VWP CIA Summary - [INSERT PROJECT NAME HERE]

09/13/2021

# VAHydro Model:

## VAHydro

The comprehensive VAHydro hydrologic model is used to evaluate potential impacts to surface water supply and other beneficial uses (including aquatic life), for withdrawal projects that have applied for a Virginia Water Protection (VWP). The VAHydro model simulates streamflow with inputs such as precipitation, climate, land use, and topography, as well as local data collected through Local and Regional Water Supply Plans and reported water use submitted to DEQ through the Annual Water Withdrawal Reporting program. The VAHydro model includes all known withdrawals and discharges, as well as operational rules of VWP permits and major hydrologic features such as reservoirs.

The VAHydro model is built on rainfall-evaporation-runoff (RER) time-series from the Chesapeake Bay Model Phase 6 which runs from 1984-2014 in the Chesapeake Bay watershed drainage, and 1984-2005 in the rivers flowing outside of the Chesapeake Bay watershed, aka the “southern rivers.” The VAHydro model features high-resolution hydrologic subsections called “river segments” (over 600 river segments in total), roughly the size of HUC 10 hydrologic units, with additional high-resolution segments added for VWP modeling projects as needed.

## CIA

DEQ assesses water supply sustainability through Cumulative Impact Analysis (CIA) modeling. CIA is a modeling and analysis approach that takes into account the varied hydrologic process occurring throughout a river network (including meteorology and human water use). By simulating a daily water balance for every individual river segment within a watershed, DEQ is able to evaluate the potential “cumulative impact” of all streamflow changes occurring upstream and downstream of any location within the river system, as well as the downstream impact of a specific proposed or permitted surface water withdrawal.

The goal of the following analysis is to estimate the potential impacts of the proposed water withdrawal upon existing beneficial uses, including both in-stream and off-stream uses. In addition, cumulative impacts from all existing withdrawals are included in the evaluation.

### Glossary of Cumulative Impact Modeling Terms

* Consumptive Use (CU): This is calculated as a fraction of modeled Flow, so it is CU = 1.0 - (Flow / Flow\_Baseline), where Flow\_Baseline = (Flow + WD - PS), and WD and PS are the total cumulative withdrawals and point source discharges above the point in the stream. In other words, for calculating baseline flow, we take modeled outflow from the river, add the withdrawals back in, and subtract the point source in order to estimate a baseline flow balance. This almost always ends up being a higher number than the modeled Flow out, so it tells us the fraction of baseline flow that is consumed. Occasionally there are water transfers and point sources from groundwater, or point sources that cross watershed boundaries that can make the CU fraction in some watersheds negative, i.e. Flow > Flow\_Baseline.

# Project Introduction

This project consists of an existing water intake constructed in the 1960’s with an upgrade in the early 1980’s. The Town owns and operates the Big Cherry Dam located approximately 3 miles upstream from the intake structure. The Town’s water treatment plant operators control the amount of water discharging the dam into the Powell River and all of the stream by-pass flow to meet the previous permit requirements of 4.0 MOD of maximum withdrawal and 0.50 MGD of by-pass flow. This is always true unless the dam is overflowing exceeding the amount of water required from various rainfall events. Therefore, the existing/proposed maximum withdrawal amounts will not have an impact on the stream in terms of rates, volumes, frequency, etc. This is a daily activity as it serves the existing water treatment plant.

Permit: Big Cherry Dam, 01-0688  
Permit Dates: 2003-08-23 to 2018-08-22

* **Annual Withdrawal Limit** = 1168 mg/yr (3.2 mgd)
  + (historically they withdraw ~2 mgd on average)
* **Daily Withdrawal Limit** = 4 mgd
* **Flow-by** = 0.5 mgd

## Location Map

*No location map available for this facility model*

# Model Overview and Scenario Descriptions

**River Model Description** Crooked Run is a tributary that joins the Shenandoah River just south of Front Royal VA. The area of Crooked Run above it’s confluence with the Shenandoah River in this model is 47.0 square miles.

