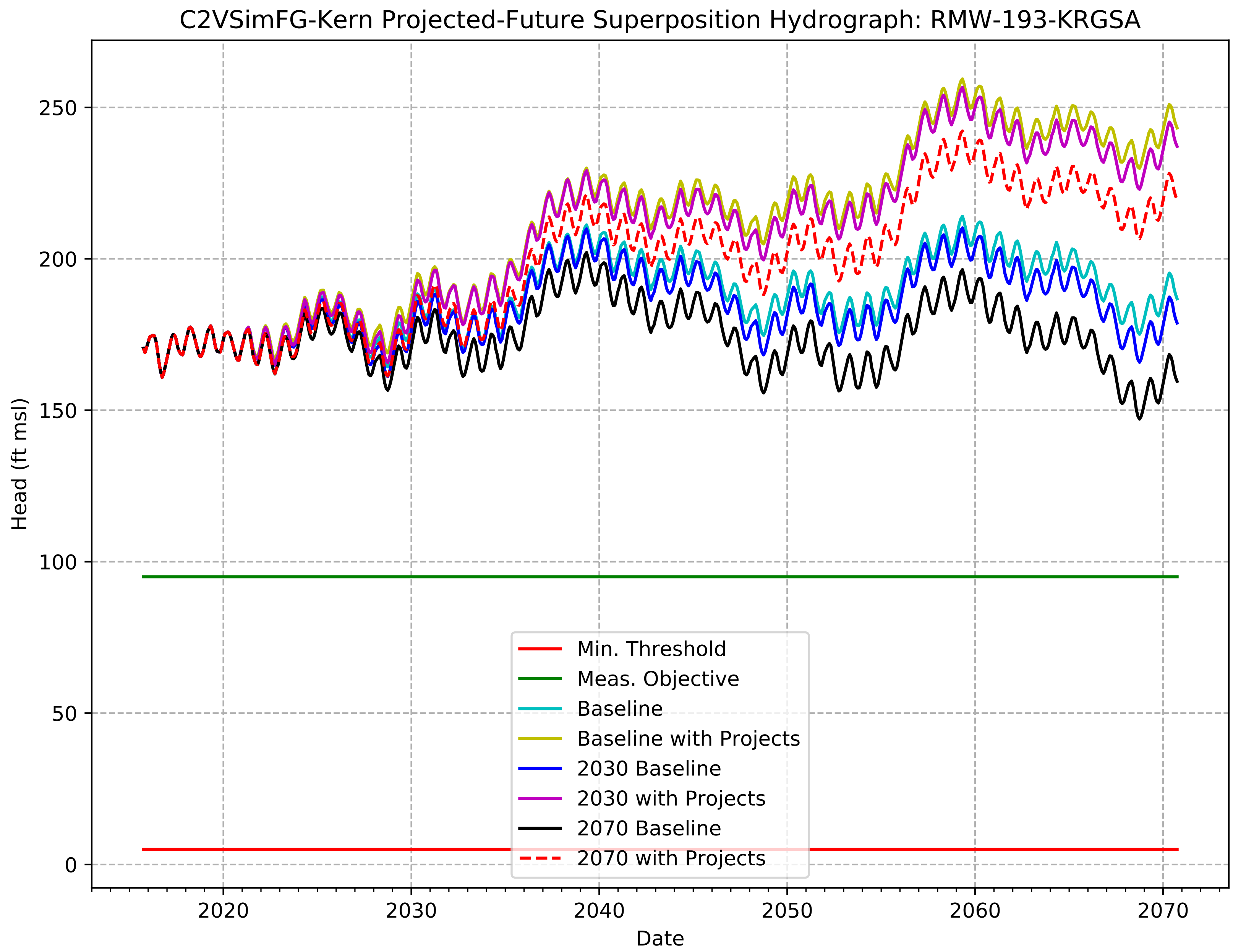


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-188-EWMA
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.
Head (ft msl)
Date
200
180
160
140
120
100
80
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

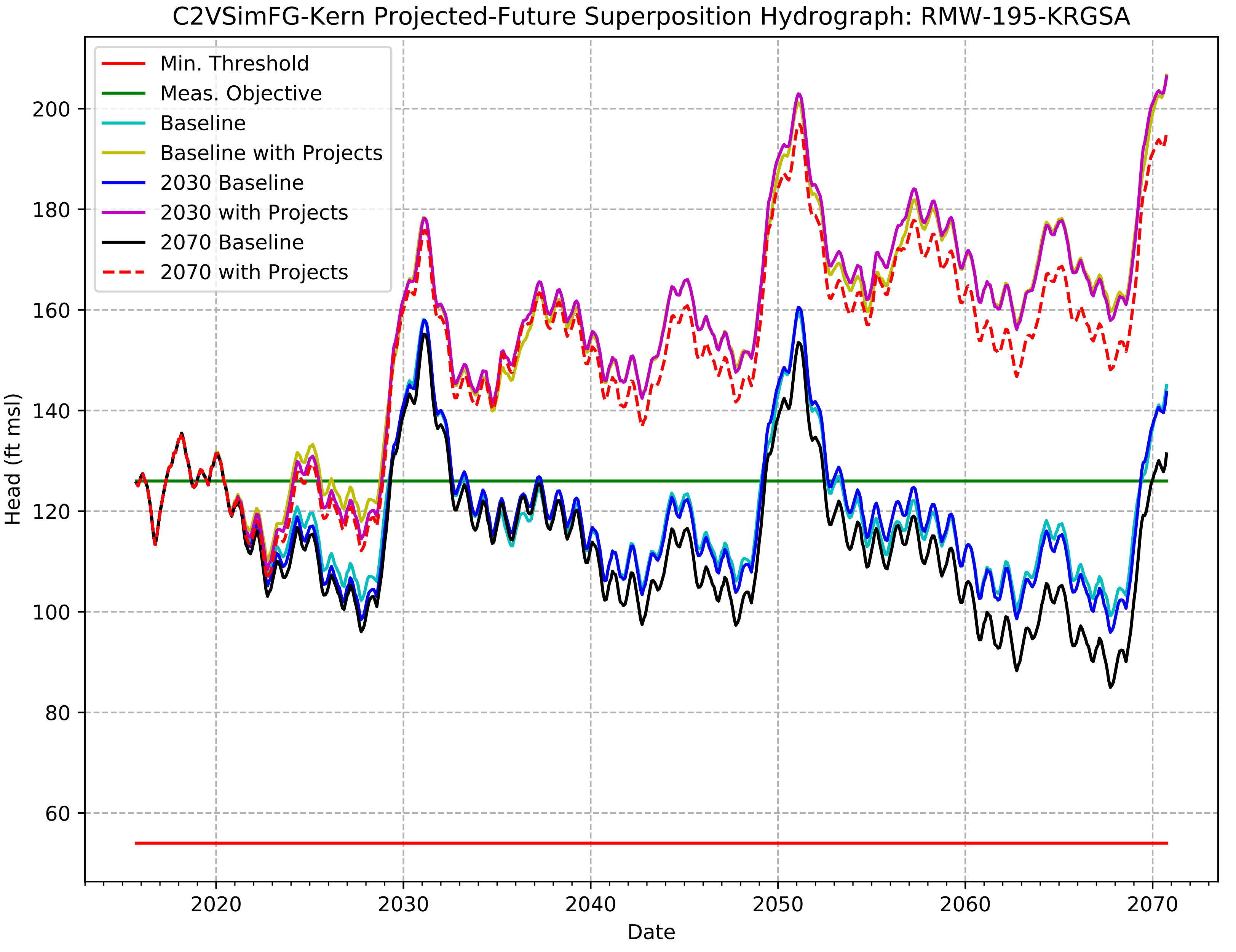

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-189-EWMA
Head (ft msl)
200
150
100
50
0
−50
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Simulated Groundwater Levels in KTWD, EWMA and
WDWA of Kern County Subbasin are considered
poorly calibrated so that the projected future
scenarios using C2VSimFG-Kern do not provide
representative groundwater trends in these areas.


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-190-EWMA
Head (ft msl)
600
590
580
570
560
550
540
530
520
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.

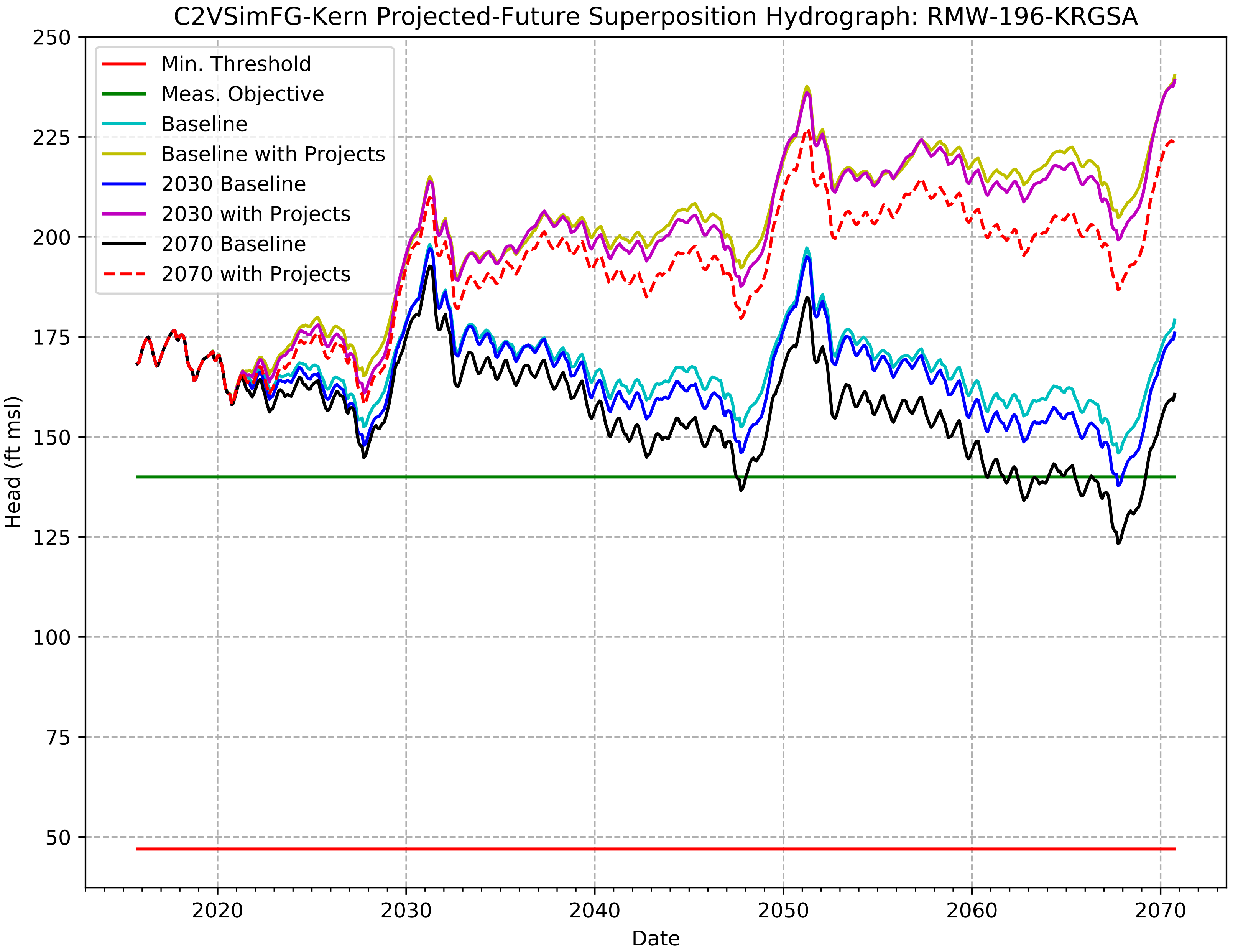

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-192-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
200
175
150
125
100
75
50
25
2020
2030
2040
2050
2060
2070
Date

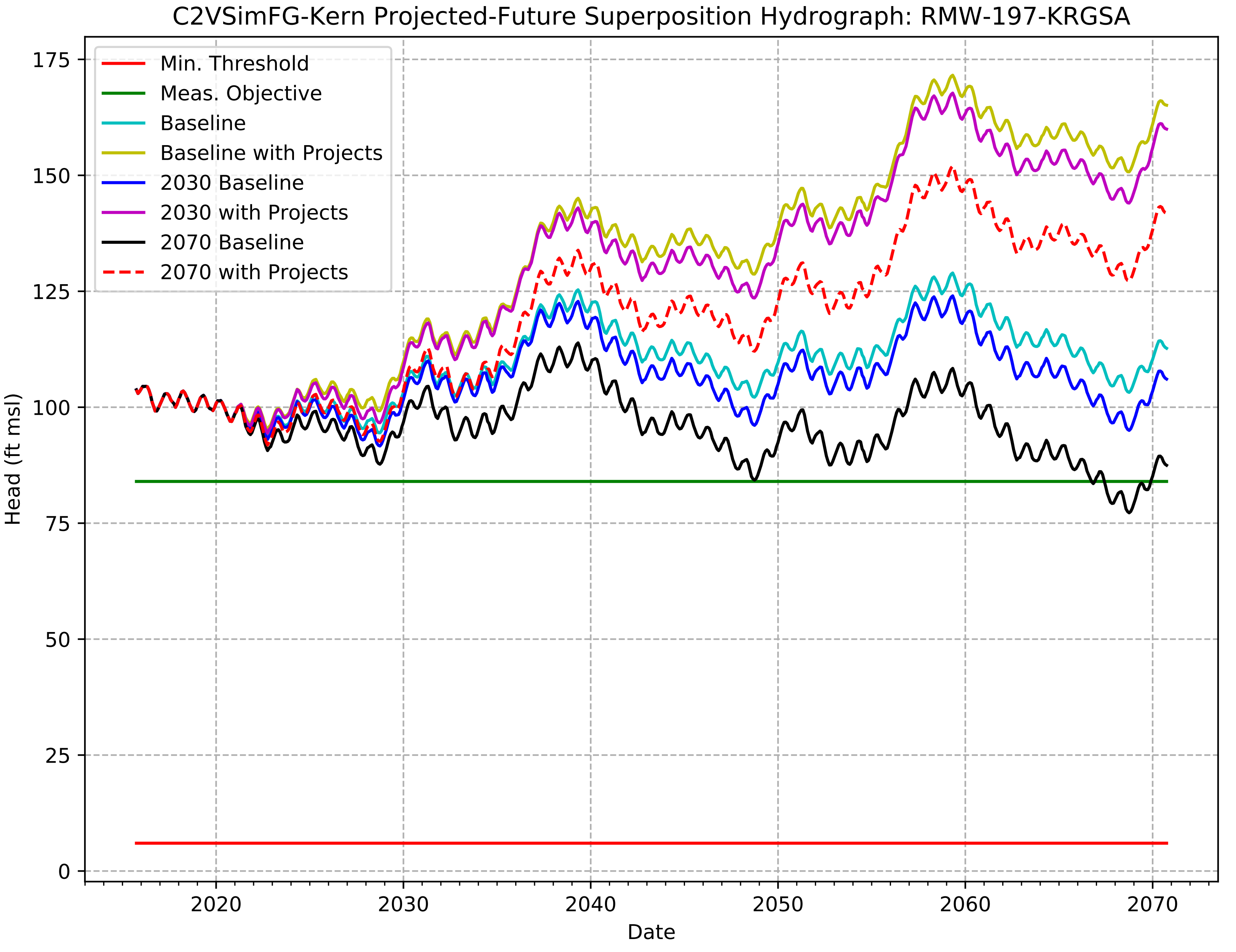


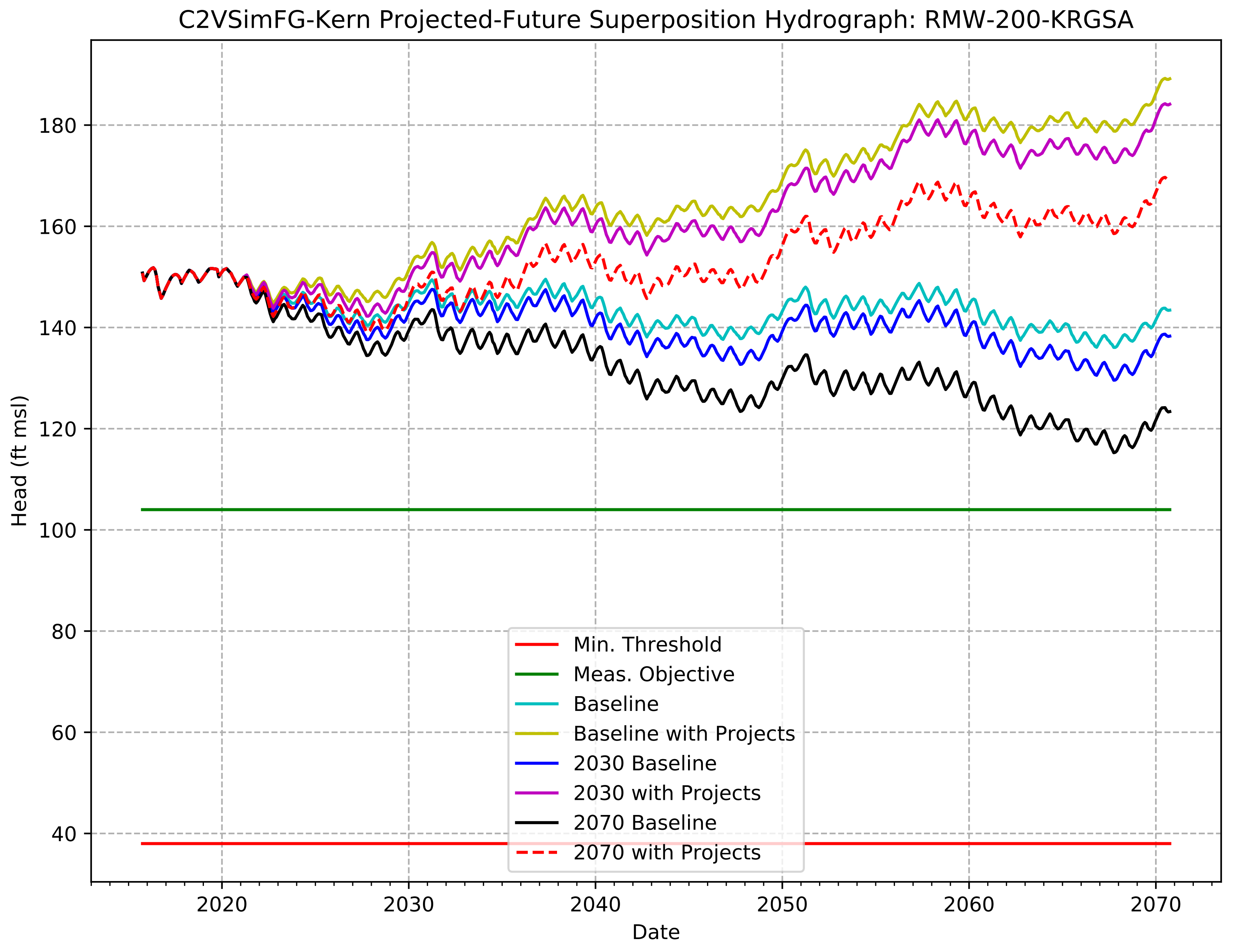
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-193-KRGSA
Head (ft msl)
0
50
100
150
200
250
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



