RIVER HYDROLOGY MONITORING

Noor Wahle & Brandon Suen
UC Berkeley
Californian Cooperative Ecosystem Studies Unit
SIEN I&M
Data Science Discovery Internship
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QUESTIONS

- How are river discharge rates and the timing and magnitude of peak flows changing?
- How is water temperature changing?
- How are water dynamics changing in response to changing climate and fire regimes?

Lyell Fork Tuolumne blw Maclure

MANAGEMENT APPLICATIONS

- Inform park management planning where surface water dynamics changes effect park resources such as wetlands, forests, and terrestrial and aquatic wildlife.
- Contribute to the understanding of the relationships between fire and hydrology and guide fire management decisions.
- Inform park managers who oversee hydropower and other related licensing.
- Flood dynamics
- Water use – in parks and
- Downstream water use (municipal, agricultural, recreational) – Hetch Hetchy, CA central valley agricultural

M Fork of the San Joaquin @ DEPO

Tuolumne R at Tioga Rd Bridge

OBJECTIVES

- Detect long term trends in **timing and volume of streamflow** at existing stream gages in selected major watersheds of SIEN. Measures:
  - Stage
  - Discharge – Instantaneous (measured), mean annual, instantaneous peak, and highest and lowest daily mean
  - Number of days to center of mass and onset of snowmelt
  - Winter and summer 3, 7, 10 and 14-day low and high flow
  - Number of days to winter and summer 7-day low flow
  - Number of days to 3 and 14-day high flow
  - Percent AMJJ/Annual flow.
- Detect long-term trends in **stream water temperature** at a subset (10) of the streamgages. Measures:
  - Continuous 15-minute water temperature
  - Daily mean water temperature
  - Daily minimum water temperature
  - Daily maximum water temperature

ANDREWS STATUS & TRENDS REPORT

SIEN contracted Ned Andrews (USGS emeritus hydrologist) to perform a status and trends analysis of hydrology in the SIEN region (report published 2012)

Approach

•27 long-term streamgage records

• Records were 24 to 96 yrs

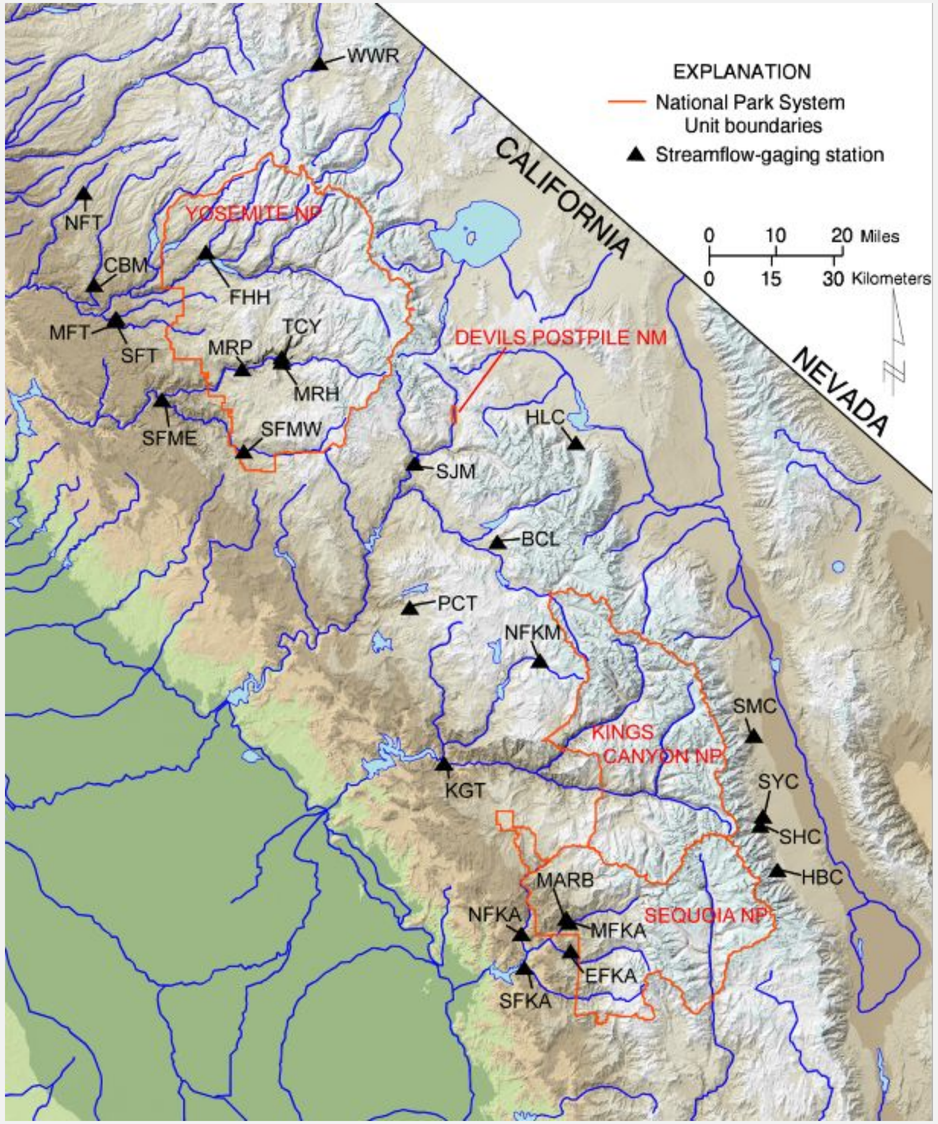
• >1200 trend analyses

Conclusions

•No trends in annual discharge (volume) even with 96 yr record, but trends in timing

•Long-term records especially important - protocol should build on existing records