**Facility & Intake Model Description** The Blue Ridge Shadows golf course is modeled as a pump-store facility with a local impoundment having no direct drainage area, and an intake on Crooked Run to refill when water is available. The impoundment is estimated to have a maximum storage of 21.84 acre-feet. Modeled demand is calculated by taking the requested annual maximum demand and scaling it according the to historical monthly use patterns for the intake. The previous permit featured a static MIF below which no pumping was possible. Model scenarios were selected in order to explore “percent of flow” type withdrawal limits in order to mimic natural flows, and also provide operational flexibility. Flow at the Crooked Run intake is simulated through the use of a rainfall-runoff model, with explicit simulation of the land-use above the intake. This differs from some historical models that would have used a USGS gage flow record from a nearby gage to simulate flows at the intake. By using the rainfall-runoff simulation at a point very close to the actual intake, modeled low-flows can be improved due to consideration of specific catchment area, land use, and other upstream withdrawals. As a result, this permit-max simulation may have lower available water because it reflects current demands with historical meteorology in a smaller watershed. Because of practical considerations of permit operation, a surrogate gage may still be employed, and that gage may have higher base flows than Crooked Creek at this intake, therefore, permit rules should attempt to account for that possibility.

The following model scenarios were simulated in order to determine the most effective means of meeting the project need and all other in-stream beneficial uses:

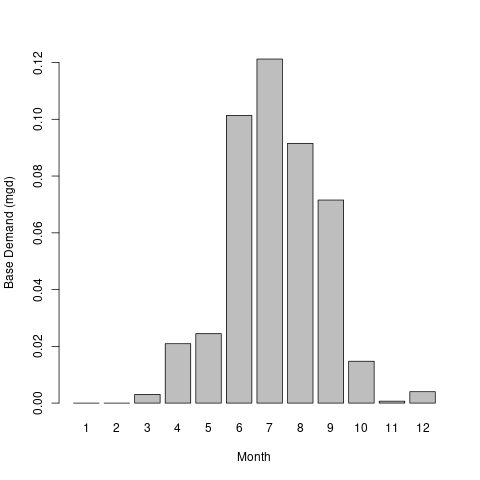
* **Existing permit conditions** (Current Permit (15.4 MGY)) - The existing permit scenario has a static minimum instream flow of 4.13 cfs, which means that all withdrawal must cease from Crooked Run when flow drops below 4.13 cfs. This MIF is based on flows in Opequon Creek near Berryville, since the alternative gage, Opequon Creek at Stephens City is no longer in service. Flowby value at the intake is area-weighted as 3.7 cfs = 9.4 \* 22.9 / 58.2, since 9.4 cfs is flowby at Berryville gage, with Drainage area 58.2 square miles, and the Crooked Creek model intake is 22.9 square miles.
* **Existing permit conditions** (Current Permit (w/36.37MGY)) - The existing permit scenario has a static minimum instream flow of 4.13 cfs, which means that all withdrawal must cease from Crooked Run when flow drops below 4.13 cfs. This MIF is based on flows in Opequon Creek near Berryville, since the alternative gage, Opequon Creek at Stephens City is no longer in service. Flowby value at the intake is area-weighted as 3.7 cfs = 9.4 \* 22.9 / 58.2, since 9.4 cfs is flowby at Berryville gage, with Drainage area 58.2 square miles, and the Crooked Creek model intake is 22.9 square miles.
* **Proposed permit conditions with 90% flowby** (90% Flow-by (w/36.37MGY)) - The 90% flow-by scenario limits the daily withdrawal from Crooked Run to no more than 10% of the flow in the stream, based on the previous days simulated flow.