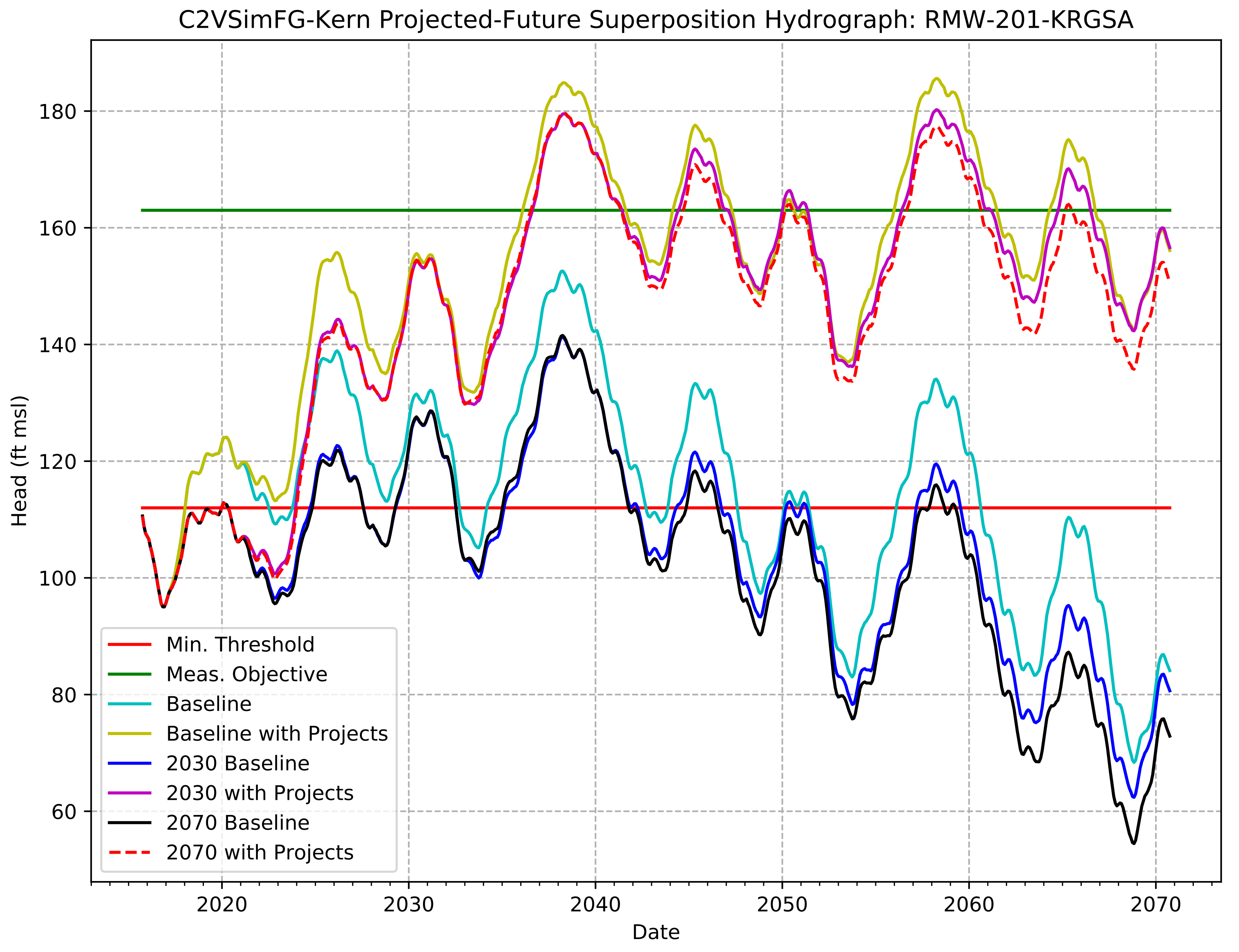
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-195-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
60
80
100
120
140
160
180
200
2020
2030
2040
2050
2060
2070
Date


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-196-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
250
225
200
175
150
125
100
75
50
2020
2030
2040
2050
2060
2070

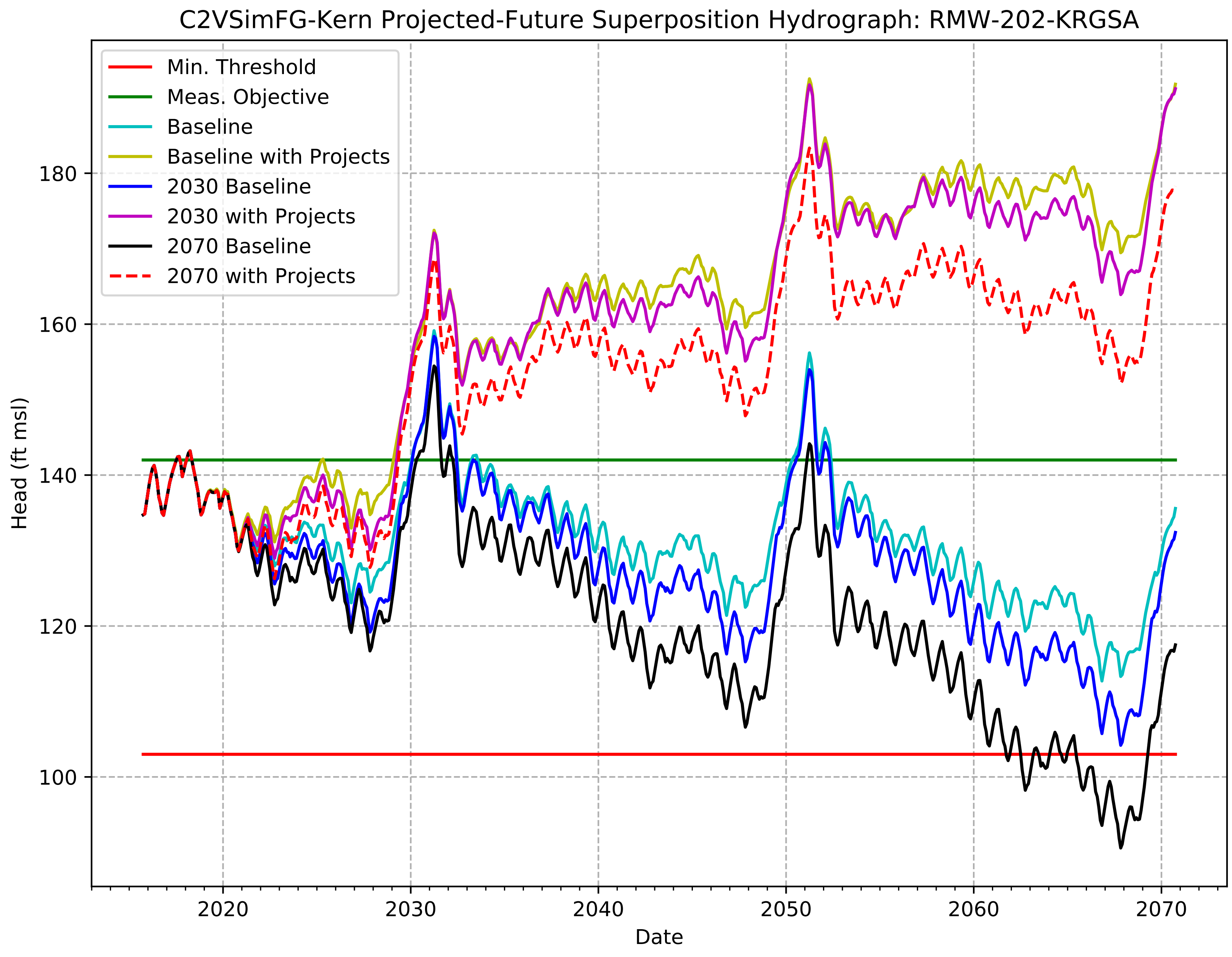

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-197-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
175
150
125
100
75
50
25
0
2020
2030
2040
2050
2060
2070

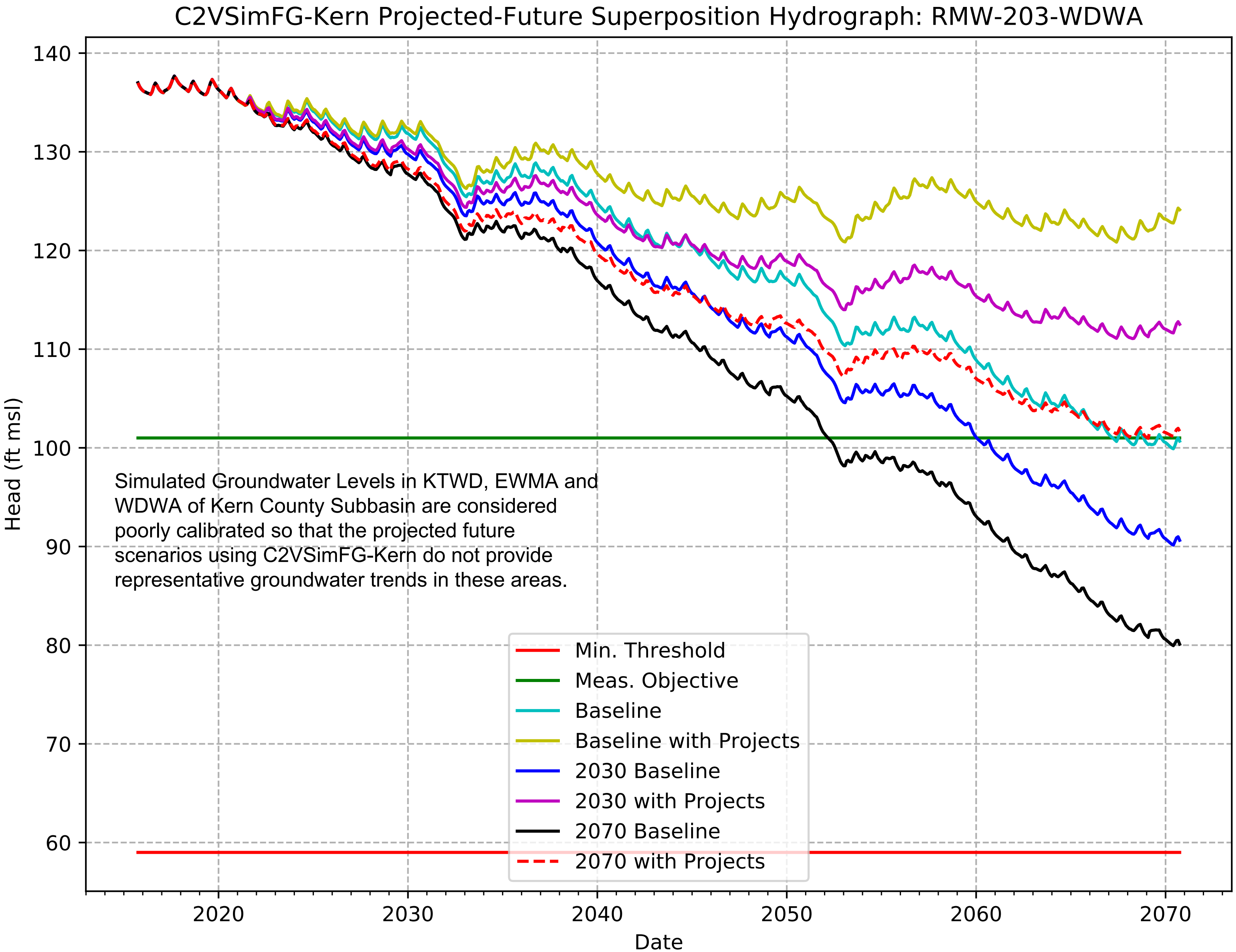


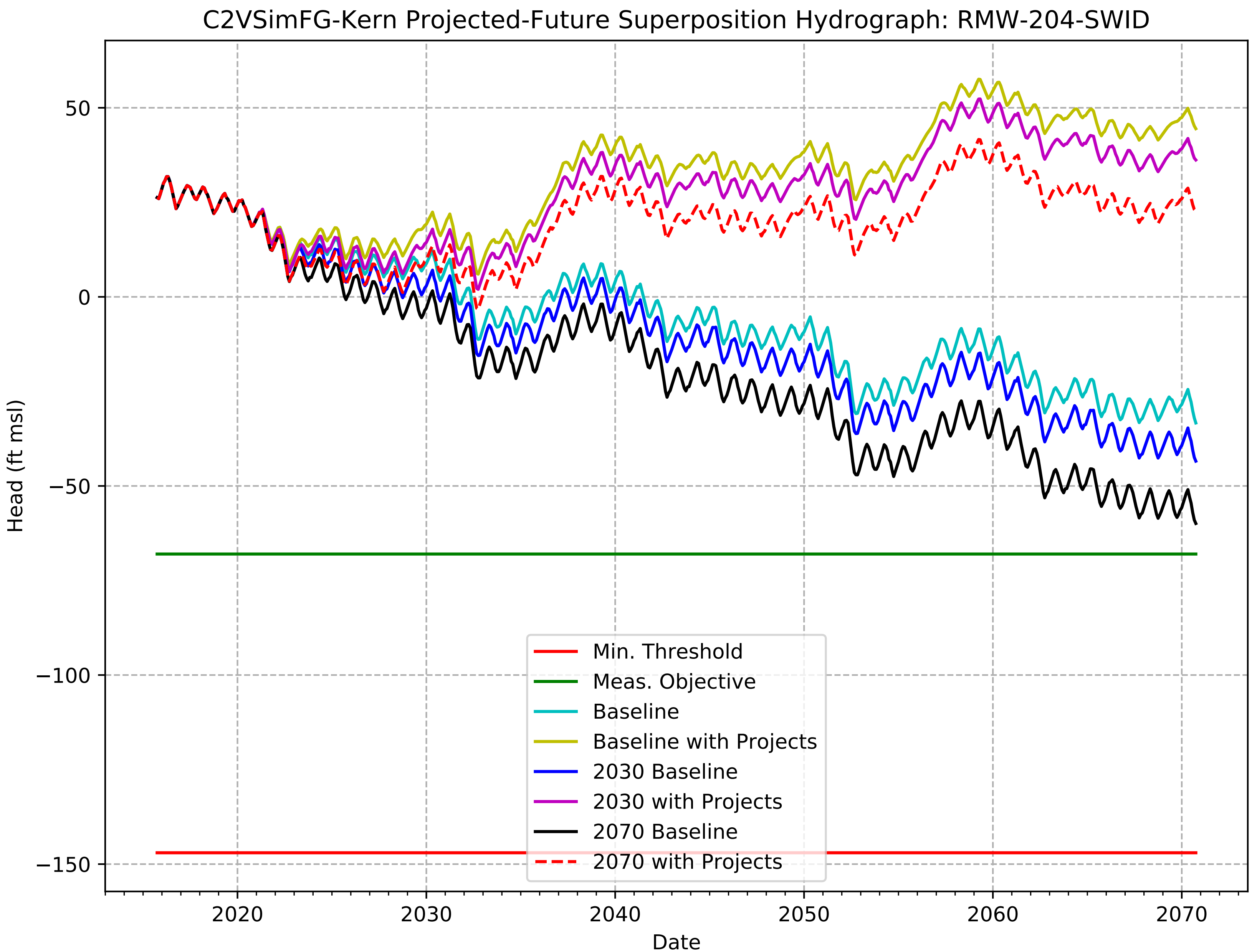
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-200-KRGSA
Head (ft msl)
Date
180
160
140
120
100
80
60
40
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



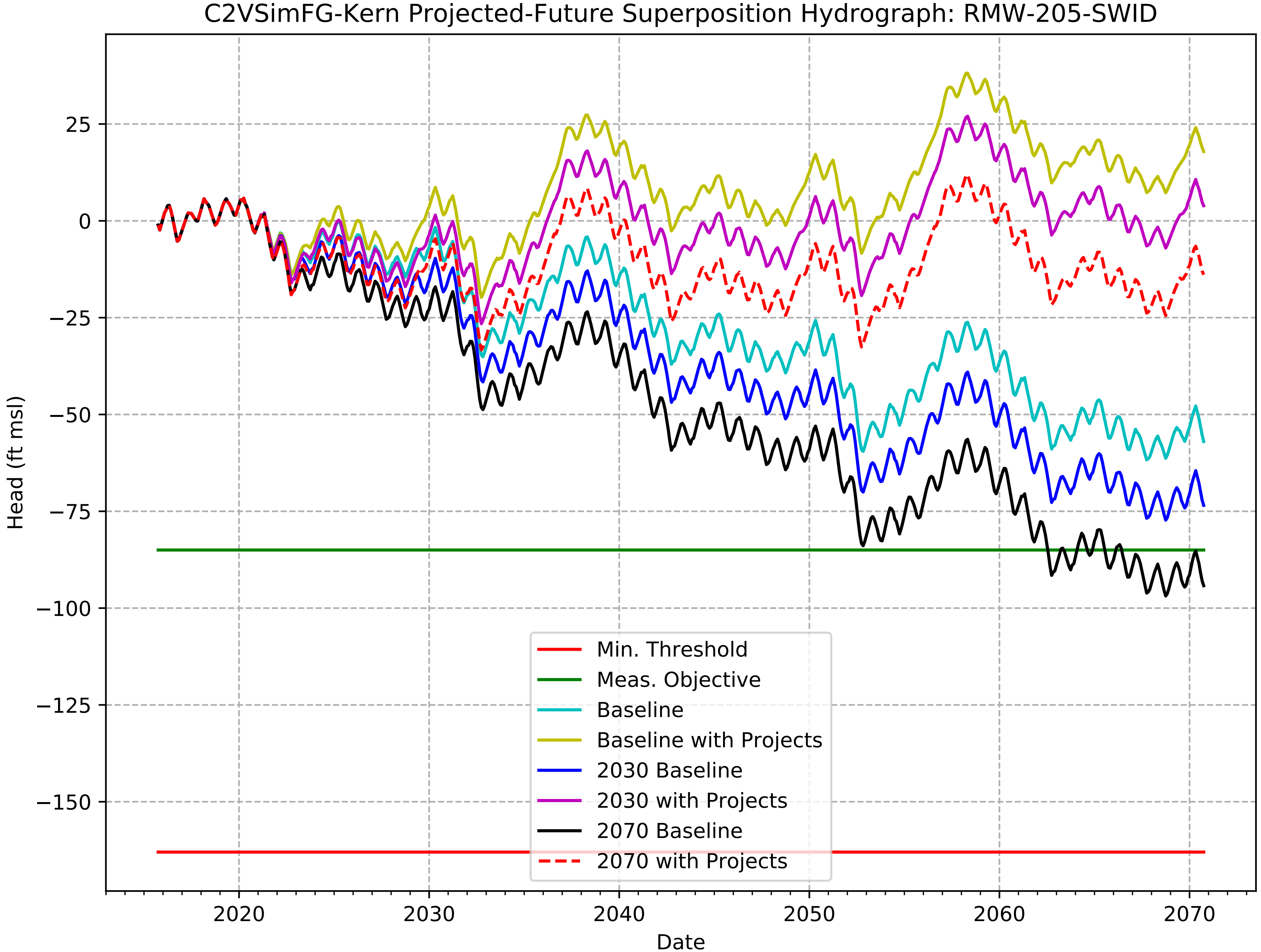
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-201-KRGSA
Head (ft msl)
Date
180
160
140
120
100
80
60
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