•Informed metrics and analyses used in SIEN protocol



Transitioning from MATLAB to R

- Started with:
  - Set of separate MATLAB programs
  - Required input files to be manually manipulated
  - Repetitive, unintuitive, and hard to follow code in places
- Conversion to R verified with automated QA/QC
- Significantly refactored programs to be much more clear and concise
- Found and fixed bug from initial MATLAB code
- Overhauled original workflow with full data pipeline

```
% snmonset
%Calculates the onset of snowmelt in calendar days from Jan. 1 as the cumulative minimum departure from
%the mean flow over the period calendar days 9 to 248.
load('MRHq.txt')
dmq=MRHq(:,4);
mth=MRHq(:,1);
day=MRHq(:,2);
yr=MRHq(:,3);
%recdyr = input('Years of Record');
recdyr = 94;
for n = 1:recdyr;
    sumq(n) = 0.0;
    smq(n) = 0.0;
    swpulse(n) = 0.0;
    cmd(n) = 0.0;
    dypulse(n) = 0.0;
end
mindys = 1;
maxdys = 365;
tma = mindys + 100;
tmb = mindys + 339;
%Calculate discharge for period from day 100 to day 339 in water year
for n = 1:recdyr;
    for m = tma:tmb;
        sumq(n) = sumq(n) + dmq(m);
        if (mth(m)== 2) && (day(m) == 29);
            maxdys = maxdys + 1;
        end
    end
    wyr(n) = yr(maxdys);
    mdq(n) = sumq(n)/240;
    for m = tma:tmb;
        cmd(n) = cmd(n) + (dmq(m) - mdq(n));
        if cmd(n) < swpulse(n)
            swpulse(n) = cmd(n);
            dypulse(n) =(m - tma) + 8;
        end
    end
    mindys = maxdys + 1;
    maxdys = maxdys + 365;
    tma = mindys + 100;
    tmb = mindys + 339;
end
    n = 1;
    fid1 = fopen('MRHqsnoset','w');
    while n <= recdyr
    fprintf(fid1,'   %5.0f    %6.2f    %6.2f       %5.0f\n'...
        ,wyr(n),mdq(n),swpulse(n),dypulse(n));
    n = n + 1;
end
fclose(fid1)
```

```r
# snmonset
#Calculates the onset of snowmelt in calendar days from Jan. 1 as the cumulative minimum departure from
#the mean flow over the period calendar days 9 to 248.
snwpulse <- function(data, outputDir = './Output/') {
  output <- data %>%
      groupByWaterYear() %>%
      includeDays(101, 340) %>% # Only observe calendar days 9 to 248
      mutate(cmd = cumsum(dmq) - mean(dmq) * row_number()) %>% # Compute necessary intermediate values
      summarize(mdq = mean(dmq), snwpulse = min(cmd), dypulse = which.min(cmd) + 7) # Produce output columns

  writeOutput(output, '%5.0f    %6.2f    %6.2f       %5.0f\n', 'MRHqsnoset', outputDir)

  output
}
```

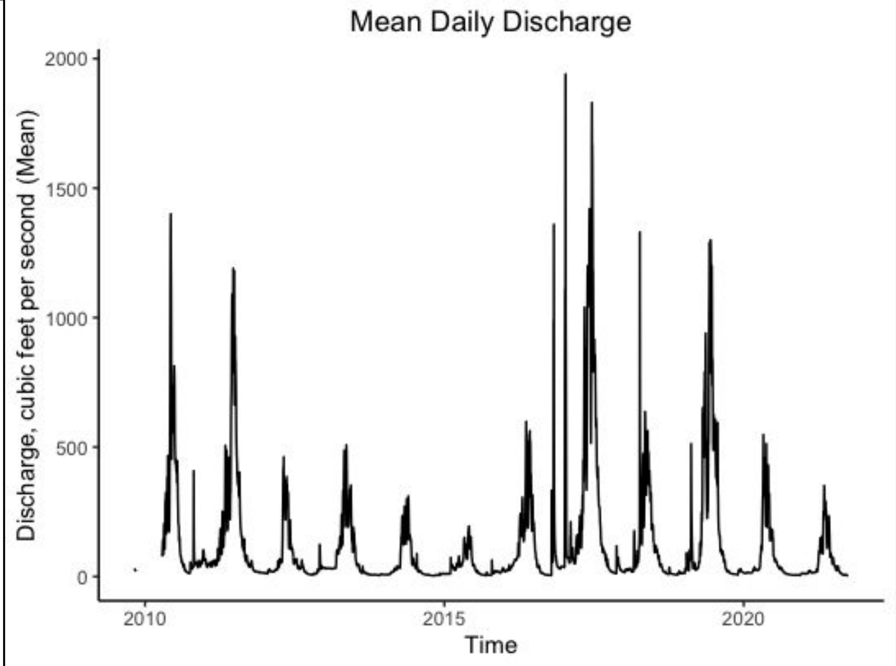
```
% lwflow
%Calculates the low flow statistics from the time series of daily values,
load('MRHq.txt')
dmq=MRHq(:,4);
mth=MRHq(:,1);
day=MRHq(:,2);
yr=MRHq(:,3);
%recdyr = input('Years of Record');
recdyr = 94;
    w3df = [];
    w7df = [];
    w14df = [];
    s3df = [];
    s7df = [];
    s14df = [];
mindys = 1;
maxdys = 365;
tma = mindys + 61;
tmb = mindys + 151;
tmc = tmb;
tmy = maxdys - 92;
tmz = maxdys;
for n = 1:recdyr;
        for m = tma:tmc;
            if(mth(m)== 2)&& (day(m)== 29);
                maxdys = maxdys + 1;
                tmb = tmb + 1;
            end
        end
        wyr(n) = yr(maxdys);
        dq = 0.0;
        for m = mindys:maxdys;
            dq = dq + dmq(m);
        end
        amQ(n) = dq/((maxdys-mindys) + 1);
        w3df(n) = 1000;
        w7df(n) = 1000;
        w14df(n) = 1000;
        s3df(n) = 1000;
        s7df(n) = 1000;
        s14df(n) = 1000;
        for m = tma:tmb;
            wq3d = (dmq(m)+dmq(m-1)+dmq(m-2))/3;
            wq7d = (dmq(m)+dmq(m-1)+dmq(m-2)+dmq(m-3)+dmq(m-4)+dmq(m-5)...
                +dmq(m-6))/7;
            wq14d = (dmq(m)+dmq(m-1)+dmq(m-2)+dmq(m-3)+dmq(m-4)+dmq(m-5)...
                +dmq(m-6)+dmq(m-7)+dmq(m-8)+dmq(m-9)+dmq(m-10)+dmq(m-11)...
                +dmq(m-12)+dmq(m-13))/14;
            if wq3d < w3df(n);
                w3df(n) = wq3d;
                mw3df(n) = m;
            end
            if wq7d < w7df(n);
                w7df(n) = wq7d;
                mw7df(n) = m - mindys;
            end
            if wq14d < w14df(n);
                w14df(n) = wq14d;
                mw14df(n) = m;
            end
        end
        for m = tmy:tmz;
            sq3d = (dmq(m)+ dmq(m-1)+ dmq(m-2))/3;
            sq7d = (dmq(m)+ dmq(m-1) + dmq(m-2) + dmq(m-3) + dmq(m-4)...
                +dmq(m-5)+ dmq(m-6))/7;
            sq14d = (dmq(m)+dmq(m-1)+dmq(m-2)+dmq(m-3)+dmq(m-4)+dmq(m-5)...
                +dmq(m-6)+dmq(m-7)+dmq(m-8)+dmq(m-9)+dmq(m-10)+dmq(m-11)...
                +dmq(m-12)+dmq(m-13))/14;
            if sq3d < s3df(n);
                s3df(n) = sq3d;
                ms3df(n) = m;
            end
            if sq7d < s7df(n);
                s7df(n) = sq7d;
                ms7df(n) = m - mindys;
            end
            if sq14d < s14df(n);
                s14df(n) = sq14d;
                ms14df(n) = m;
            end
        end
        mindys = maxdys + 1;
        maxdys = maxdys + 365;
        tma = mindys + 61;
        tmb = mindys + 151;
        tmc = tmb;
        tmy = maxdys - 92;
        tmz = maxdys;
end
for n = 1:recdyr;
    w3df(n);
    mw3df(n);
    w7df(n);
    mw7df(n);
end
        w3dx = sort(w3df);
        w7dx = sort(w7df);
        w14dx = sort(w14df);
        s3dx = sort(s3df);
        s7dx = sort(s7df);
        s14dx = sort(s14df);
        for n = 1:recdyr;
            exdP(n) = n/(recdyr + 1);
        end
        xxp = [0.98, 0.95, 0.90, 0.80, 0.70, 0.6, 0.50, 0.3333, 0.20,...
            0.1429, 0.10, 0.0667, 0.05, 0.040, 0.0333, 0.02857, 0.025,...
            0.02222, 0.020];
        for p = 2:19;
            ri(p) = 1/xxp(p);
            for n = 2:recdyr;
                if exdP(n-1) < xxp(p) && exdP(n) >= xxp(p);
                    Px = ((xxp(p)-exdP(n))/(exdP(n-1)-exdP(n)));
                    w7D(p) = w7dx(n) + Px*(w7dx(n-1)-w7dx(n));
                    w3D(p) = w3dx(n) + Px*(w3dx(n-1)-w3dx(n));
                    w14D(p) = w14dx(n) + Px*(w14dx(n-1)-w14dx(n));
                    s3D(p) = s3dx(n) + Px*(s3dx(n-1)-s3dx(n));
                    s7D(p) = s7dx(n) + Px*(s7dx(n-1)-s7dx(n));
                    s14D(p) = s14dx(n) + Px*(s14dx(n-1)-s14dx(n));
                end
            end
        end
mean(amQ)
fid1 = fopen('mrhlwf1D','w');
fid2 = fopen('mrhlwf2D','w');
fid3 = fopen('mrhlwf3DX','w');
fid4 = fopen('mrhMAQ','w');
for n = 1:recdyr;
    fprintf(fid1,'%7.f %7.3f %7.3f %7.3f %7.3f %7.3f %7.3f %7.f %7.f\n'...
            ,wyr(n), w3df(n),w7df(n),w14df(n),s3df(n),s7df(n),s14df(n),...
            mw7df(n),ms7df(n));
        fprintf(fid4,'   %7.f     %10.2f\n',wyr(n),amQ(n));
end
for n = 1:recdyr;
    fprintf(fid2,' %7.3f  %7.3f  %7.3f  %7.3f  %7.3f  %7.3f   %7.3f\n'...
        ,exdP(n),w3dx(n),w7dx(n),w14dx(n),s3dx(n),s7dx(n),s14dx(n));
end
for p = 2:19;
    fprintf(fid3,' %7.3f  %7.3f   %7.3f  %7.3f  %7.3f  %7.3f  %7.3f\n'...
        ,xxp(p),w3D(p),w7D(p),w14D(p),s3D(p),s7D(p),s14D(p));
    p = p + 1;
end
fclose(fid1);
fclose(fid2);
fclose(fid3);
fclose(fid4);
```