# Intake Site Description & Current Estimated Stream Flows

**Table 1:** Modeled monthly current flow statistics for Blue Ridge Shadows at Crooked Run in cubic feet per second (cfs). Columns show the minimum (Min) and average (Mean) modeled flow, and a range of non-exceedance flow percentiles, that is, the column header indicates the percent of flows that do *not* exceed the given value. For example, the “10%” states that only 10% of flows in the given month are expected to be less than the indicated value, and therefore, 90% of the flows in that month are expected to be greater than the given value. For example, in the table below the 10% column states that 10% of flows within the month of January would be less than 4.7 cfs.

| **Month** | **Min** | **5%** | **10%** | **25%** | **30%** | **50%** | **Mean** |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Jan | 0.3 | 2.7 | 4.7 | 8.9 | 9.9 | 14.8 | 23.7 |
| Feb | 0.3 | 3.2 | 5.8 | 12.2 | 13.1 | 17.5 | 28.1 |
| Mar | 0.2 | 4.9 | 7.5 | 13.3 | 15.8 | 24.9 | 43.1 |
| Apr | 1.1 | 4.9 | 6.4 | 11.4 | 12.6 | 18.3 | 31.4 |
| May | 1.3 | 3.9 | 5.3 | 8.6 | 9.5 | 13.3 | 21.9 |
| Jun | 0.3 | 1.3 | 1.9 | 3.9 | 4.6 | 7.8 | 12.3 |
| Jul | 0.0 | 0.2 | 0.5 | 1.5 | 1.8 | 3.1 | 5.5 |
| Aug | 0.0 | 0.0 | 0.1 | 0.6 | 0.8 | 1.8 | 4.7 |
| Sep | 0.0 | 0.0 | 0.0 | 0.3 | 0.4 | 1.4 | 10.1 |
| Oct | 0.0 | 0.1 | 0.3 | 1.1 | 1.3 | 3.4 | 8.9 |
| Nov | 0.0 | 0.0 | 0.7 | 2.9 | 3.5 | 6.6 | 15.6 |
| Dec | 0.0 | 1.2 | 2.7 | 6.6 | 7.9 | 13.5 | 22.3 |

## Facility Base Demand Before Conservation: 90% Flow-by (w/36.37MGY)



# Model Results Summary

Four scenarios are presented below to examine the alternatives for this permit re-issuance. A summary of how permit rules affect available water for this permit, and how this operation may impact instream beneficial uses, and other downstream water withdrawals is presented.

* **Existing permit conditions** - The static minimum instream flow in this scenario results in reduced water availability during 5 out of 30 years of the long-term simulation. During 4 years out of the 30 years simulated, pond storage is totally depleted and pumping from Crooked run is reduced below the modeled need for periods in excess of 1 month. For example, during summer 1991, average flow in Crooked Run drops below 4 cfs for over 4 months, coinciding with the period of greatest demand for this facility. Modeled pond storage dropped below 50% in 19 out of 30 years simulated. However, by employing a static MIF in this scenario, instream flows in Crooked Run are maximized under drought conditions.
* **Existing permit conditions** - The static minimum instream flowby coupled with the drought year demand in the JPA of 36.37 results in reduced water availability during 28 out of 30 years of the long-term simulation. Modeled pond storage dropped below 50% in 28 out of 30 years simulated. During 27 years out of the 30 years simulated, pond storage is totally depleted and pumping from Crooked run is reduced below the modeled need for periods in excess of 1 month.
* **Proposed permit conditions with 90% flowby** - The 90% flow-by scenario results in more flexibility to pump under extremely dry conditions, as compared to the current static MIF permit condition. As a result, the operation is able to meet off-stream need during all simulated periods, with pond drawdown below 50% occuring 5 times in the 30 year simulation.

## Conclusion

Overall, remodeling to consider a net % change to flow (after the point source return flow) has improved the outlook across all scenarios examined, and supports moving towards a “percent of flow” flowby approach. When modeling as a net % change in flow, the reservoir is not chronically drawn down as was shown in previous model results.