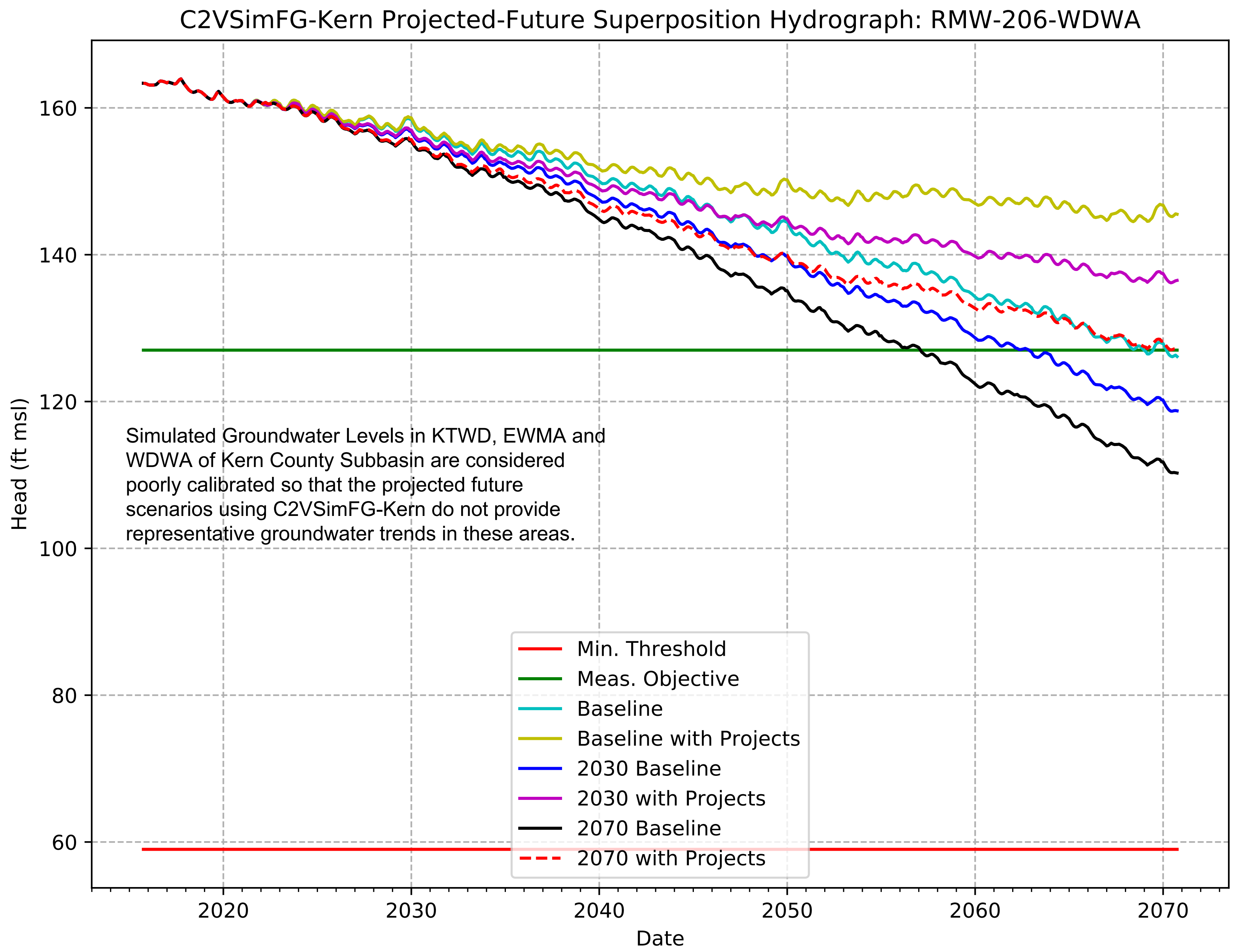

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-202-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
100
120
140
160
180
Date
2020
2030
2040
2050
2060
2070


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-203-WDWA
Head (ft msl)
140
130
120
110
100
90
80
70
60
2020
2030
2040
2050
2060
2070
Date
Simulated Groundwater Levels in KTWD, EWMA and
WDWA of Kern County Subbasin are considered
poorly calibrated so that the projected future
scenarios using C2VSimFG-Kern do not provide
representative groundwater trends in these areas.
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

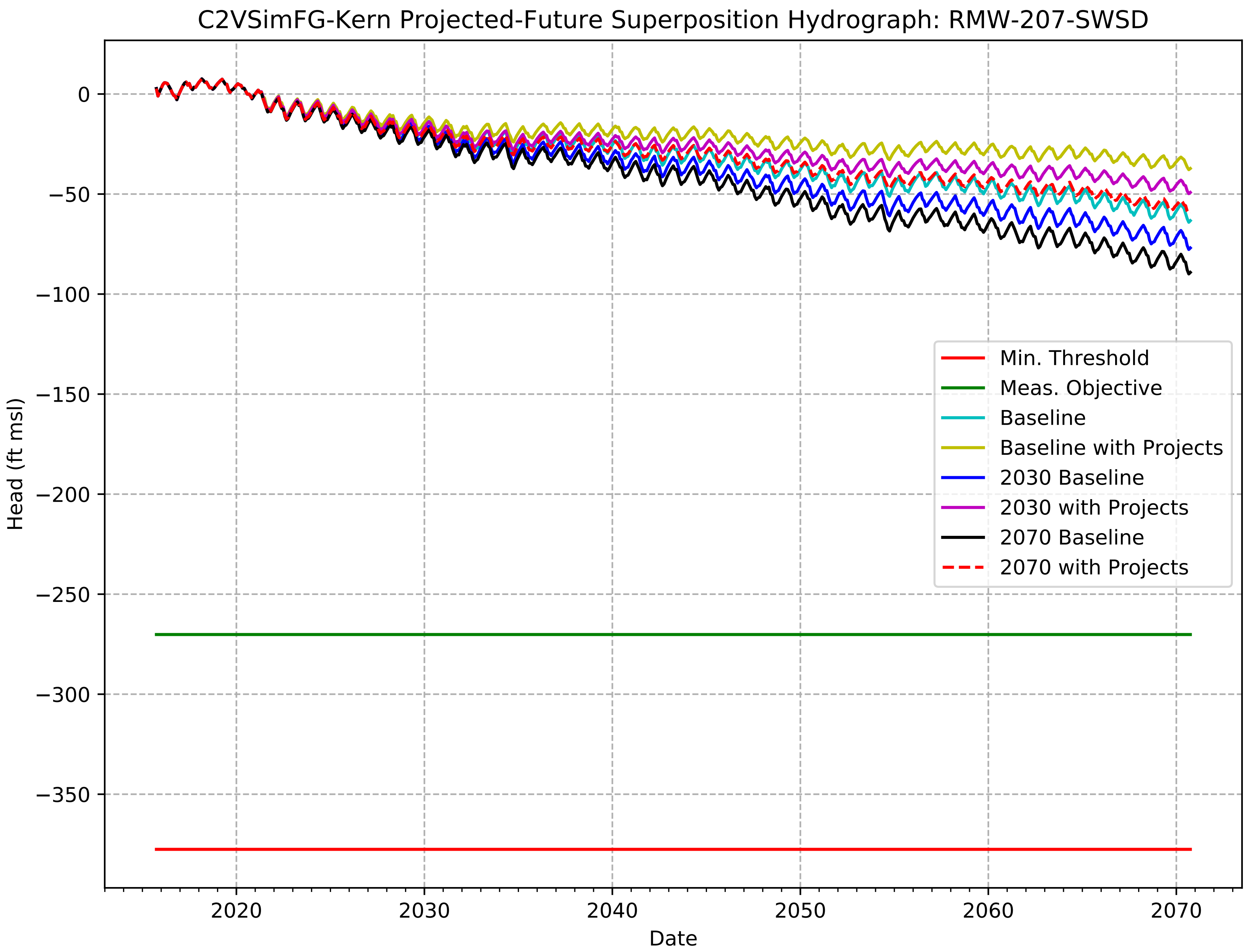


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-204-SWID
Head (ft msl)
50
0
−50
−100
−150
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

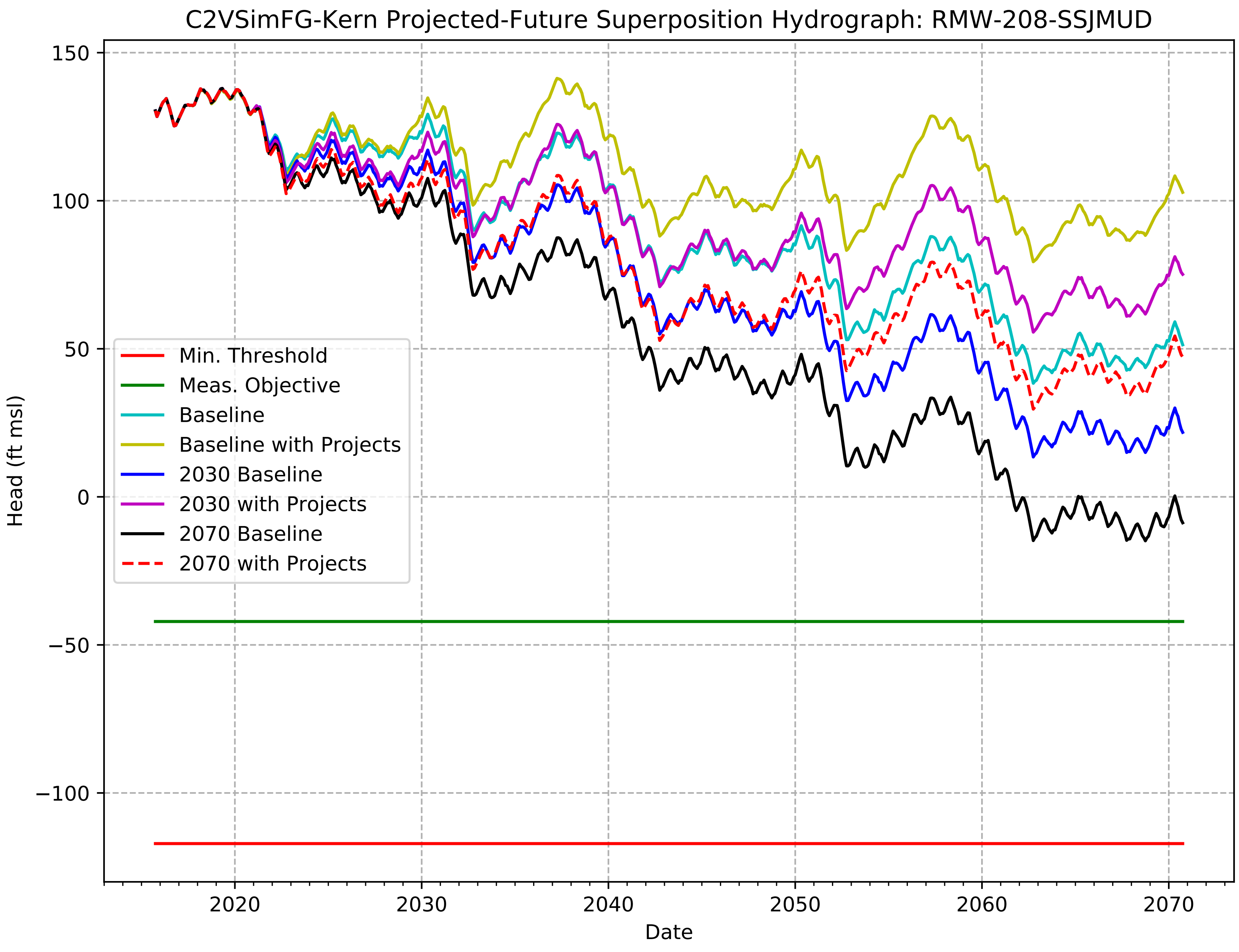

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-205-SWID
Head (ft msl)
Date
25
0
−25
−50
−75
−100
−125
−150
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



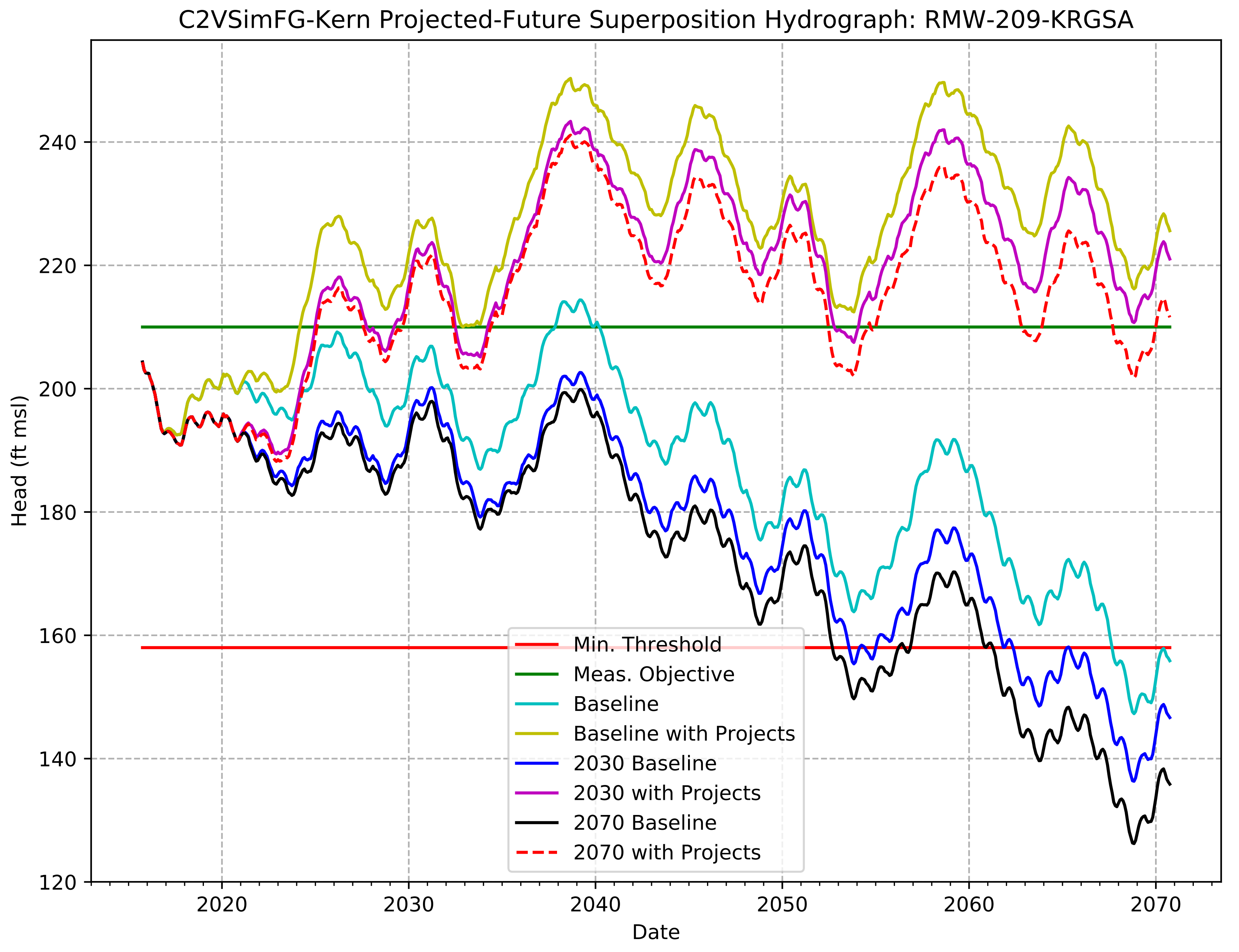
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-206-WDWA
Head (ft msl)
160
140
120
100
80
60
2020
2030
2040
2050
2060
2070
Date
Simulated Groundwater Levels in KTWD, EWMA and WDWA of Kern County Subbasin are considered poorly calibrated so that the projected future scenarios using C2VSimFG-Kern do not provide representative groundwater trends in these areas.
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