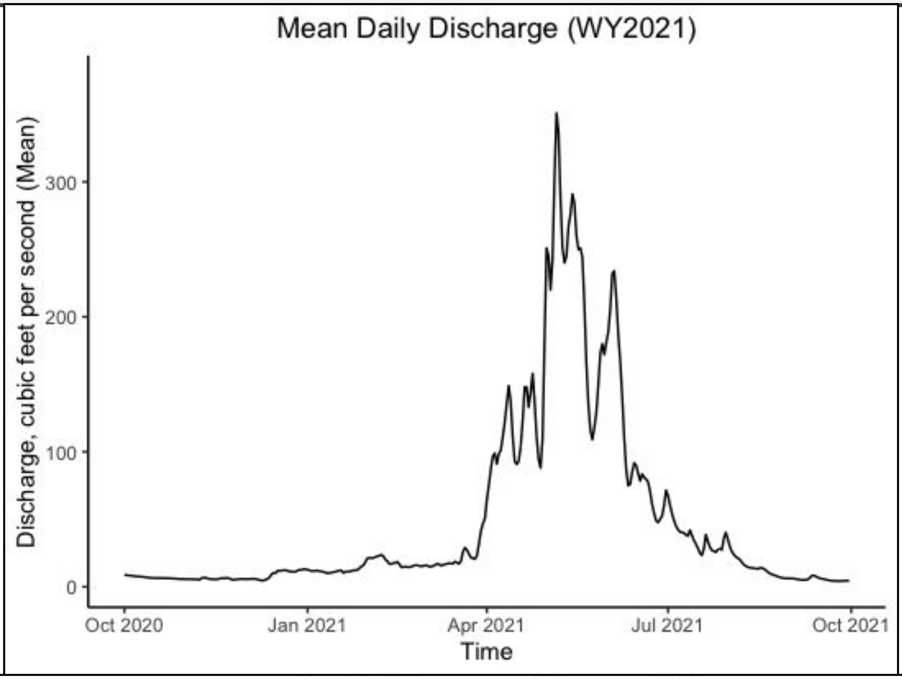
```r
# lwflow
#Calculates the low flow statistics from the time series of daily values,
lwflow <- function(data, outputDir = './Output/') {
    yearly <- data %>% groupByWaterYear()

    outputMAQ <- yearly %>% summarize(amQ = mean(dmq))

    writeOutput(outputMAQ, '    %7.f      %10.2f\n', 'mrhMAQ', outputDir)

    lagged <- yearly %>% lagX()
    sumMin <- function(df, lower) df %>% sumLag(min, m7d = which.min(lag7) + lower - 2)

    winter <- lagged %>%
        filter(mth %in% c(12, 1, 2) | (mth == 3 & day == 1)) %>%
        sumMin(62)

    summer <- lagged %>%
        includeDays(273, 365) %>%
        sumMin(273)

    output1D <- winter %>%
        inner_join(summer, by = 'waterYear', suffix = c('w', 's')) %>%
        select(waterYear, m3w:m14w, m3s:m14s, m7dw, m7ds)

    writeOutput(output1D, '%7.f %7.3f %7.3f %7.3f %7.3f %7.3f %7.3f %7.f %7.f\n', 'mrhlwf1D', outputDir)

    output2D <- output1D %>%
        mutate(exp = row_number() / (n() + 1), across(m3w:m14s, sort)) %>%
        select(exp, m3w:m14s)

    writeOutput(output2D, '%7.3f  %7.3f  %7.3f  %7.3f  %7.3f  %7.3f   %7.3f\n', 'mrhlwf2D', outputDir)

    output3DX <- output2D %>% genOutput3X()
    writeOutput(output3DX, '%7.3f  %7.3f   %7.3f  %7.3f  %7.3f  %7.3f  %7.3f\n', 'mrhlwf3DX', outputDir)

    list(outputMAQ, output1D, output2D, output3DX)
}
```