With the current permit operations and a limit of 3.2 mgd they likely wouldn’t be able to meet a 90% flowby and retain 60 days remaining storage in the reservoir during the drought of record. However a flowby closer to 80% would likely be effective at maintaining storage levels and ensuring they can sustainably meet demand during dry periods while still better preserving the natural flow regime over a static 0.5 mgd flowby approach. This project may also be able to get to a 90% flowby by reducing demands from 3.2 mgd to around 3.0 mgd, and/or by including drought triggers in the permit to help maintain storage levels in the reservoir during dry periods (this permit doesn’t currently have drought triggers in place). Additionally, this facility has emergency connections with neighboring towns which may be sufficient to maintain supply during times of extreme drought. Note that demand is projected to decline according to water supply plan.

# Cumulative Impact Analysis

This table summarizes the cumulative impacts to flows, aquatic life, and off-stream demand for the project. The section entitled “River Segment Model Statistics” contains mean flows (Flow Out), and drought flows (30 and 90 Day Low Flow), as well as an estimated percent total consumptive use as a result of all withdrawals (Cumulative Withdrawal) and discharges (Cumulative Point Source) in the watershed. Minimum Days of Storage Remaining describes the number of days of remaining storage available during the driest period of the model simulation (applicable to impoundment models only). Estimates for richness change are also presented both as an absolute number of species (Richness Change (abs)) and as a percentage of the total number of species present (Richness Change (%)). Richness change calcualtions are derived from the estimated percent total consumptive use (For additional details on “elfgen” methodology, see <https://onlinelibrary.wiley.com/doi/full/10.1111/1752-1688.12876>). The section entitled “Facility Model Statistics” shows the withdrawals, return flows (Point Source), and the model estimate for potential unmet demand due to demands exceeding the allowable withdrawal at the intake based on the cumulative conditions in the watershed and the flow-by rules in effect. There will be one or more columns in this table representing each scenario considered for this analysis.

## Stats Comparison Table:

| **Description** | **Current Permit (15.4 MGY)** | **Current Permit (w/36.37MGY)** | **90% Flow-by (w/36.37MGY)** |
| --- | --- | --- | --- |
| runid | 4 | 400 | 600 |
| River Segment Model Statistics: |  |  |  |
| Name | Crooked Run | Crooked Run | Crooked Run |
| Flow Out (cfs) | 34.57 | 34.53 | 34.5 |
| Minimum Days of Storage Remaining | NA | NA | NA |
| 30 Day Low Flow (cfs) | 0.12 | 0.12 | 0.11 |
| 90 Day Low Flow (cfs) | 0.73 | 0.75 | 0.72 |
| Consumptive Use Fraction | 0 | 0 | 0 |
| Cumulative Withdrawal (mgd) | 0.09 | 0.09 | 0.1 |
| Cumulative Point Source (mgd) | 0 | 0 | 0 |
| Richness Change (abs) | NA | NA | NA |
| Richness Change (%) | NA | NA | NA |
| Facility Model Statistics: |  |  |  |
| Name | Blue Ridge Shadows Golf Club:Shenandoah River | Blue Ridge Shadows Golf Club:Shenandoah River | Blue Ridge Shadows Golf Club:Shenandoah River |
| base\_demand\_mgy | 15.04 | 35.98 | 35.98 |
| wd\_mgy | 14.55 | 26.01 | 31.79 |
| unmet\_demand\_mgy | 0.49 | 9.97 | 4.2 |
| Requested Demand (mgd) | 0.04 | 0.1 | 0.1 |
| Withdrawal Met (mgd) | 0.04 | 0.07 | 0.09 |
| Point Source (mgd) | 0 | 0 | 0 |
| Maximum 30 day potential unmet demand (mgd) | 0.08 | 0.29 | 0.25 |