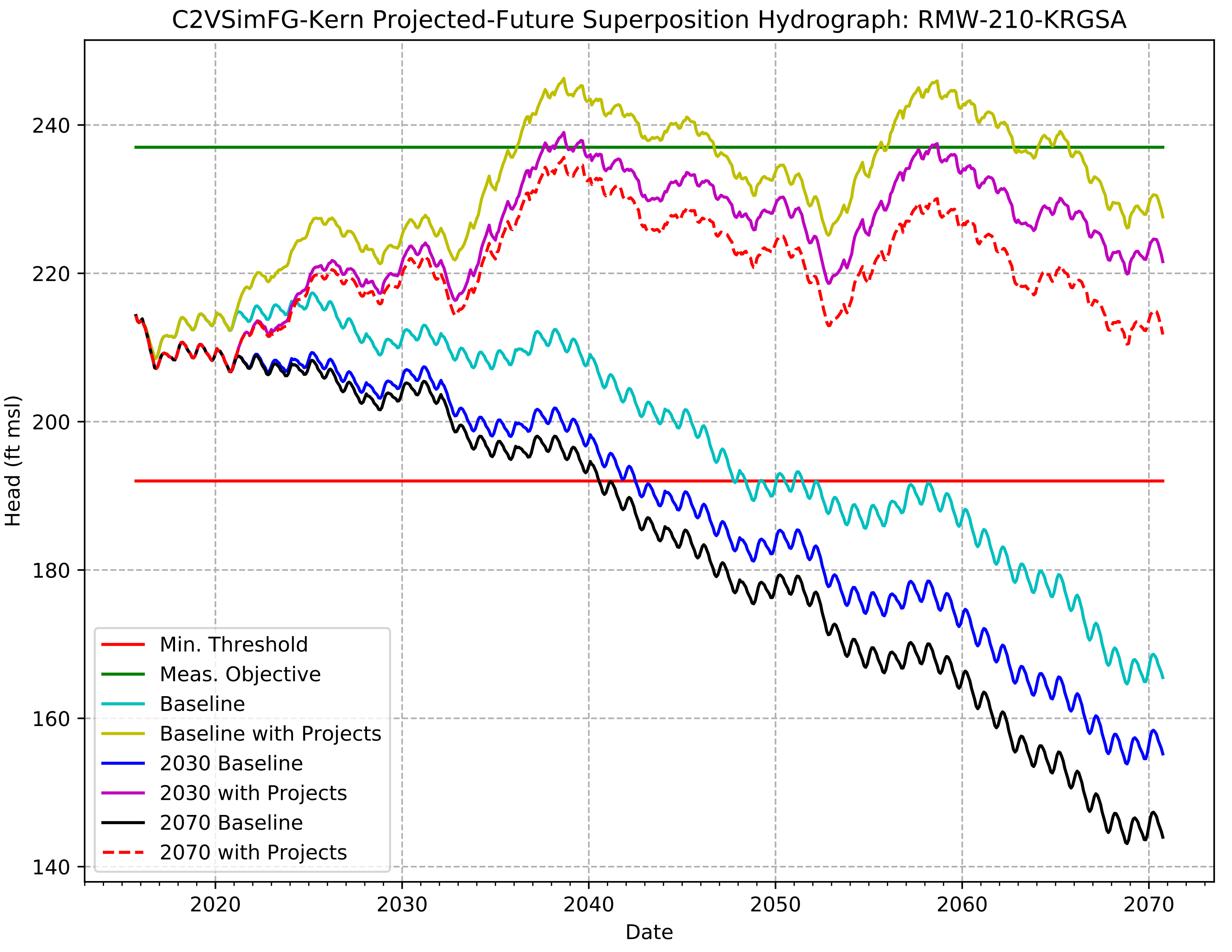


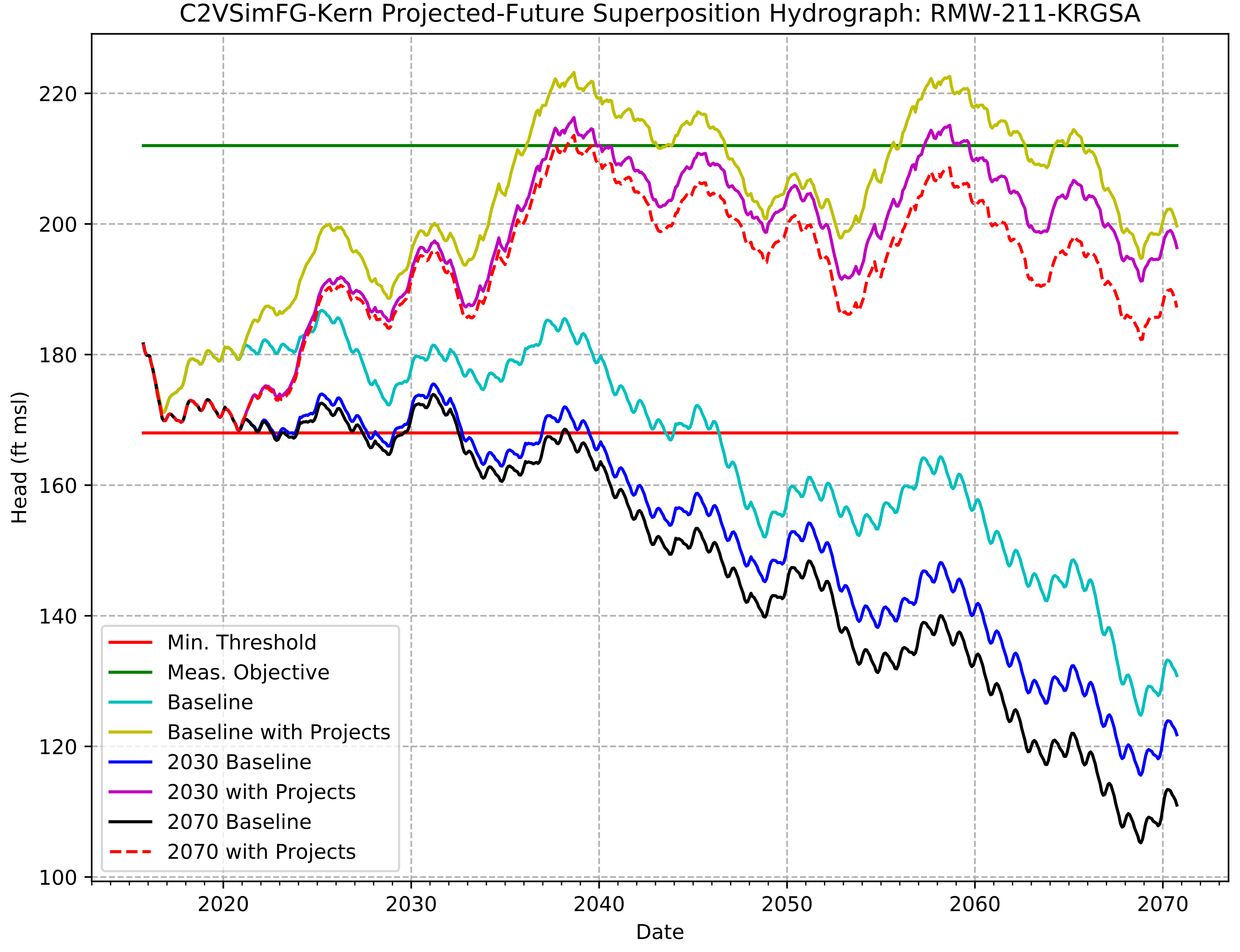
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-207-SWSD
Head (ft msl)
0
−50
−100
−150
−200
−250
−300
−350
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



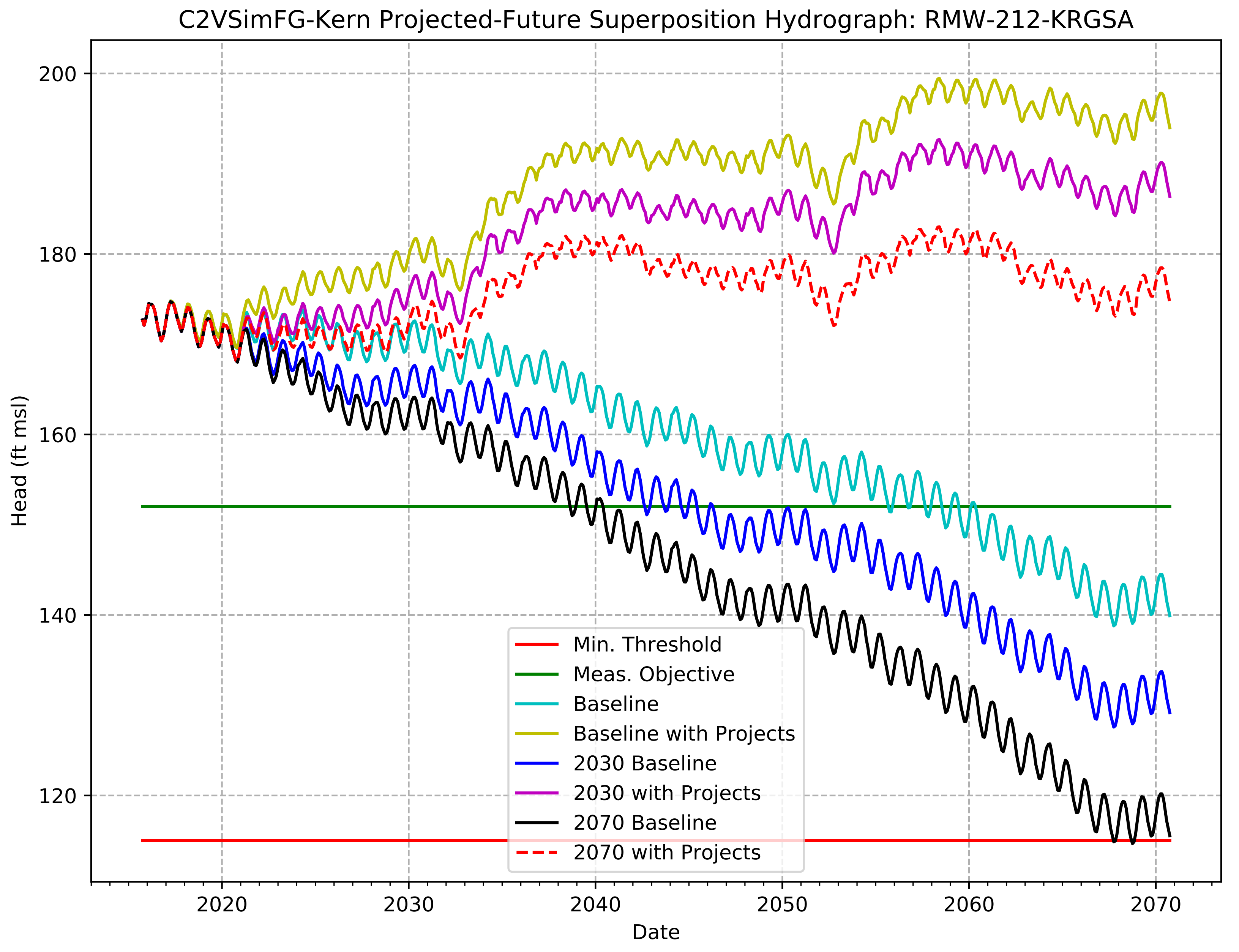
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-208-SSJMUD
Head (ft msl)
150
100
50
0
−50
−100
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-209-KRGSA
Head (ft msl)
Date
120
140
160
180
200
220
240
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

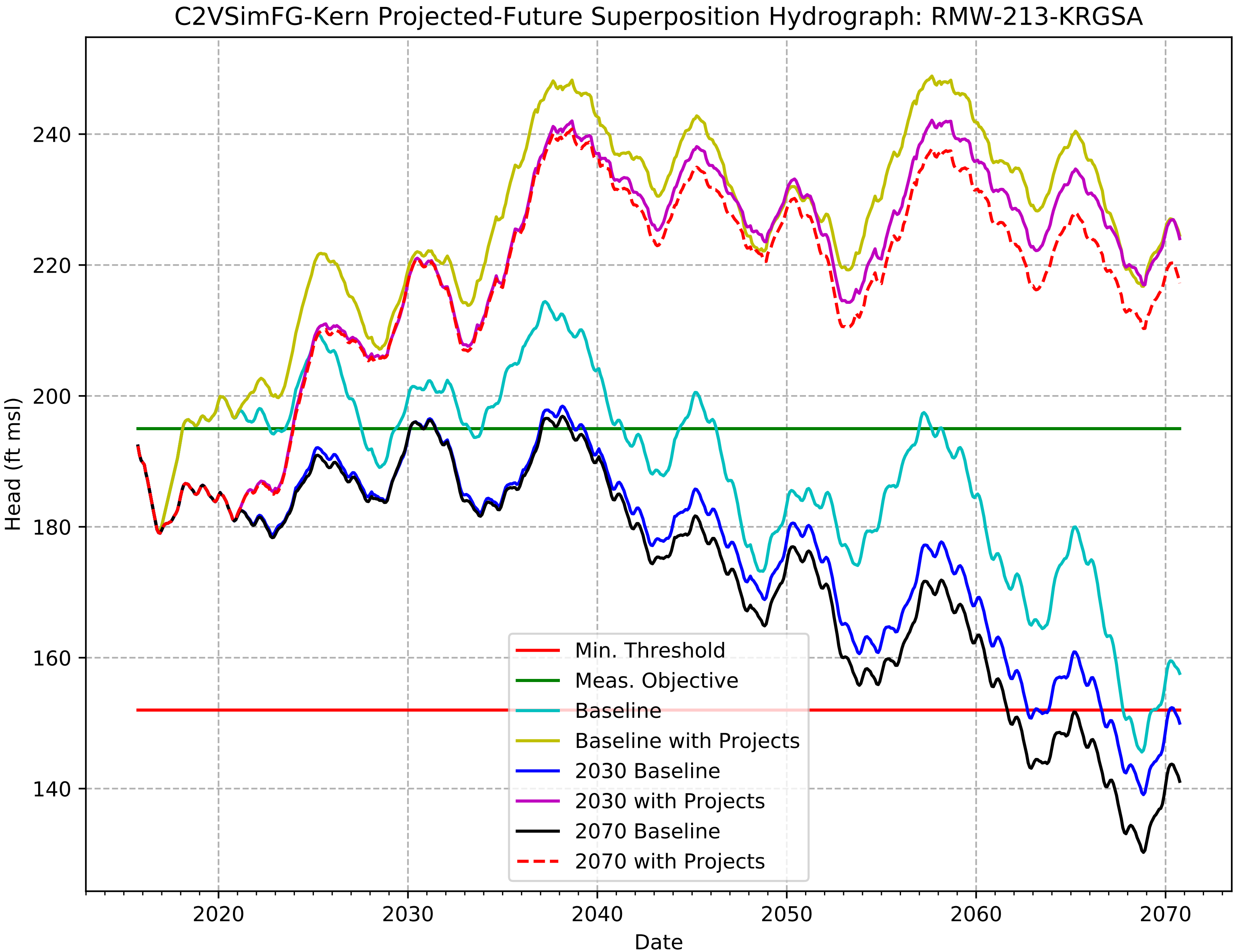

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-210-KRGSA
Head (ft msl)
Date
240
220
200
180
160
140
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



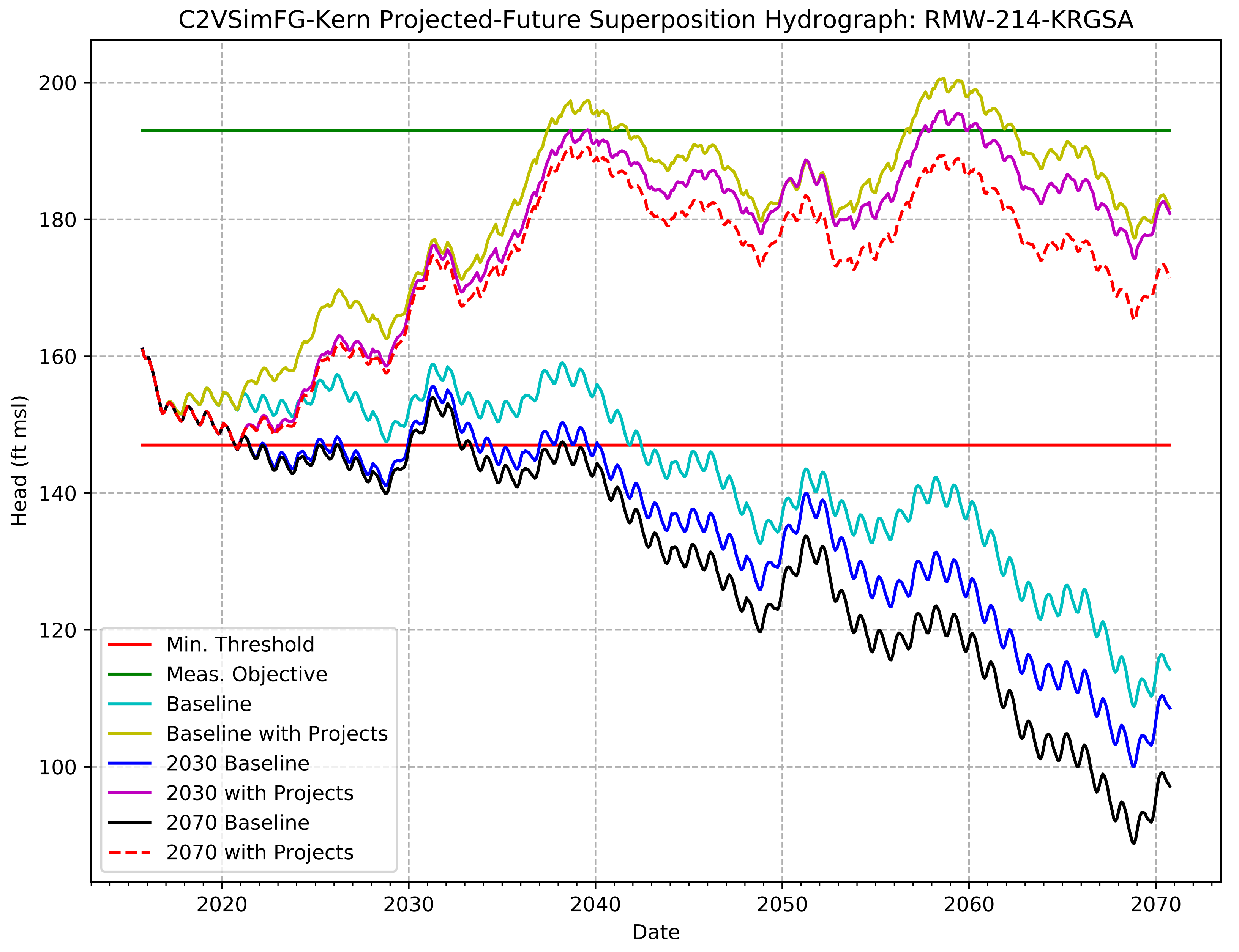
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-211-KRGSA
Head (ft msl)
Date
220
200
180
160
140
120
100
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