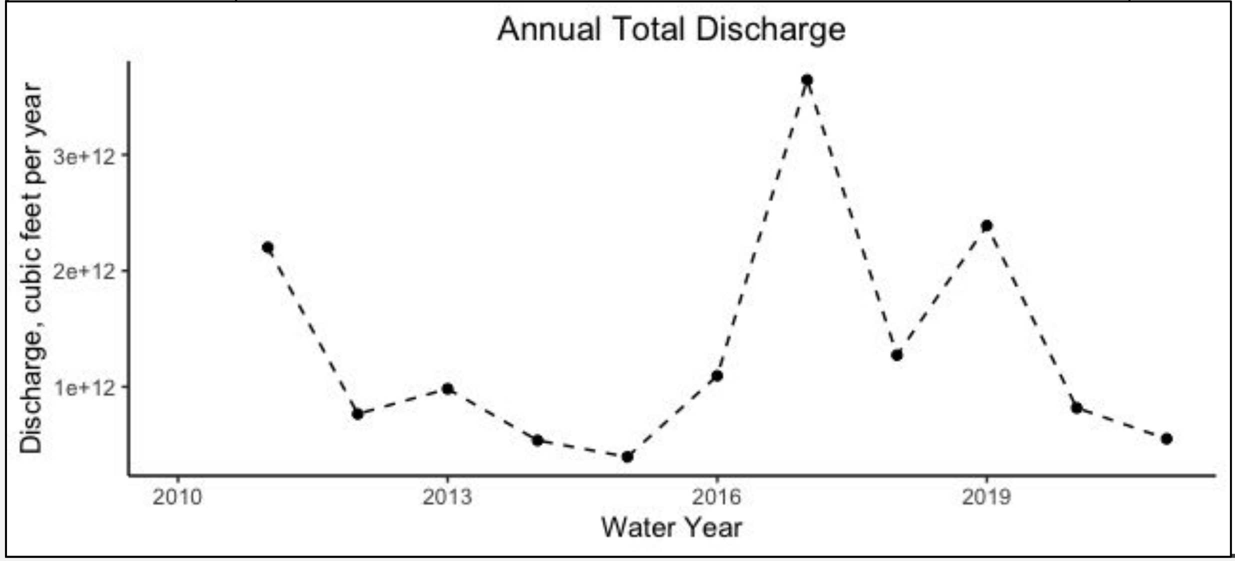
Data Pipeline

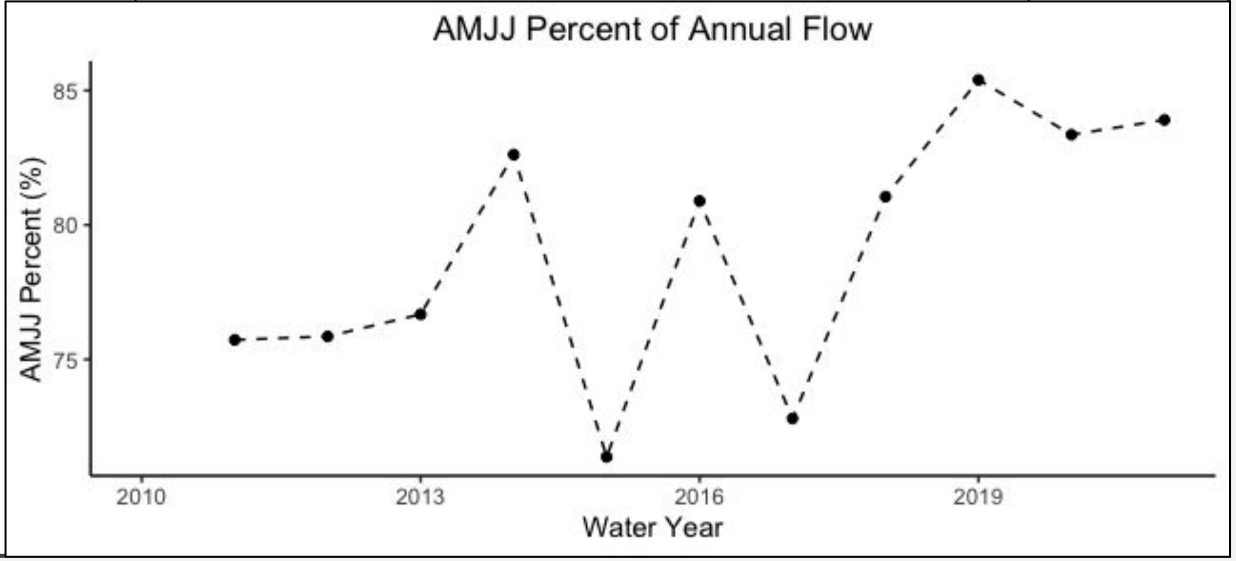
- Contained within a single R Markdown (Rmd) file
- Automatically processes input from USGS data files
- Runs all programs together on input and generates all appropriate output files
- Displays summary statistics for each output column
- Produces a variety of visualizations

San Joaquin

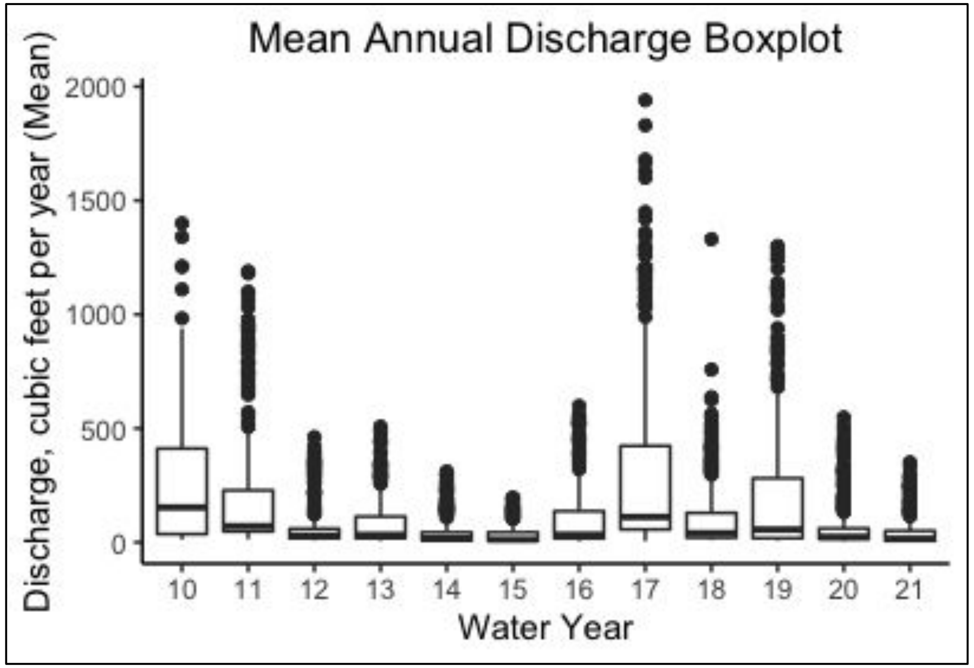

Mean Daily Discharge
Discharge, cubic feet per second (Mean)
0
500
1000
1500
2000
2010
2015
2020
Time

