Calfornia Water Storage

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```
knitr::opts_chunk$set(echo = TRUE)
```

```
# Read in required packages

library(tidyverse)
```

```
## ── Attaching packages ─────────────────────── tidyverse 1.3.0 ──
```

```
## ✓ ggplot2 3.3.0     ✓ purrr   0.3.3
## ✓ tibble  2.1.3     ✓ dplyr   0.8.5
## ✓ tidyr   1.0.2     ✓ stringr 1.4.0
## ✓ readr   1.3.1     ✓ forcats 0.5.0
```

```
## ── Conflicts ────────────────────────── tidyverse_conflicts() ──
## x dplyr::filter() masks stats::filter()
## x dplyr::lag()    masks stats::lag()
```

```
library(janitor)
```

```
##
## Attaching package: 'janitor'
```

```
## The following objects are masked from 'package:stats':
##
##     chisq.test, fisher.test
```

```
library(Hmisc)
```

```
## Loading required package: lattice
```

```
## Loading required package: survival
```

```
## Loading required package: Formula
```

```
##
## Attaching package: 'Hmisc'
```

```
## The following objects are masked from 'package:dplyr':
##
##     src, summarize
```

```
## The following objects are masked from 'package:base':
##
##     format.pval, units
```

```
library(ggthemes)
library(viridis)
```

```
## Loading required package: viridisLite
```

```
library(hrbrthemes)
```

```
## NOTE: Either Arial Narrow or Roboto Condensed fonts are required to use these themes.
```

```
##       Please use hrbrthemes::import_roboto_condensed() to install Roboto Condensed and
```

```
##       if Arial Narrow is not on your system, please see https://bit.ly/arialnarrow
```

```
library(networkD3)
library(knitr)
```

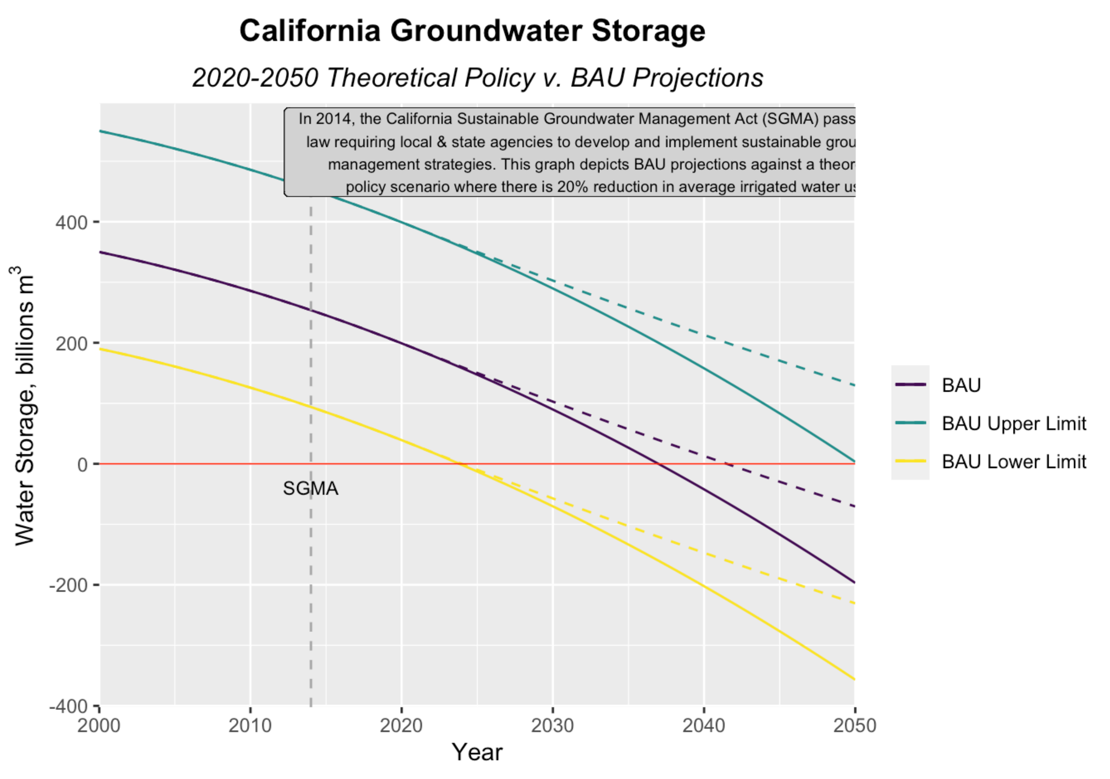
Background

In 2014, Governor Jerry Brown signed in to law the Sustainable Groundwater Management Act (SGMA) which requires local governments and state agencies to develop and implement sustainable groundwater water management strategies. SGMA requires an immediate halt of overdraft from high and medium priority basins in an effort to bring groundwater basins into balanced levels of inputs and storage replenishment.[1]

Analysis

Utilizing water storage estimates from the stochastic model estimates depicted in the Sankey diagrams, I reproduced “Business As Usual” (BAU) projections against a theoretical policy scenario where there is 20% reduction in average irrigated water use using a linear regression as shown below. The graph pulls the projected data points between 2000 and 2050 in order to anticipate water storage values. Included in the graph, is the upper and lower limit estimates on water storage boundaries within a 90% confidence interval for both BAU and the theoretical policy.

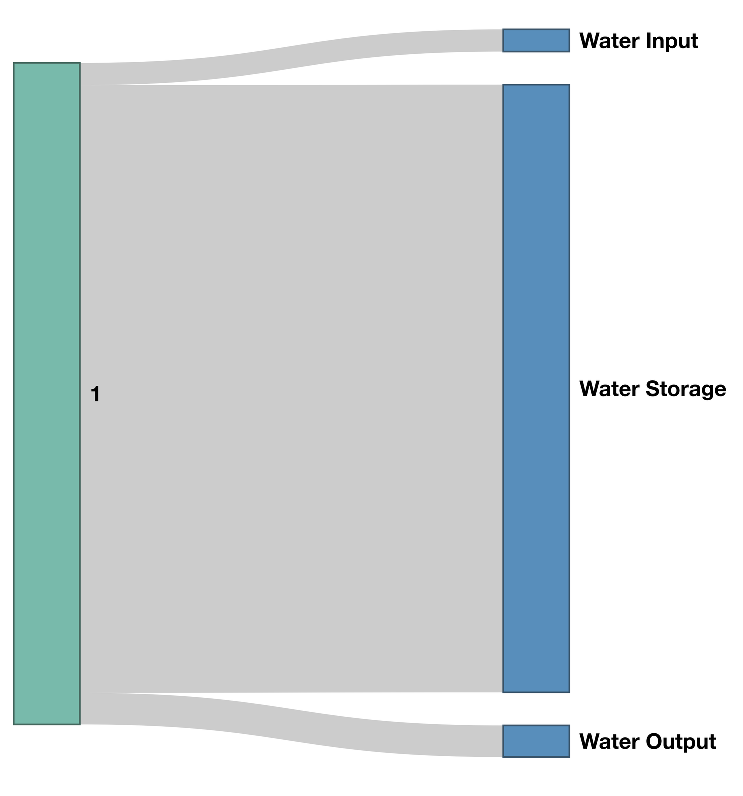
```
# Figure 2.** Graph visualizes the deviation in groundwater depletion from "Business As Usual" versus a theoretic
al policy implementation (dotted-line)
# We know that the data is normally distributed. Continuing on....
# Plot the main line ((BAU) line (water_storage)
# Use geom_ribbon to depict the upper and lower limits that are included in the data. Note: geom_ribbon is used s
ince upper and lower values of the envelop are available in the input data.
# Plot individual lines for the upper and lower limit to clearly annotate the limits.
# annotate the zero water storage point on the graph