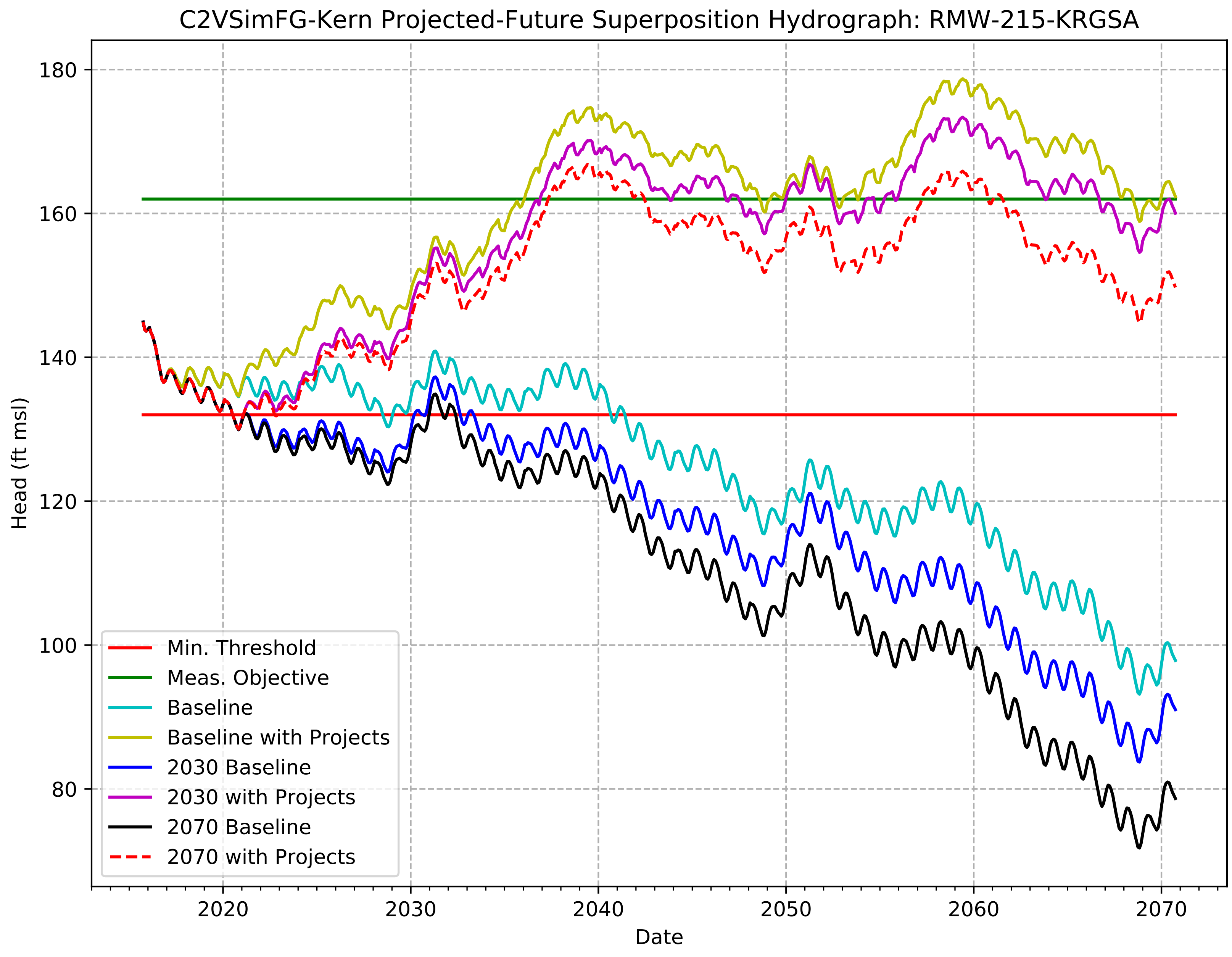
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-212-KRGSA
Head (ft msl)
200
180
160
140
120
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

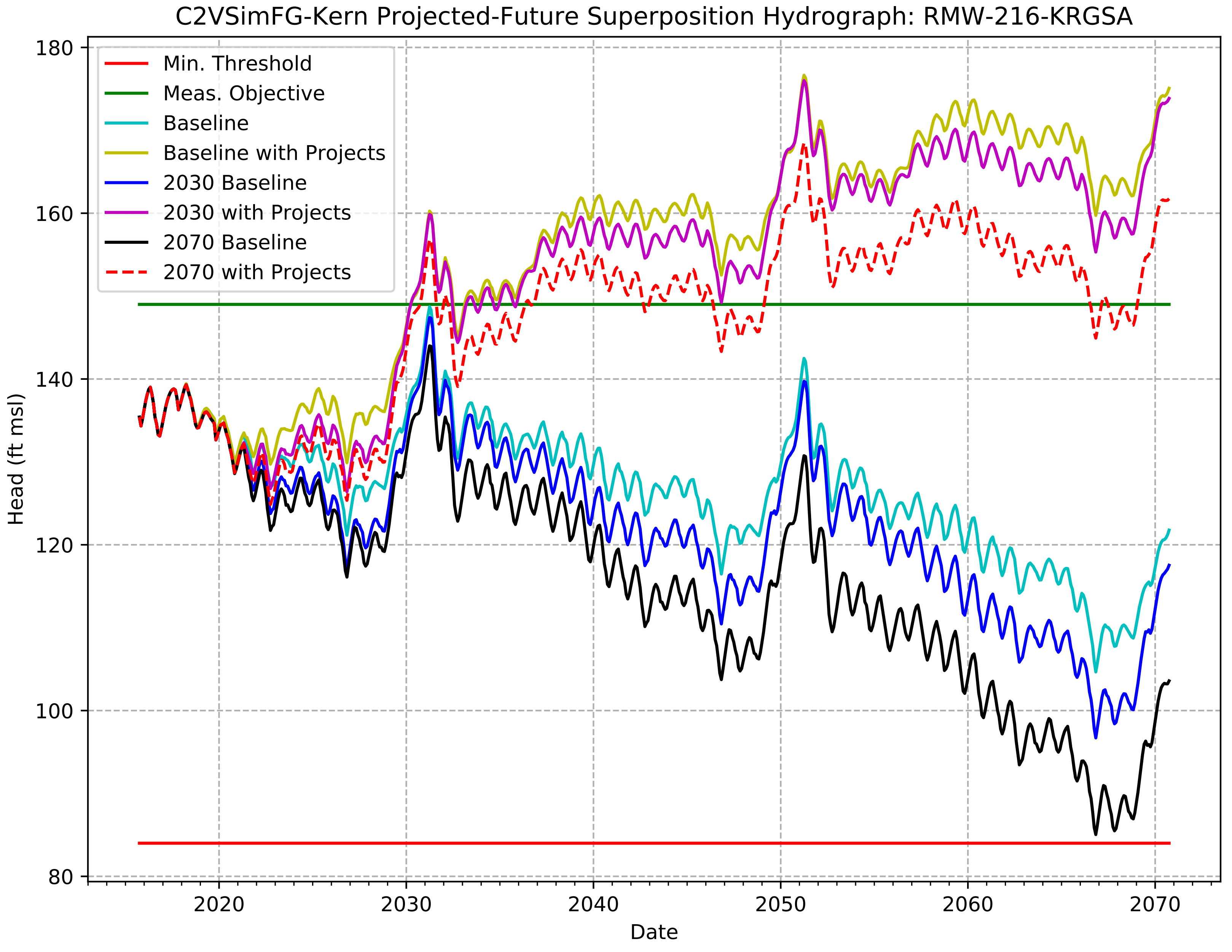


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-213-KRGSA
Head (ft msl)
Date
240
220
200
180
160
140
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

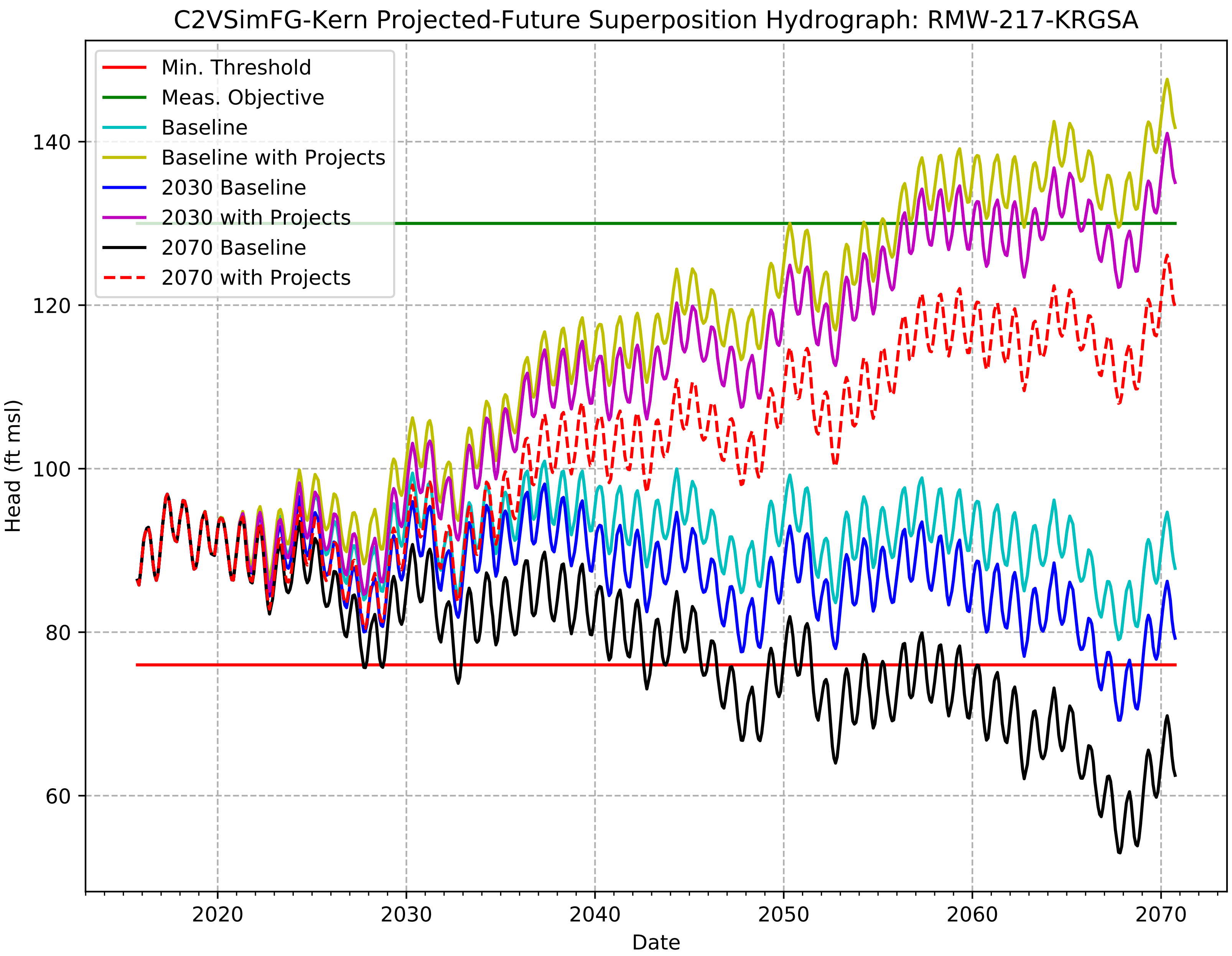


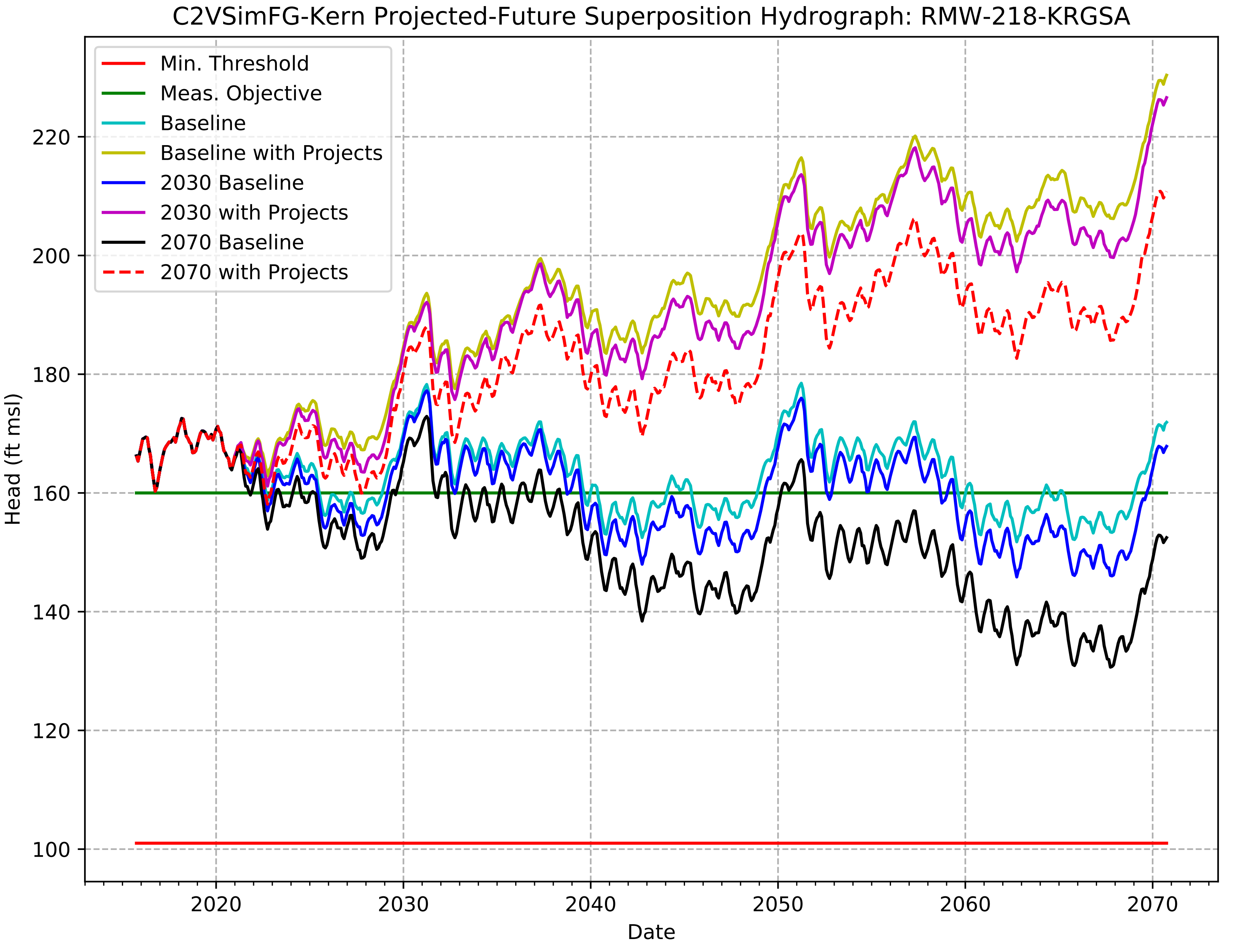
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-214-KRGSA
Head (ft msl)
Date
200
180
160
140
120
100
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-215-KRGSA
Head (ft msl)
180
160
140
120
100
80
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

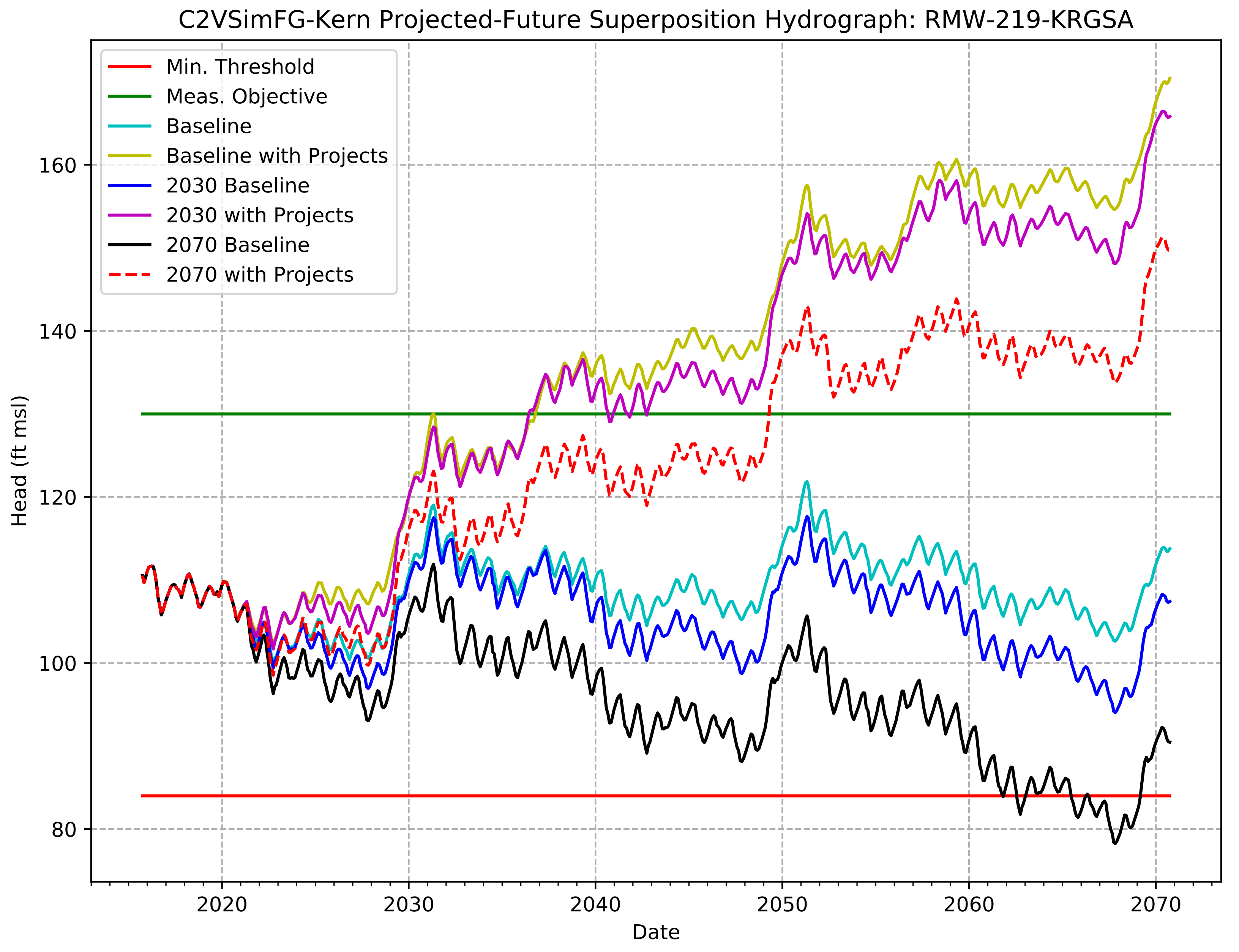


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-216-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
180
160
140
120
100
80
2020
2030
2040
2050
2060
2070
Date