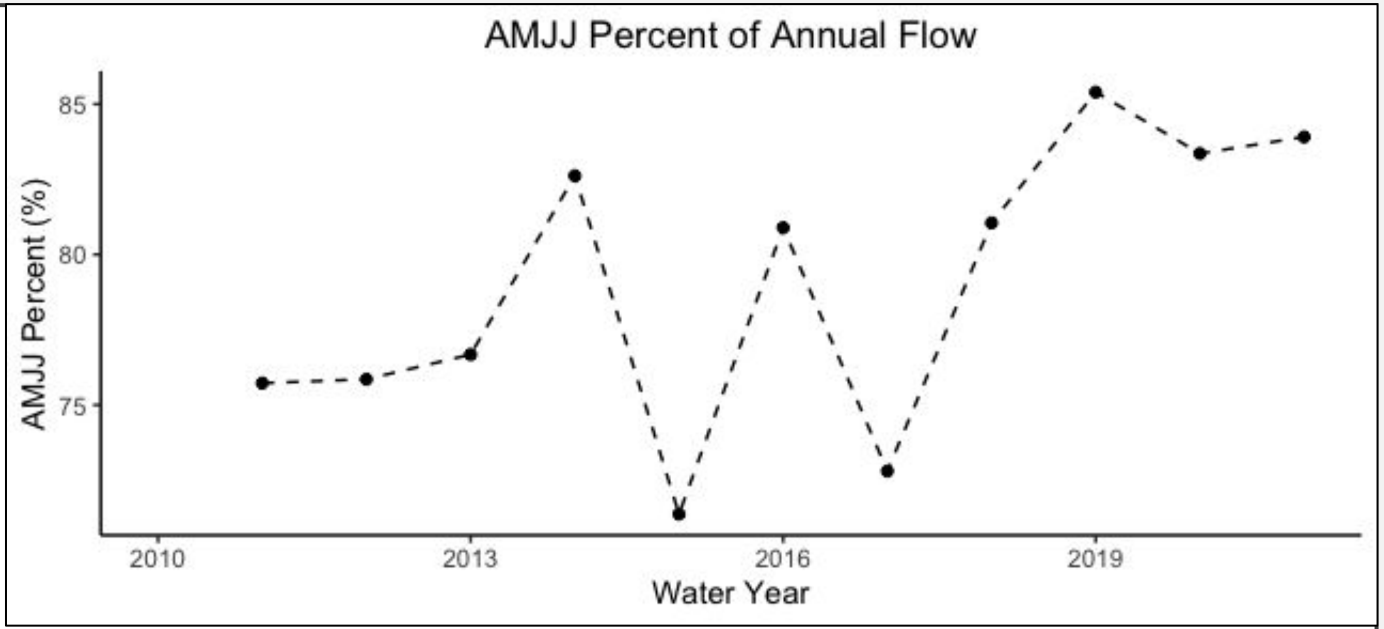

Mean Daily Discharge (WY2021)
Discharge, cubic feet per second (Mean)
0
100
200
300
Oct 2020
Jan 2021
Apr 2021
Jul 2021
Oct 2021
Time

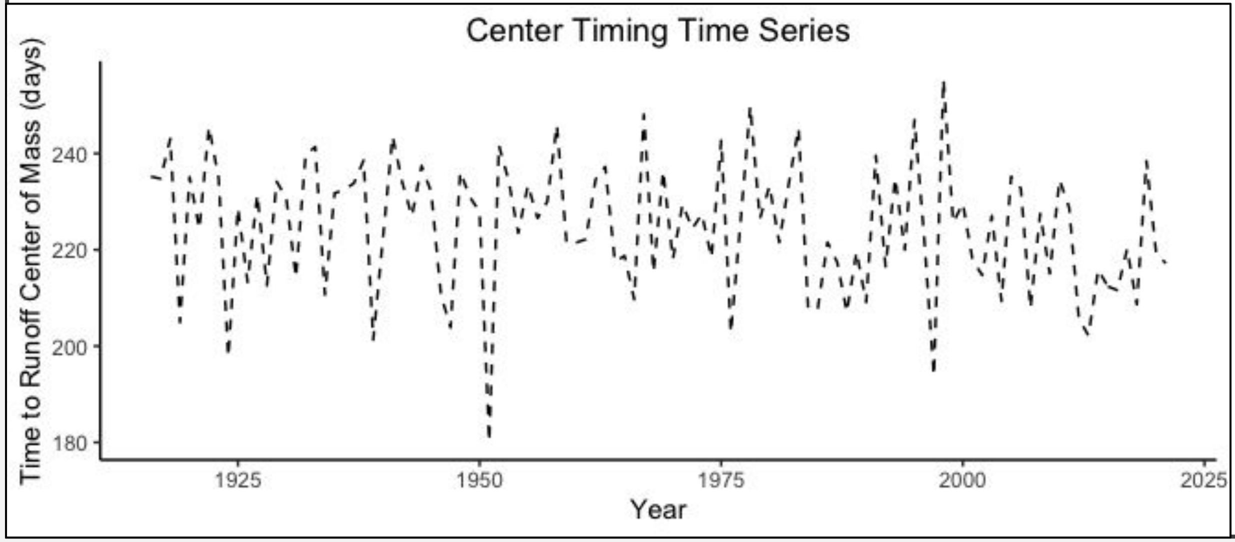

Annual Total Discharge
Discharge, cubic feet per year
1e+12
2e+12
3e+12
2010
2013
2016
2019
Water Year