water_plot <- ggplot(water_clean, aes(x = year, y = policy_storage)) +
  geom_line(aes(col = "#440154FF"), linetype = 2) +
  geom_line(aes(x= year, y= policy_upper, col = "#FDE725FF"), linetype = 2) +
  geom_line(aes(x = year, y = policy_lower, col = "violet"), linetype = 2) +
  geom_line(aes(x= year, y = water_storage, col = "#440154FF")) +
  geom_line(aes(x= year, y = water_upper_limit, col = "#FDE725FF")) +
  geom_line(aes(x= year, y = water_lower_limit, col = "violet")) +
  geom_hline(yintercept=0, color="red", size=0.3, linetype = 1 ) +
  geom_vline(xintercept = 2014, color = "darkgrey", size = 0.5, linetype = 2) +
  scale_x_continuous(expand = c(0,0), limits = c(2000,2050)) +
  labs(x = "Year",
       y = "Water Storage, billions" ~m^3,
       title = "California Groundwater Storage \n",
       subtitle = "2020-2050 Theoretical Policy v. BAU Projections") +
  annotate("text", x = 2014, y = -40,
             label = "SGMA",
             color = "black", fontface = 1,
          face = 'bold', size = 3) +
  geom_label(
    label=
    "In 2014, the California Sustainable Groundwater Management Act (SGMA) passed into
    law requiring local & state agencies to develop and implement sustainable groundwater
    management strategies. This graph depicts BAU projections against a theoretical
    policy scenario where there is 20% reduction in average irrigated water use.",
    x=2033.2,
    y=515,
    label.padding = unit(0.15, "lines"), # Rectangle size around label
    label.size = 0.15,
    size = 2.5,
    color = "black",
    fill="lightgrey"
  ) +
   theme(
      plot.title = element_text(size=14, hjust = 0.5, vjust = -3, face = 'bold'),
      plot.subtitle = element_text(size=12, hjust = 0.5, face = 'italic'))

water_plot + scale_colour_viridis(discrete = TRUE, option = "viridis", name = "",labels=c("BAU","BAU Upper Limit"
,"BAU Lower Limit"))
```