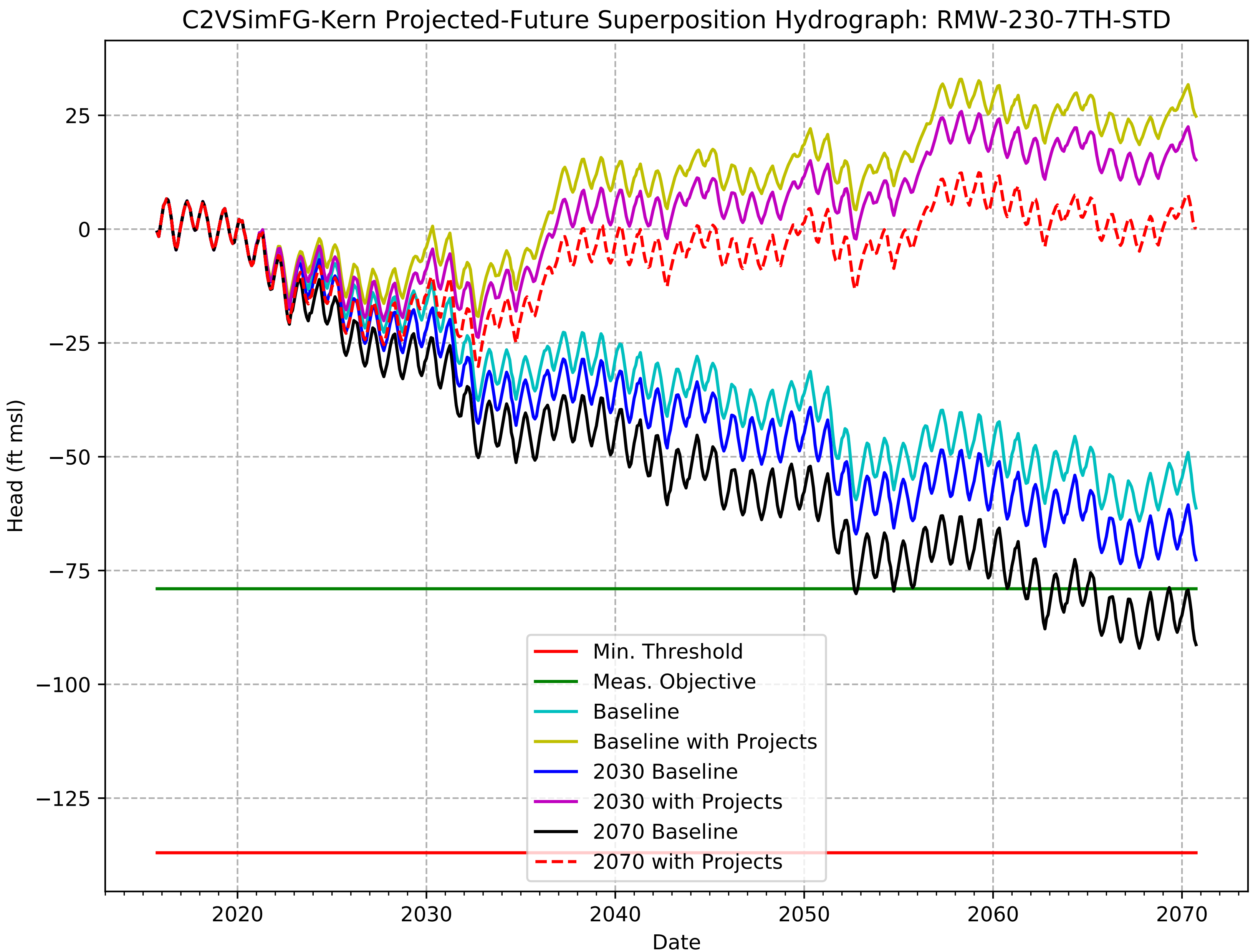

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-217-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
140
120
100
80
60
2020
2030
2040
2050
2060
2070
Date



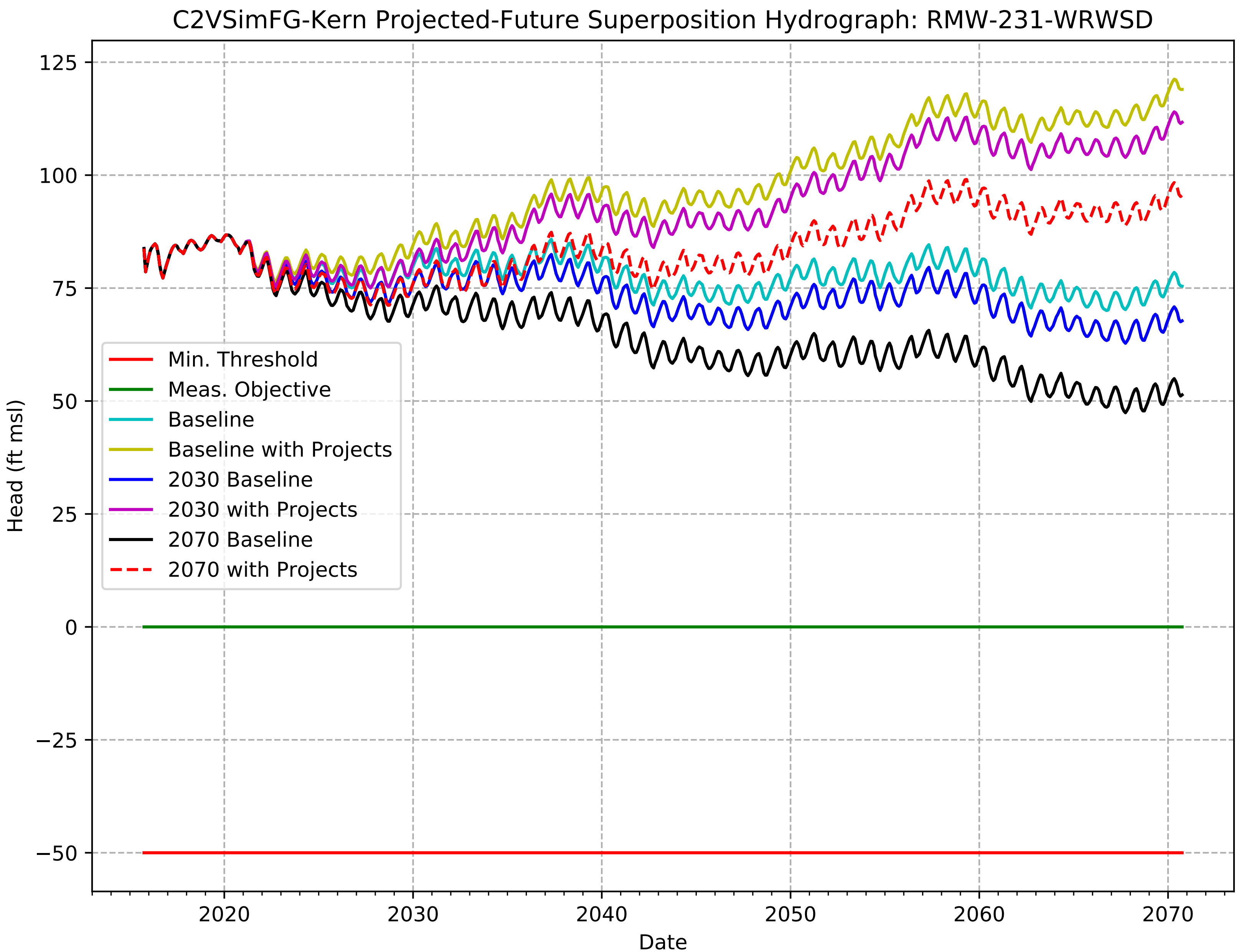
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-218-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
100
120
140
160
180
200
220
2020
2030
2040
2050
2060
2070
Date

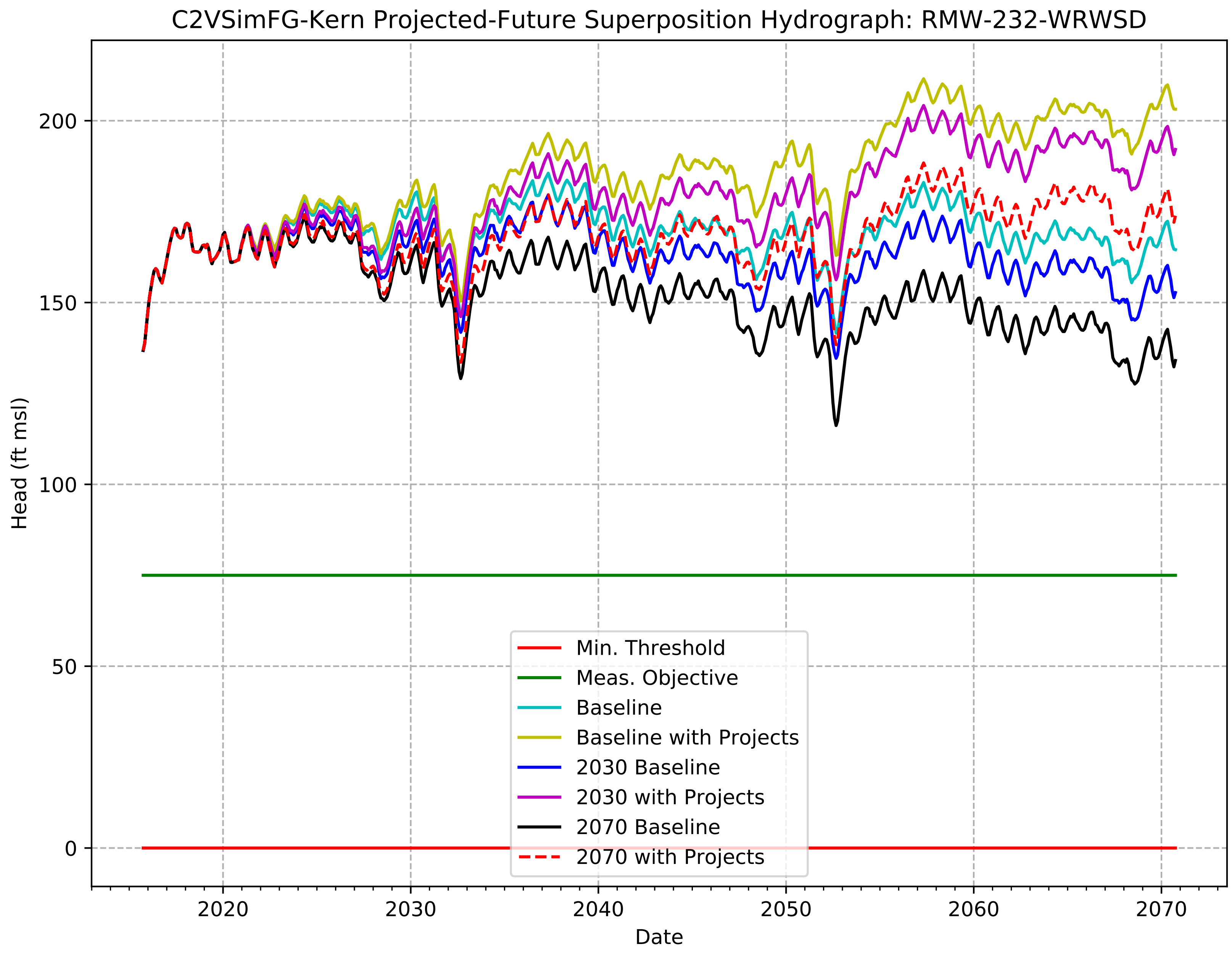


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-219-KRGSA
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
80
100
120
140
160
2020
2030
2040
2050
2060
2070
Date

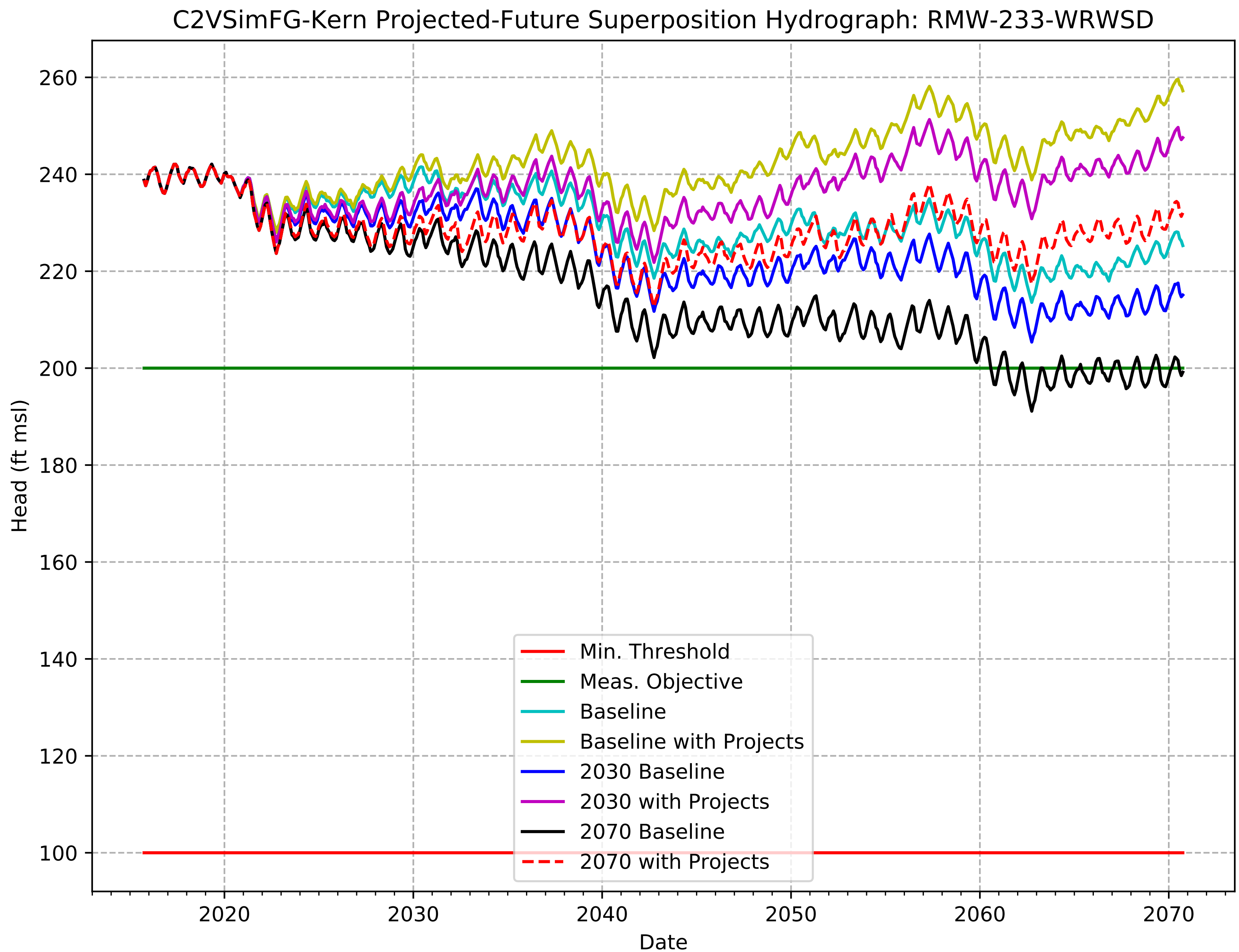


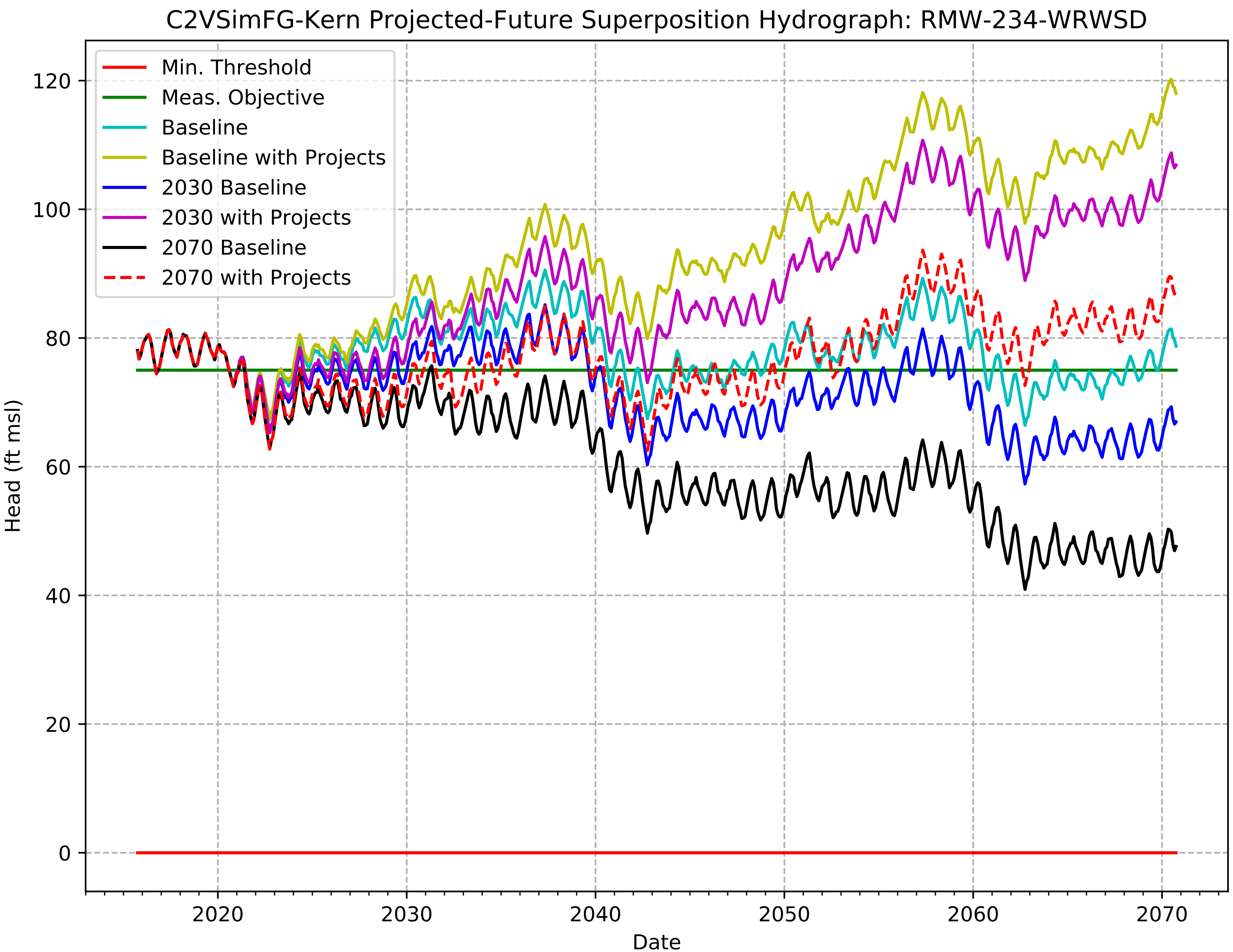
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-230-7TH-STD
Head (ft msl)
25
0
−25
−50
−75
−100
−125
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-231-WRWSD
Head (ft msl)
Date
125
100
75
50
25
0
−25
−50
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