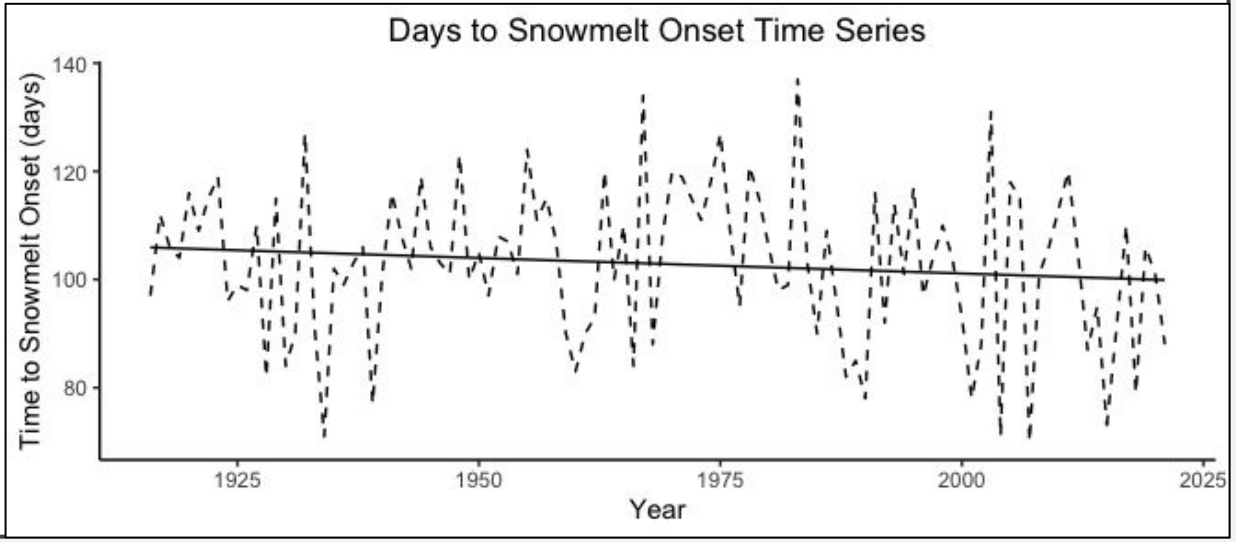

AMJJ Percent of Annual Flow
AMJJ Percent (%)
75
80
85
2010
2013
2016
2019
Water Year