# Reservoir Storage Plots:

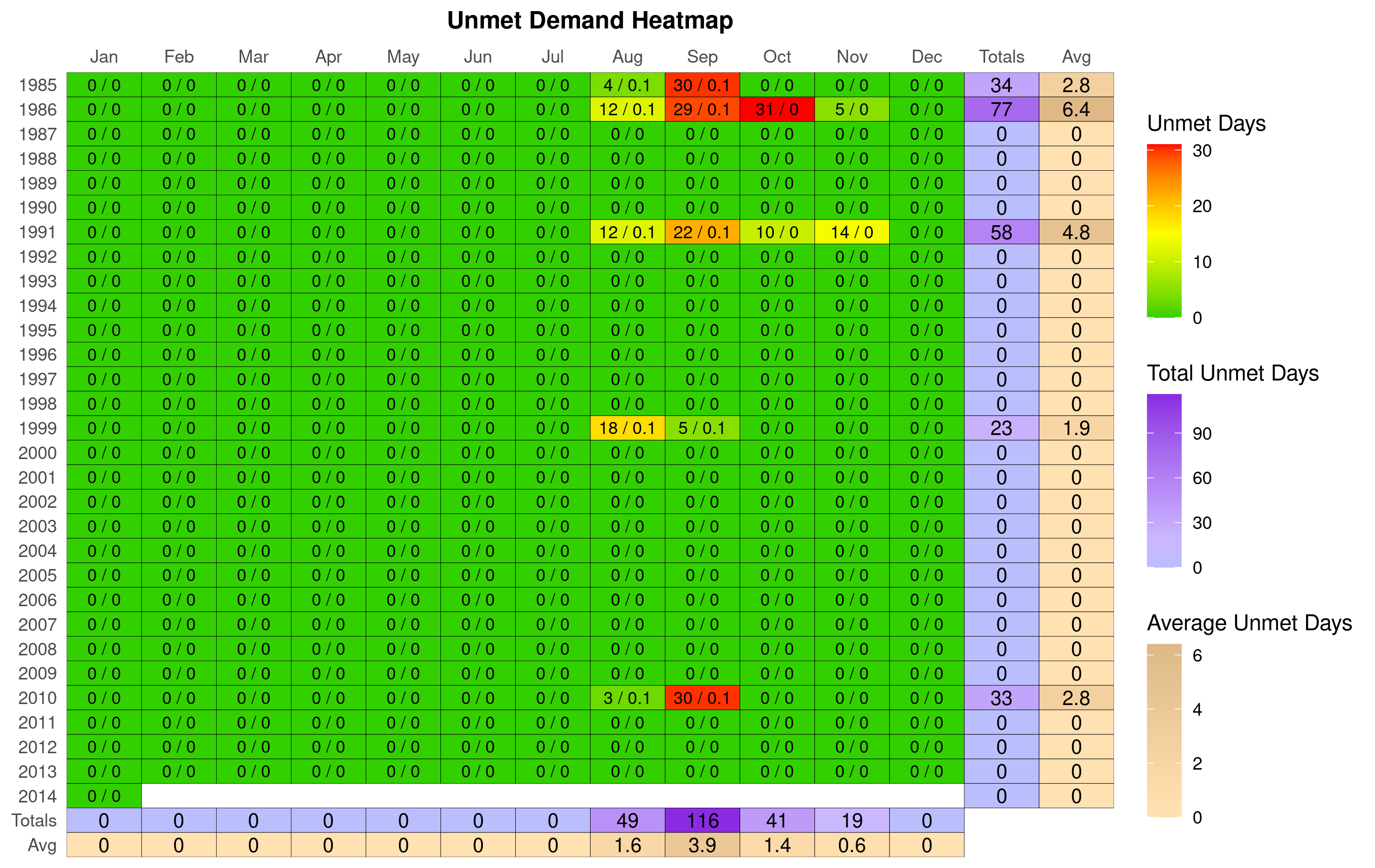
The following reservoir storage plots depict changes in reservoir storage under each scenario (indicated in black), as well as simulated inflow to the reservoir (blue), simulated outflow from the reservoir (green), and system demand for the given scenario (red). For water supply reservoirs, a minimum of 60 days of remaining storage over the course of the simulation is recommended. System demand varies seasonally.