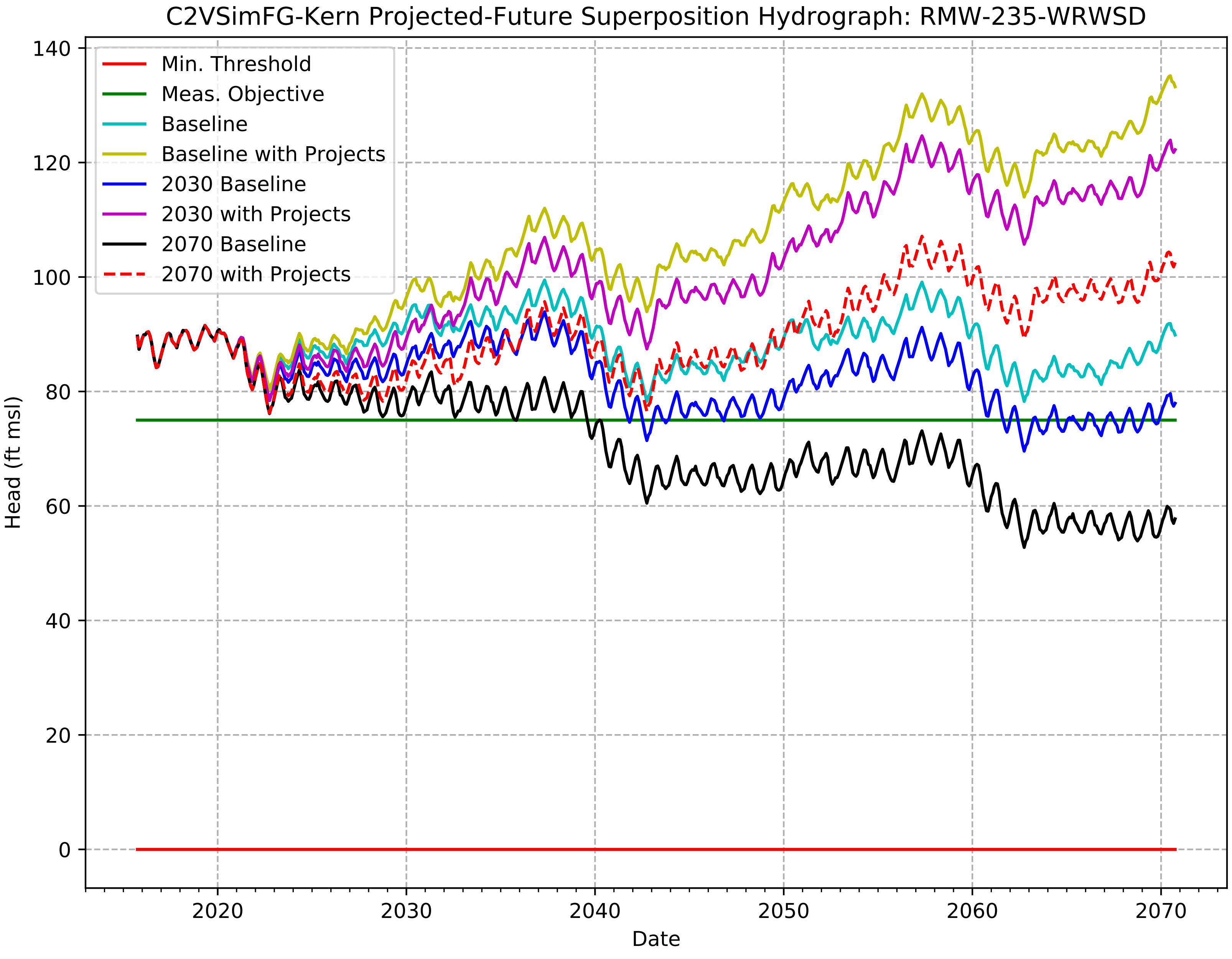


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-232-WRWSD
Head (ft msl)
Date
0
50
100
150
200
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

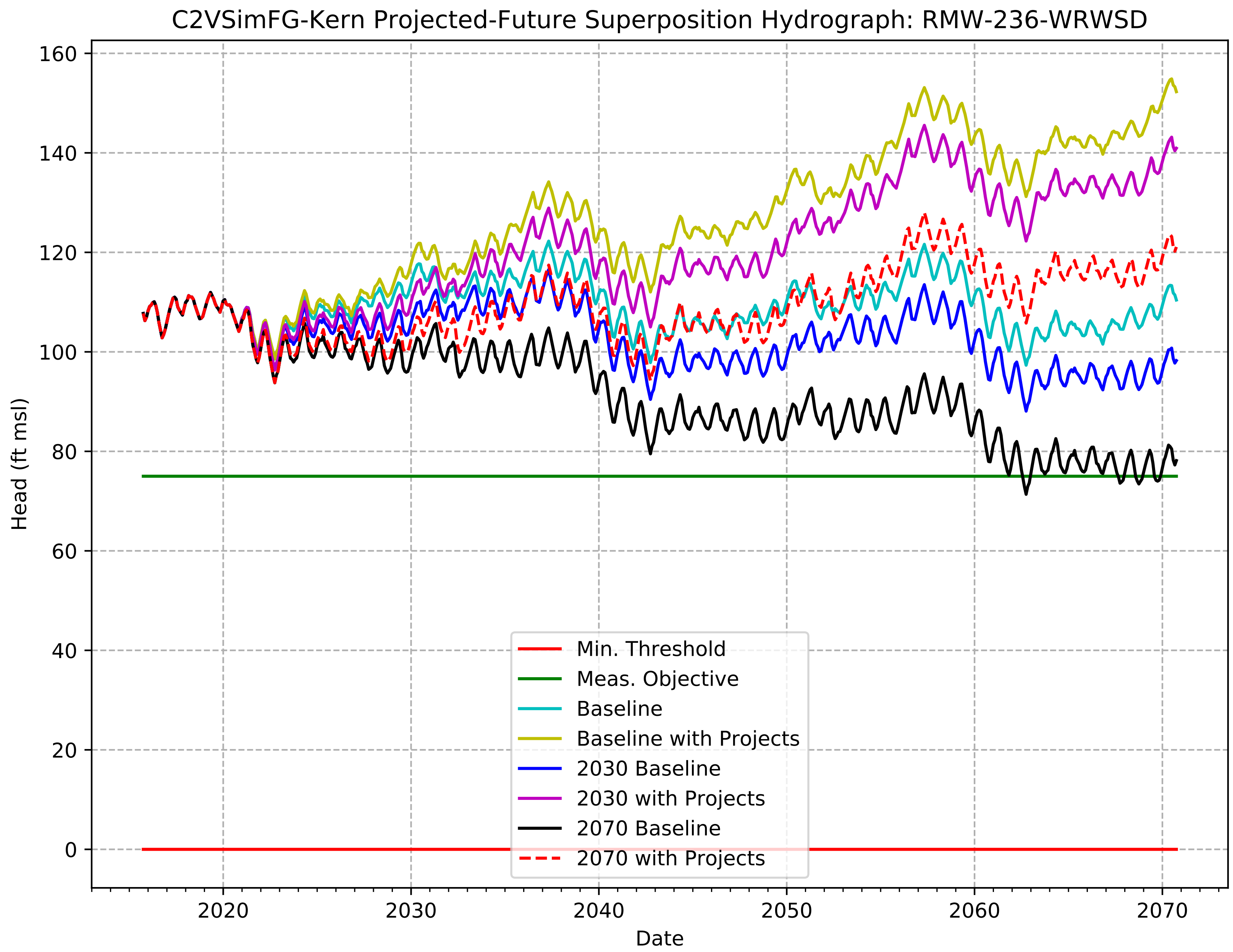

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-233-WRWSD
Head (ft msl)
Date
260
240
220
200
180
160
140
120
100
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



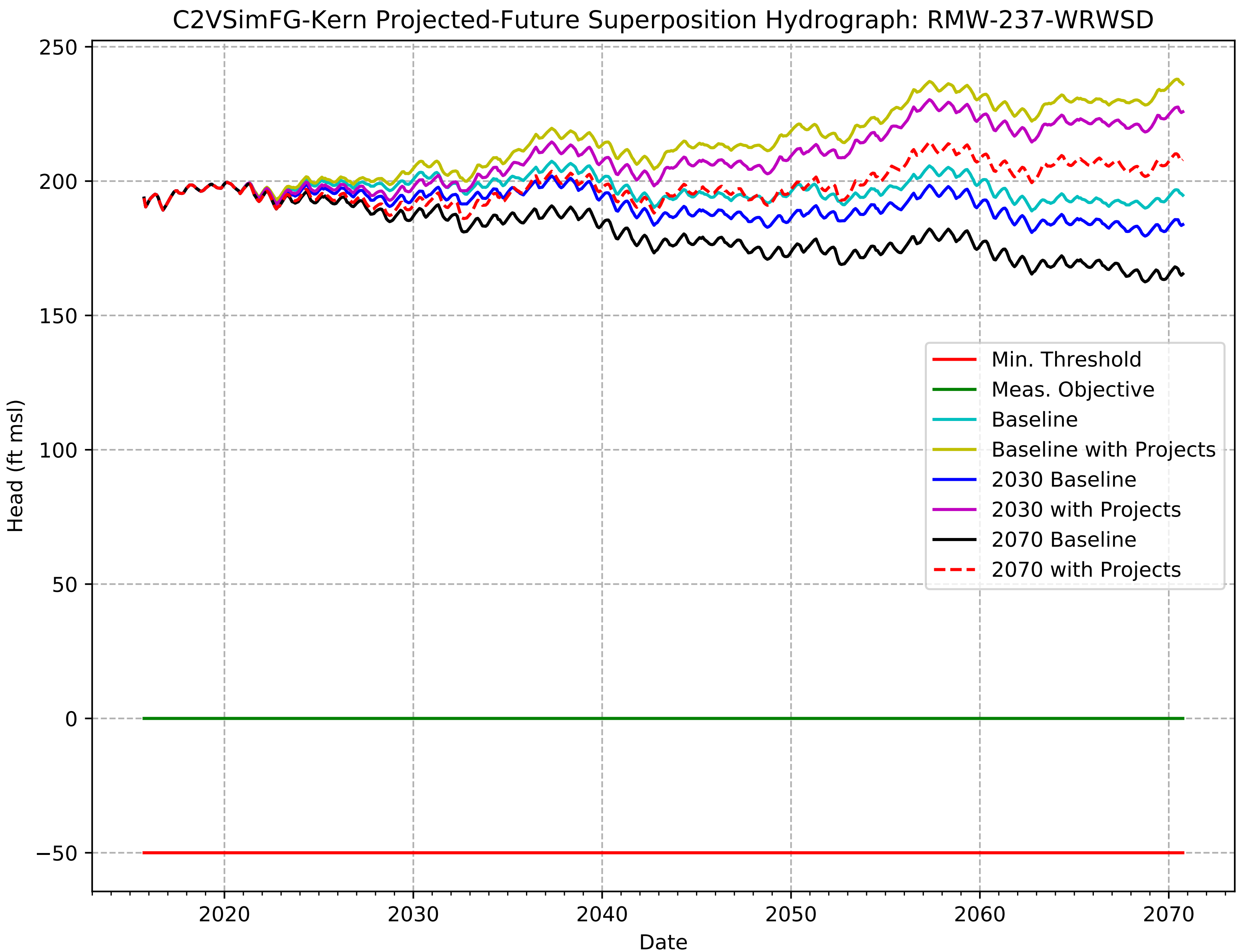
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-234-WRWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
0
20
40
60
80
100
120
2020
2030
2040
2050
2060
2070
Date

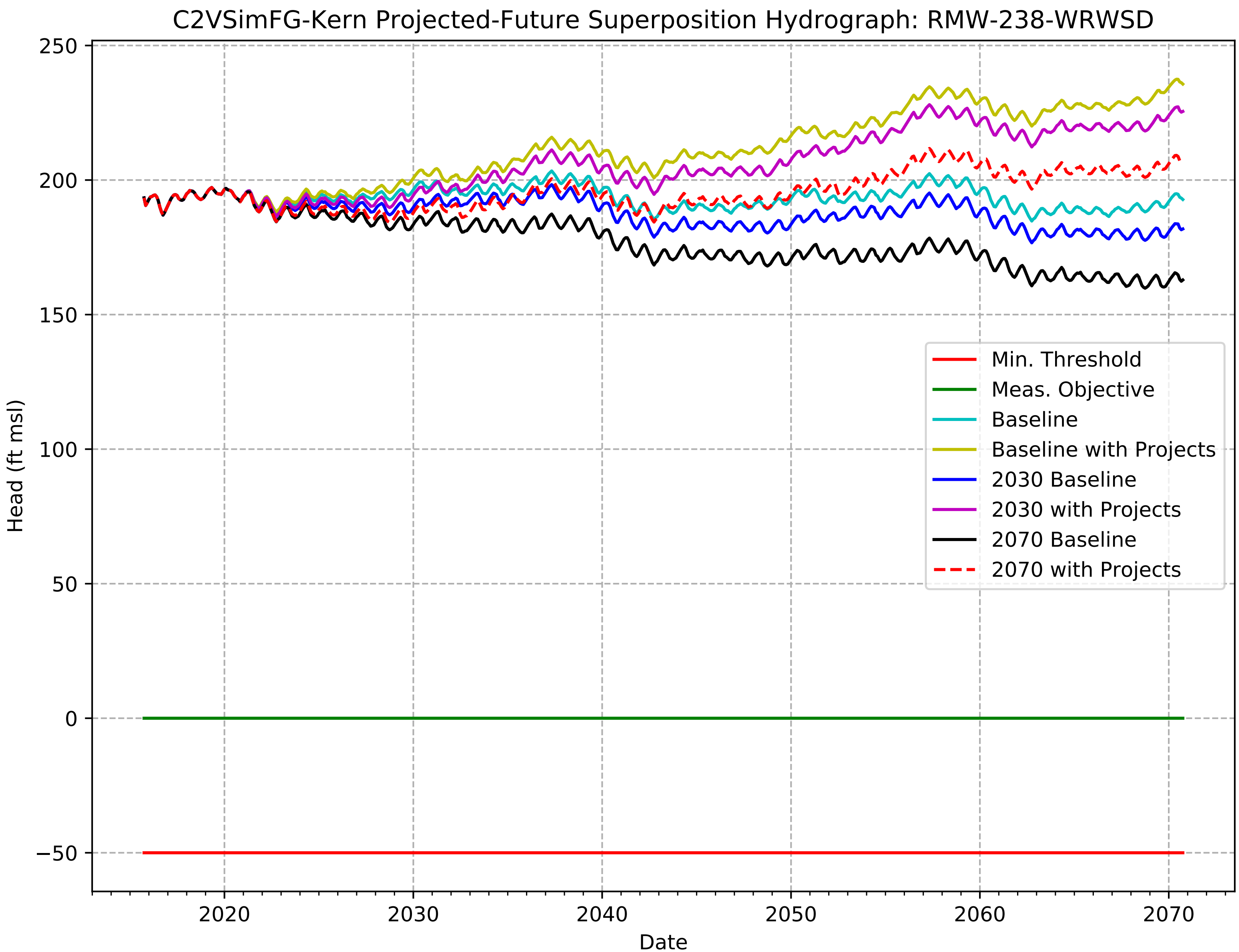


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-235-WRWSD
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects
Head (ft msl)
Date
0
20
40
60
80
100
120
140
2020
2030
2040
2050
2060
2070