San Joaquin, Happy Isles

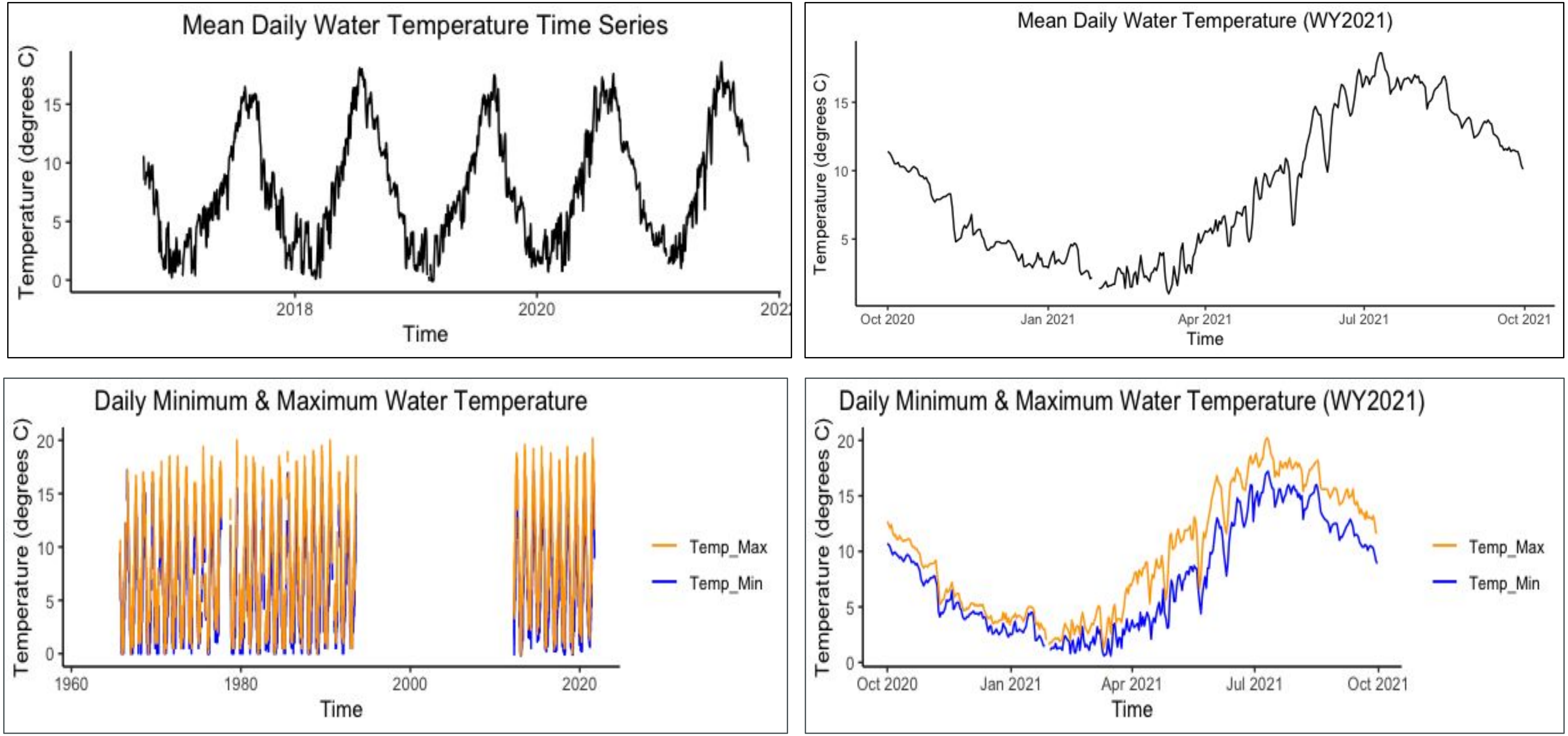






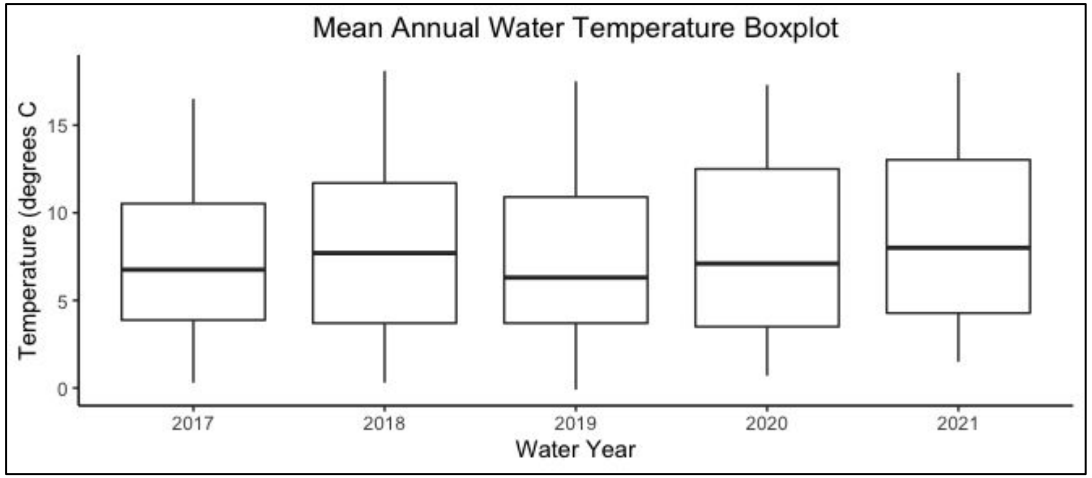


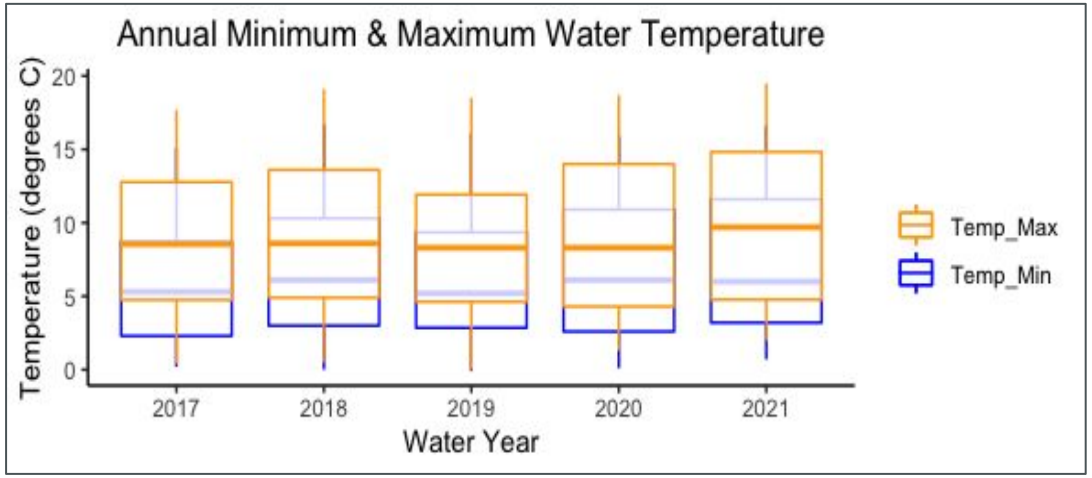
Merced

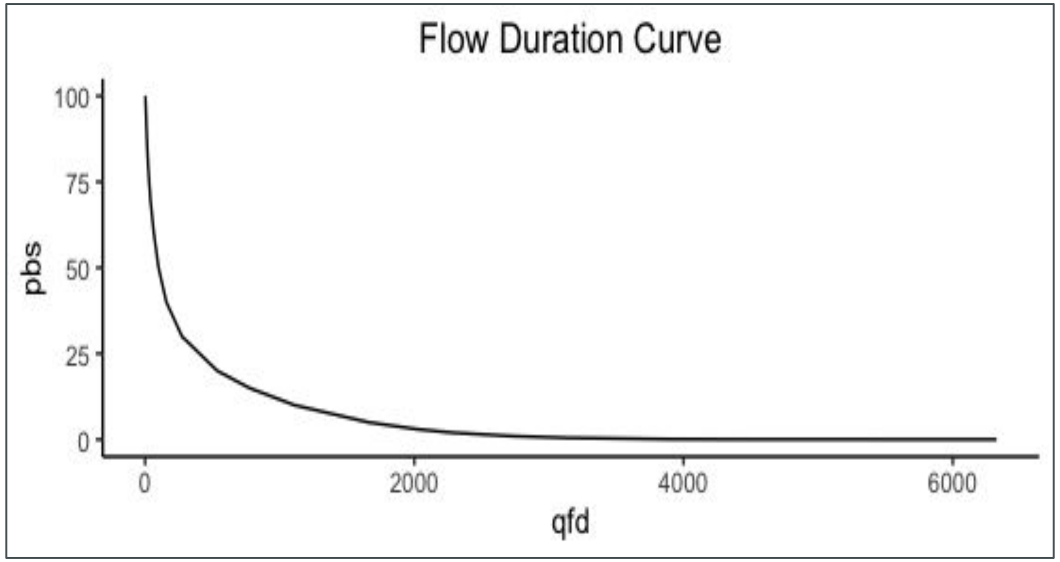


Mean Daily Water Temperature Time Series
Temperature (degrees C)
0
5
10
15
2018
2020
Time
Mean Daily Water Temperature (WY2021)
Temperature (degrees C)
5
10
15
Oct 2020
Jan 2021
Apr 2021
Jul 2021
Oct 2021
Time
Daily Minimum & Maximum Water Temperature
Temperature (degrees C)
0
5
10
15
20
1960
1980
2000
2020
Time
Temp_Max
Temp_Min
Daily Minimum & Maximum Water Temperature (WY2021)
Temperature (degrees C)
0
5
10
15
20
Oct 2020
Jan 2021
Apr 2021
Jul 2021
Oct 2021
Time
Temp_Max
Temp_Min