[1] “No riverseg impoundment for run id 4” [1] “No riverseg impoundment for run id 400” [1] “No riverseg impoundment for run id 600”

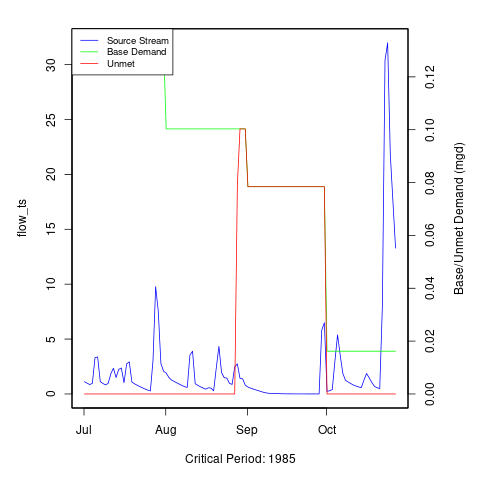
# Unmet Demand Plots:

The following heatmaps depict the number of days with unmet demands for each month of the simulation (due to demands exceeding allowable withdrawal at the intake based on the cumulative conditions in the watershed and the flow-by rules in effect). Heatmaps also show the amount of unmet demand for each month [Unmet Days / Amount (mgd)]. Hydrographs are shown for the period of the simulation with greatest unmet demand.

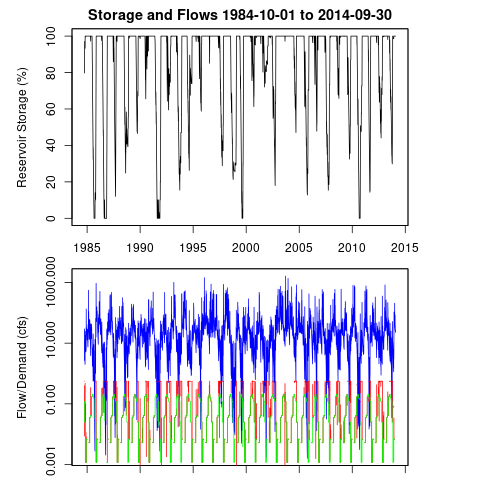
## Heatmap: Current Permit (15.4 MGY)