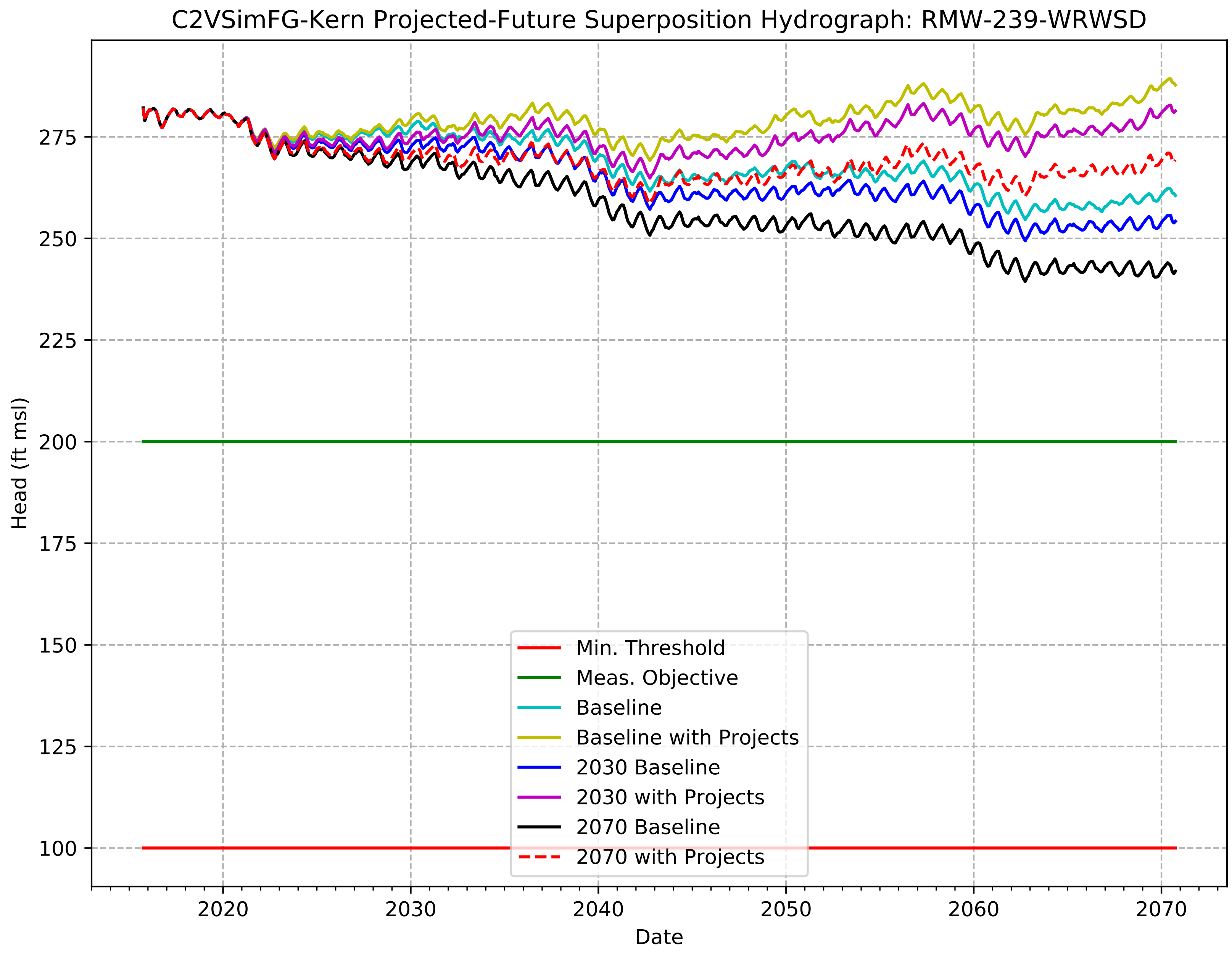


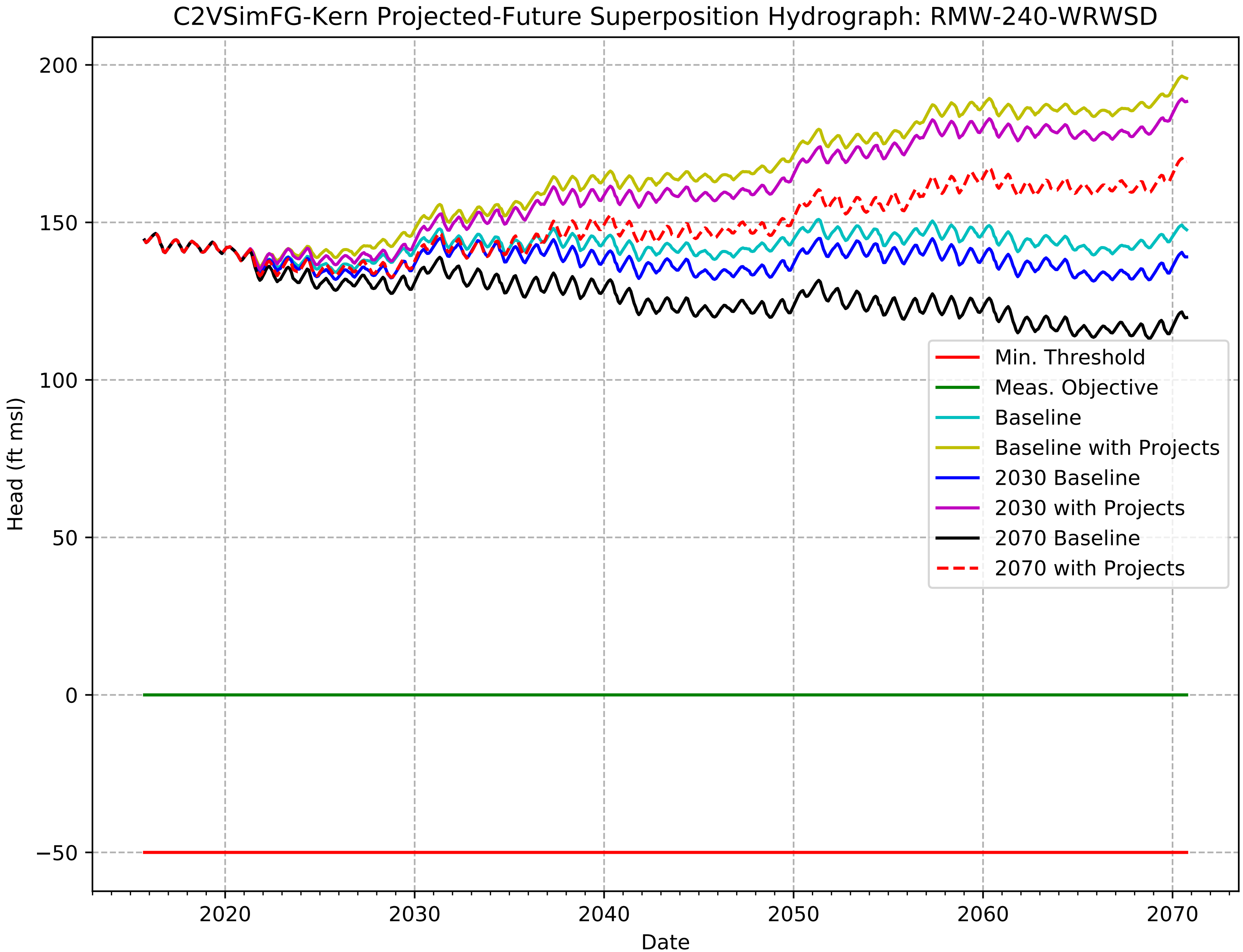
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-236-WRWSD
Head (ft msl)
Date
160
140
120
100
80
60
40
20
0
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

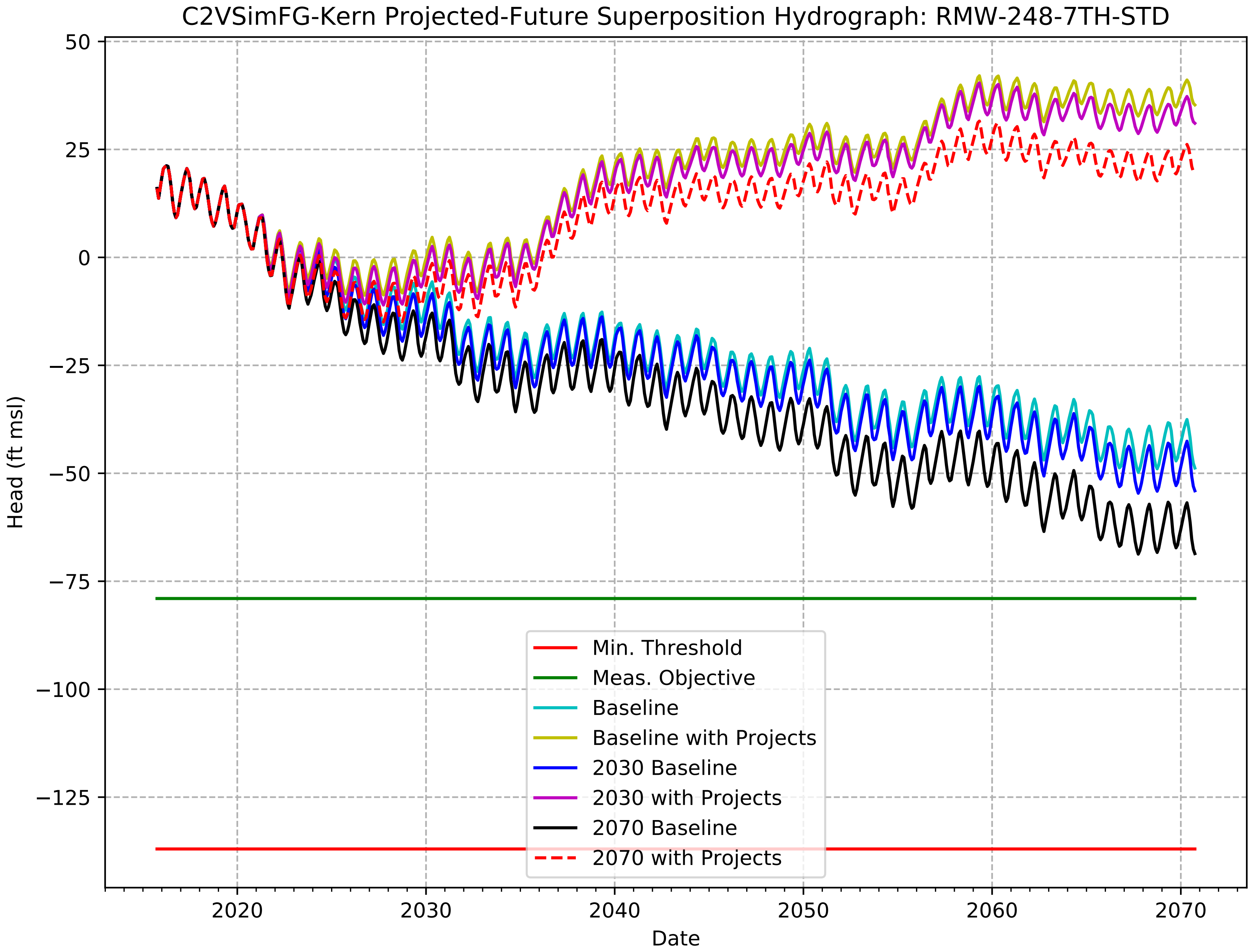

C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-237-WRWSD
Head (ft msl)
Date
250
200
150
100
50
0
−50
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



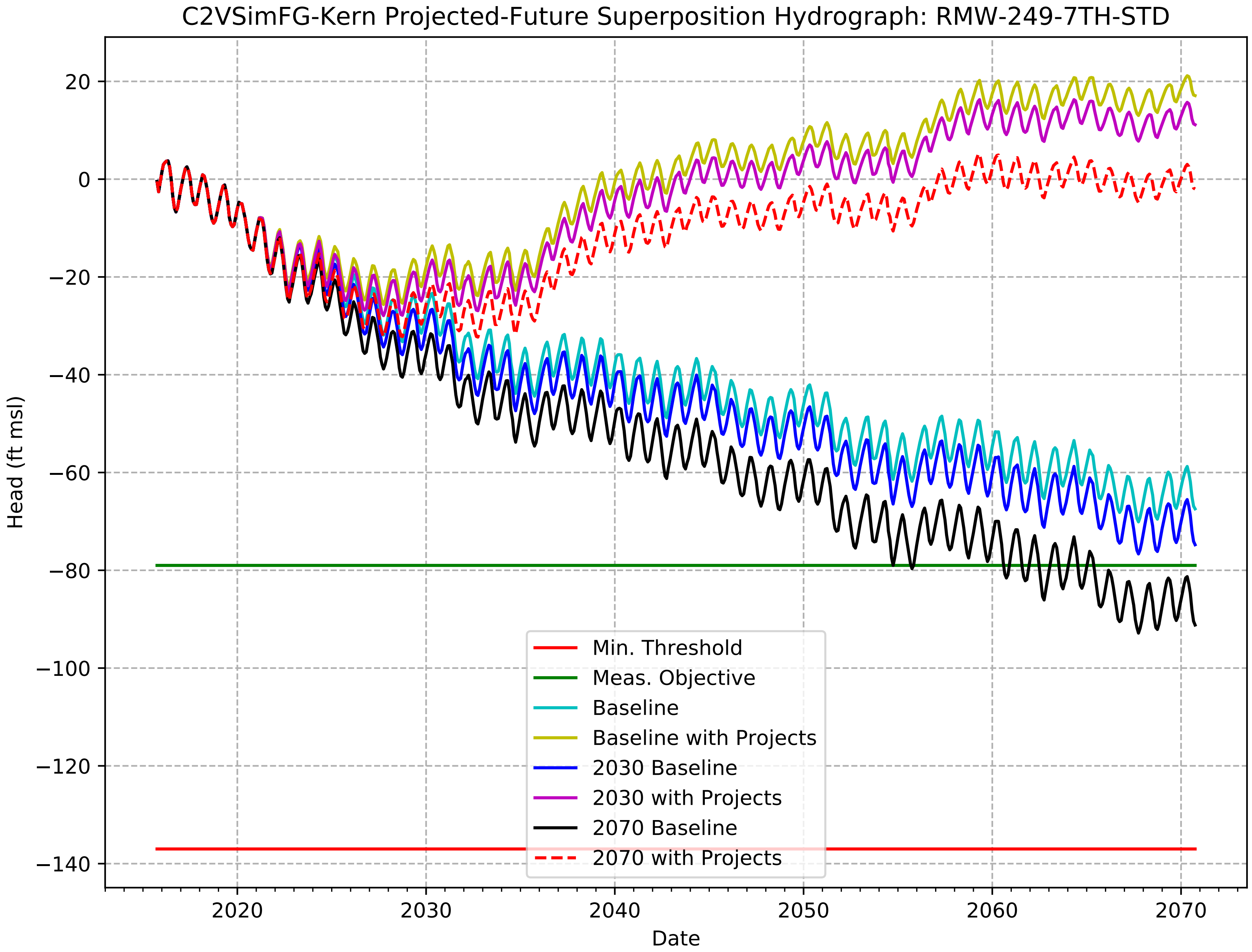
C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-238-WRWSD
Head (ft msl)
Date
250
200
150
100
50
0
−50
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-239-WRWSD
Head (ft msl)
275
250
225
200
175
150
125
100
Date
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects


C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-240-WRWSD
Head (ft msl)
Date
200
150
100
50
0
−50
2020
2030
2040
2050
2060
2070
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-248-7TH-STD
Head (ft msl)
50
25
0
−25
−50
−75
−100
−125
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects



C2VSimFG-Kern Projected-Future Superposition Hydrograph: RMW-249-7TH-STD
Head (ft msl)
20
0
−20
−40
−60
−80
−100
−120
−140
2020
2030
2040
2050
2060
2070
Date
Min. Threshold
Meas. Objective
Baseline
Baseline with Projects
2030 Baseline
2030 with Projects
2070 Baseline
2070 with Projects

APPENDIX C

RB INYOKERN DATA CENTER WSA – CONSISTENCY WITH DWR GUIDELINES

Inyokern Data Center WSA – Consistency with DWR Guidelines

Guidelines Section Number and Title (DWR, 2003)	Guidelines Direction	Relevant WSA Section and Response
Section 1 (page 2). Does SB 610 or SB 221 apply to the proposed project?	Is the project subject to SB 610? Is the project subject to CEQA (Water Code §10910(a)? If yes, continue.	WSA Section 1.1. Yes, the project is subject to SB610 and CEQA.
	Is it a "Project" as defined by Water Code §10912(a) or (b)? If yes, to comply with SB 610, go to Section 2.0, page 4.	WSA Section 1.1. Yes, the Project is considered to meet the definition of "project" per Water Code §10912(a) or (b).
	Is the project subject to SB 221? Does the tentative map include a "subdivision" as defined by Government Code §66473.7(a)(1)? If no, stop.	No, the Project does not include a "subdivision", SB 221 does not apply to the Project, and no further action relevant to SB 221 is required.
Section 2.0 (page 4). Who will prepare the SB 610 analysis?	Is there a public water system ("water supplier") for the project (Water Code §10910(b)? If no, go to Section 3.0, page 6.	WSA Section 2.1. Yes, the project site will connect to the Inyokern CSD public water system.
Section 3.0 (page 6). Has an assessment already been prepared that includes this project?	Has this project already been the subject of an assessment (Water Code §10910(h)? If no, go to Section 4.0, page 8.	No, the Project has not been the subject of an assessment.
Section 4.0 (page 8). Is there a current Urban Water Management Plan?	Is there an adopted urban water management Plan (Water Code §10910(c)? If yes, continue. If yes, the information from the UWMP related to the proposed water demand for the project may also be used for carrying out Section 5.0, Steps 1 and 2, Section 7; proceed to Section 5, page 10 of the Guidelines.	WSA Section 2.4 No, the Inyokern CSD is not required to adopted an UWMP.
	Is the project water demand for the project accounted for in the most recent UWMP (Water Code §10910(c)(2)? If no, go to Section 5.0, page 10.	Not applicable.
Section 5.0 (page 10). What information should be included in an assessment?	Step One (page 13). Documenting wholesale water supplies.	The Project is not a retail water supplier and would not include the use of wholesale water supplies.
	Step Two (page 17). Documenting Supply if Groundwater is a Source.	The South Lahontan Basin – Indian Wells Valley Subbasin is the proposed water supply. WSA Sections 1.3, 2.3, 2.4, and 2.5.

Guidelines Section Number and Title (DWR, 2003)	Guidelines Direction	Relevant WSA Section and Response
	Specify if a groundwater management plan or any other specific authorization for groundwater management for the basin has been adopted and how it affects the water supplier's use of the basin.	WSA Section 2.3 Yes, the Indian Wells Valley Groundwater Authority Groundwater Sustainability Plan was published in 2020.
	Description and analysis of the amount and location of groundwater pumped by the water supplier for the past five years. Include information on proposed pumping locations and quantities. The description and analysis are to be based on information that is reasonably available, including, but not limited to, historic use records from DWR.	Site-specific historic records are not available. WSA Section 1.3 provides a description of the Project's water requirements.
	Analysis of the location, amount, and sufficiency of groundwater that is projected to be pumped by the water supplier.	WSA Section 3.2. The quantity of water available in the Indian Wells Valley Subbasin is sufficient for the Project.
	Step 3 (page 21). Documenting project demand (Project Demand Analysis).	WSA Section 1.3. Construction of the Project will require 16.9 acre-feet per year.
	Step 4 (page 26). Documenting dry year(s) supply.	WSA Section 3.2. Addresses water supply availability, including during dry years.
	Step 5 (page 31). Documenting dry year(s) demand.	WSA Section 3.2 addresses annual demands, including dry years and multiple dry years conditions, including during dry year scenarios.
Section 6.0 (page 33). Is the projected water supply sufficient or insufficient for the proposed project		WSA Section 4.0 summarizes how the identified water supply/supplies are considered sufficient for the Project.
Section 7.0 (page 35). If the projected supply is determined to be insufficient. Section 8.0 (page 38). Final SB 610 assessment actions by lead agencies.	Does the assessment conclude that supply is "sufficient"? If no, continue. The lead agency shall review the WSA and must decide whether additional water supply information is needed for its consideration of the proposed project. The lead agency "shall determine, based	WSA Section 4.0 concludes that sufficient water supplies are available for the Project. The WSA for the Project must be approved prior to or in concurrence with the EIR.

Guidelines Section Number and Title (DWR, 2003)	Guidelines Direction	Relevant WSA Section and Response
	on the entire record, whether projected water supplies will be sufficient to satisfy the demands of the project, in addition to existing and planned future uses."	
	The description of the groundwater basin may be excerpted from the groundwater management plan, from DWR Bulleting 118, California's Ground Water, or from some other document that has been published and that discusses the basin boundaries, type of rock that constitutes the aquifer, variability of the aquifer material, and total groundwater in storage (average specific yield times the volume of the aquifer).	WSA Section 2.2 provides a description of the groundwater basin characteristics using all available resources, including DWR Bulletin 118.
	In an adjudicated basin the amount of water the urban supplier has the legal right to pump should be enumerated in the court decision.	The Project is not in an adjudicated basin.
	Bulletin 160, California Water Plan Update. Estimates at the basin or subbasin level will be projected for some basins in Bulletin 118. If the basin has not been evaluated by DWR, data that indicate groundwater level trends over a period of time should be collected and evaluated.	
	If the evaluation indicates an overdraft due to existing groundwater extraction or projected increases in groundwater extraction, describe actions and/or programs designed to eliminate the long-term overdraft condition.	WSA Section 3.2. The referenced and Appendicized GSP describe in detail the subject actions and programs.