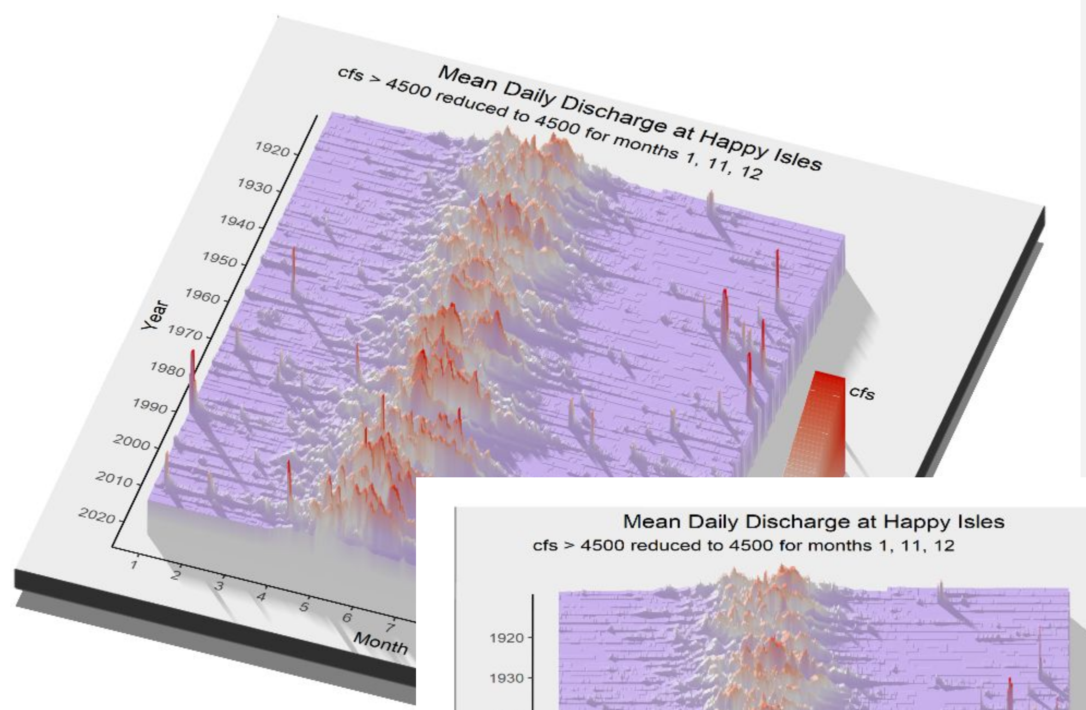
Merced, Happy Isles

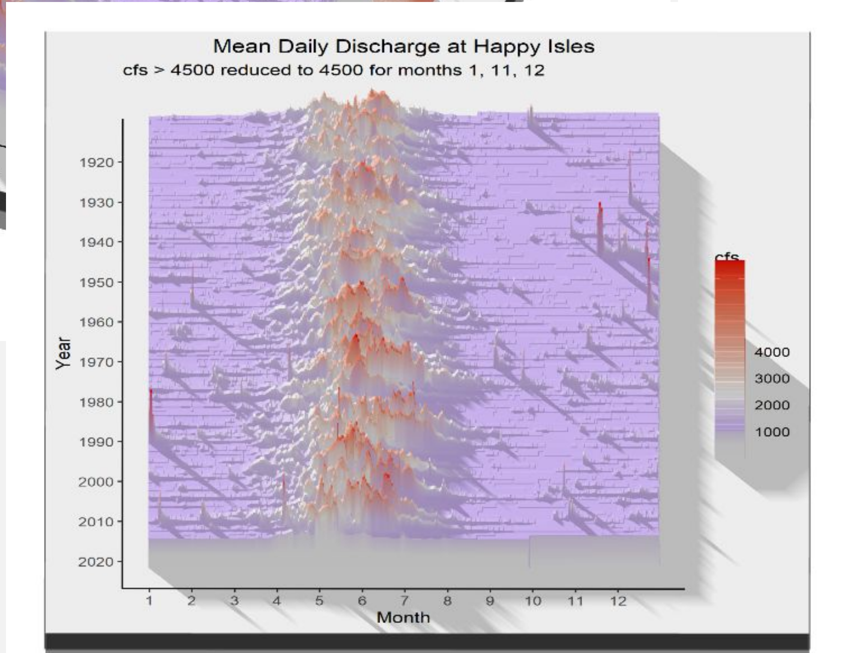


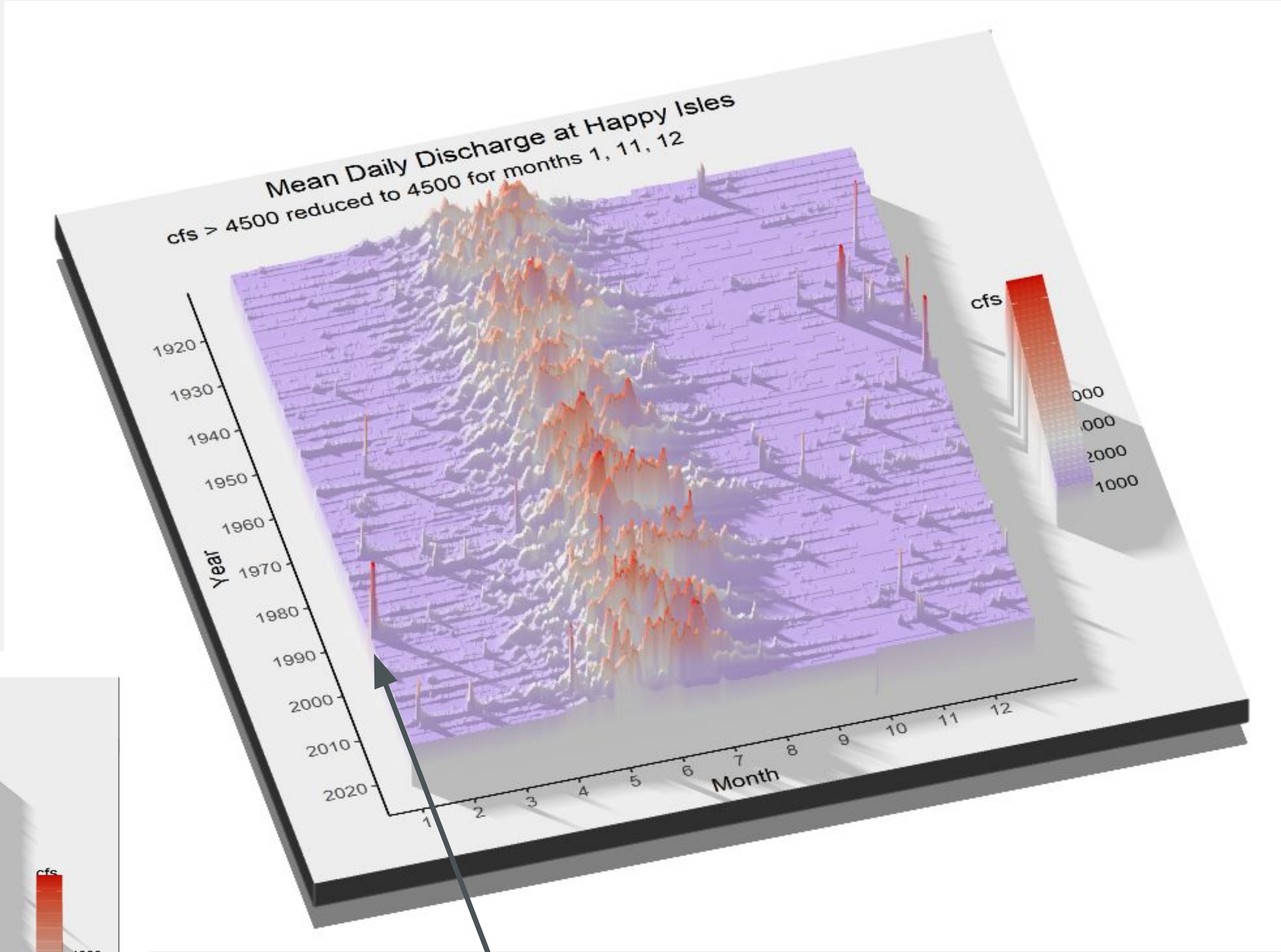




Rayshader cfs plots of Happy Isles: 1915 - 2021







January 1997 Atmospheric River > 7500 cfs

Compare 2-d derived values with 3-d raw data plots