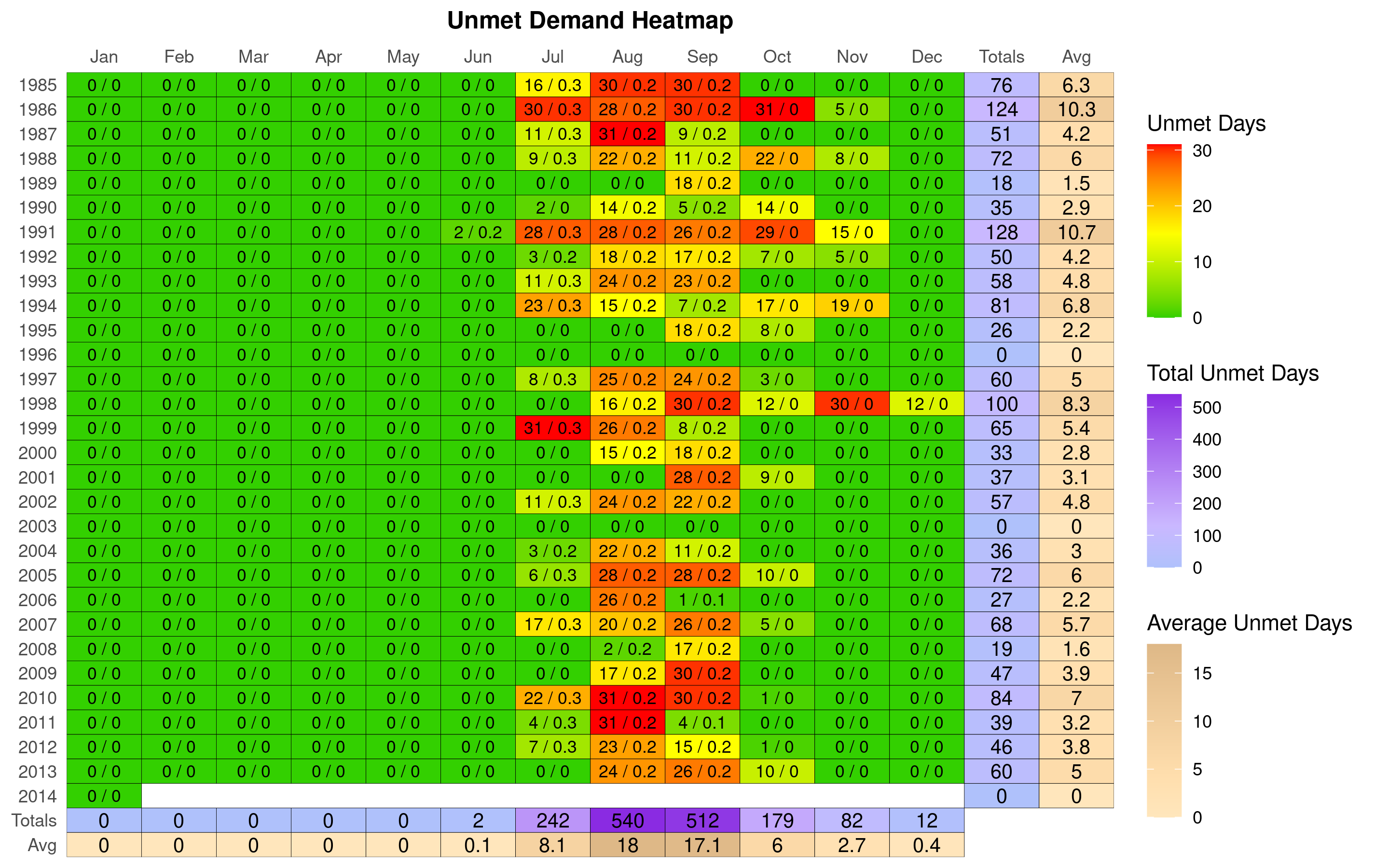
## Hydrograph: Current Permit (15.4 MGY)



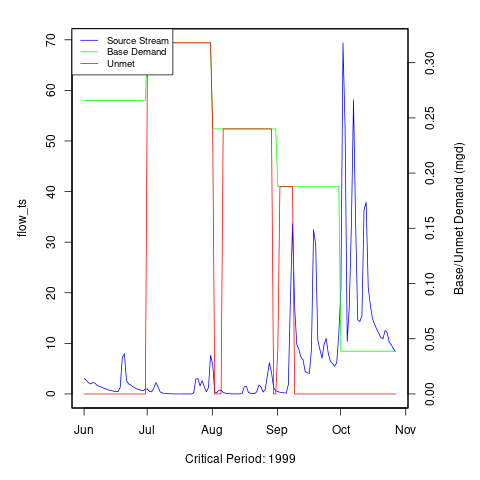
## Reservoir Storage: Current Permit (15.4 MGY)



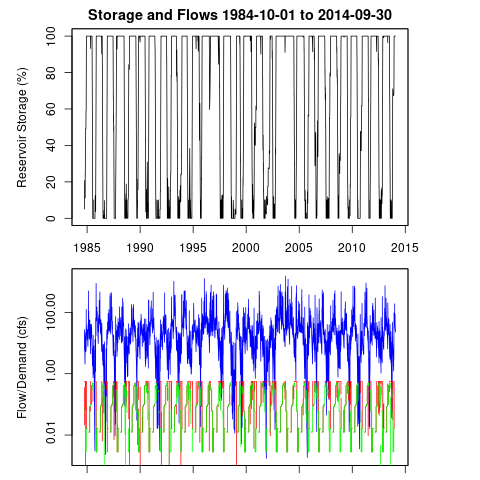
## Heatmap: Current Permit (w/36.37MGY)