```
# Create a model showing input, storage, output in 2020 vs 2050

my_color <- 'd3.scaleOrdinal() .domain(["Water Input", "Water Output"]) .range(["#69b3a2", "steelblue"])'
```

```
#Set up a simple mass balance model of groundwater driven by inputs and outputs.
# Specify the initial inputs and outputs for 2000. This requires determining the inputs and outputs.

water_only <- water_clean %>%
  dplyr::select(water_inputs, water_storage, water_outputs, year) %>%
  filter(year == 2000) %>%
  dplyr::select(-year)

names(water_only) <- c("Water Input", "Water Storage", "Water Output")



data_long <- water_only %>%
  rownames_to_column %>%
  gather(key = 'key', value = 'value', -rowname) %>%
  filter(value > 0)

colnames(data_long) <- c("source", "target", "value")

data_long$target <- paste(data_long$target, " ", sep="")

nodes <- data.frame(name=c(as.character(data_long$source), as.character(data_long$target)) %>% unique())

data_long$IDsource=match(data_long$source, nodes$name)-1
data_long$IDtarget=match(data_long$target, nodes$name)-1

sankeyNetwork(Links = data_long, Nodes = nodes,
                     Source = "IDsource", Target = "IDtarget",
                     Value = "value", NodeID = "name",
                     sinksRight=FALSE, colourScale=my_color, nodeWidth=40, fontSize=13, nodePadding=20)
```

```
## Links is a tbl_df. Converting to a plain data frame.
```



Recommendation

As represented in the supporting materials, the implementation of the SGMA policy will extend the longevity of statewide groundwater from a BAU depletion expected in 2036. However, the lower limits forecasted do not begin to deviate with a policy implementation until well-after depletion which is estimated at 2024. Therefore, it is my recommendation to Senator Meyer that it is essential for local governments and state agencies to base their management strategies on the lower limit trend and implement SGMA policy as soon as possible. Due to time constraints, there are several available options for immediate implementation to avoid groundwater depletion. One option resides in redistributing the 32% of treated urban water that is currently being discharged to the sea into agriculture and landscape purposes.[2] Alternatively, investing further grant funds toward desalinization projects across the state to augment municipal and industrial water supplies may also be utilized. Although an option for short-term alleviation, desalinization is not economically nor environmentally conducive for long-term implementation.[3]

References

[1]. California Department of Water. Sustainable Groundwater Management Act, 2014. https://water.ca.gov/Programs/Groundwater-Management/SGMA-Groundwater-Management

[2]. Curmi, E., Fenner, R., Richards, K. et al. Water Resource Manage (2013) 27: 3035. https://doi.org/10.1007/s11269-013-0331-2

[3]. Congressional Research Service, 2015, Desalination and Membrane Technologies: Federal Research and Adoption. R40477, www.crs.gov

```
#### **NOTES**

#1. Only a small amount of urban water (6 % out of the 40 % of urban water that is treated) is recycled and reuse
d (0.3×109 m3) (Slice I and Slice X) (Department of Water Resources 2009). In fact most of this water is discharg
ed to the sea; this amount could have potential for reuse in agriculture, landscaping or urban purposes.

#2. Most extracted groundwater is used for agricultural purposes, whilst most surface water either flows in river
s, or is pumped to reservoirs and wetlands to maintain ecosystem services or is delivered to farmers for irrigati
on. Desalination is a small part of the water supply

#3. Environmental water in California is the largest user of water

#4. shows the services that water provides (Slice VIII). The largest use of urban water is for landscaping and ga
rdening,

#5. The avoided water, which is a form of virtual water, shows the amount of additional irrigation water that wou
ld be required in California to produce the crops, milk and meat imported into the state.

#SGMA requires governments and water agencies of high and medium priority basins to halt overdraft and bring grou
ndwater basins into balanced levels of pumping and recharge. Under SGMA, these basins should reach sustainability
within 20 years of implementing their sustainability plans. For critically over-drafted basins, that will be 2040
. For the remaining high and medium priority basins, 2042 is the deadline.

#In his signing statement, the governor emphasized that “groundwater management in California is best accomplishe
d locally.” Through the Sustainable Groundwater Management Program, DWR provides ongoing support to local agencie
s through guidance and financial and technical assistance.

# there is a 90% chance that the actual amount of groundwater in CA is somewhere between the approximate lower li
mit of 190x109  m3 and an approximate upper limit of 550x109  m3 .

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it of 190x109  m3 and an approximate upper limit of 550x109  m3 .

#Reducing losses to particular sinks could also be a way to improve water management; for example by increasing t
he amount of water that is recycled every year, therefore reducing the amount that is discharged into the ocean.

# In 2000, the California groundwater storage was 350 billion m^3.  The water input into the storage for that yea
r was 13 billion m^3 and water output was 18 billion m^3.

# If the state of California continues business as usual, by 2050 the water storage will have been depleted and w
ater input will be at 10.3 billion m^3 and water output will reach 27 billion m^3.
```