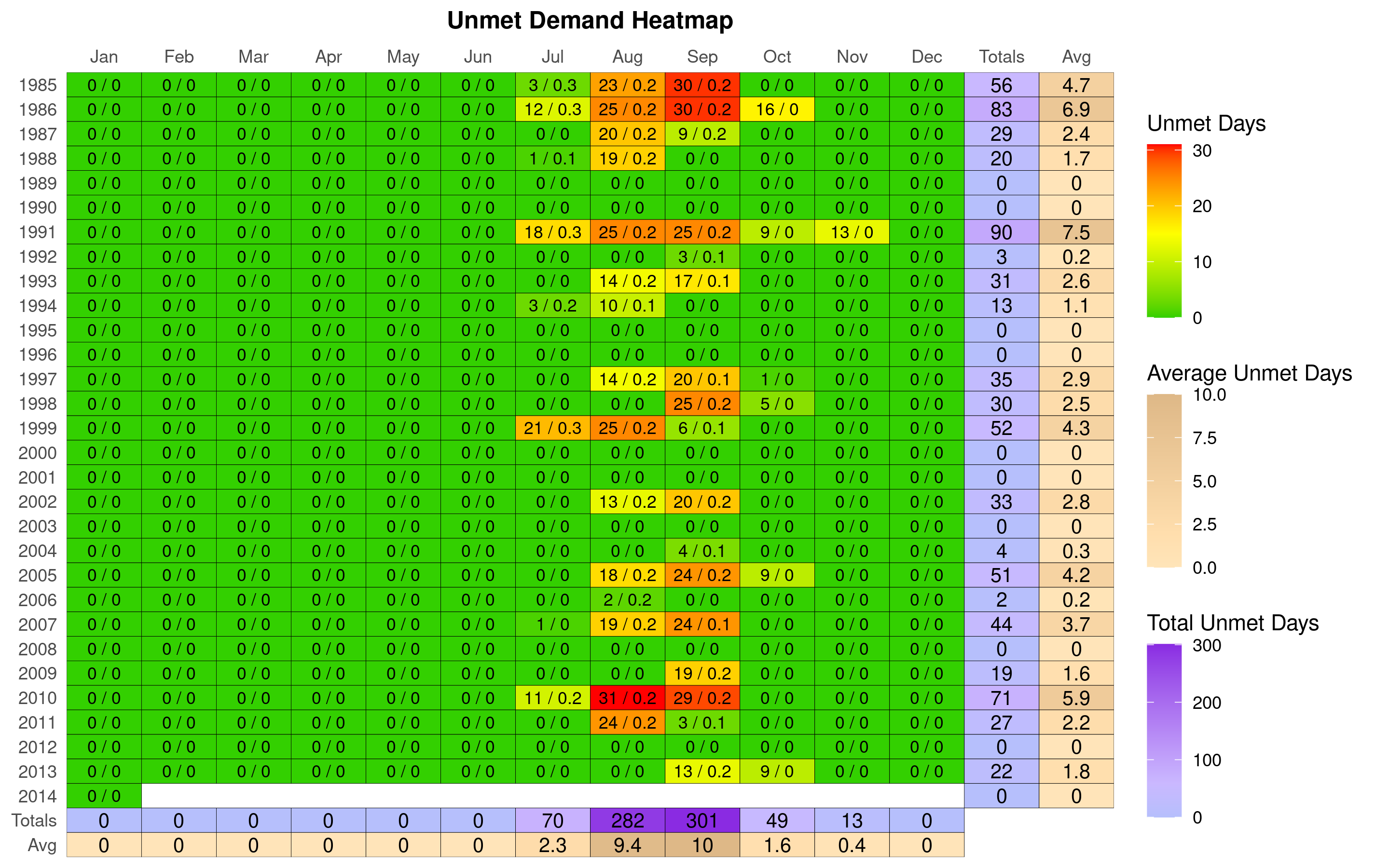
## Hydrograph: Current Permit (w/36.37MGY)



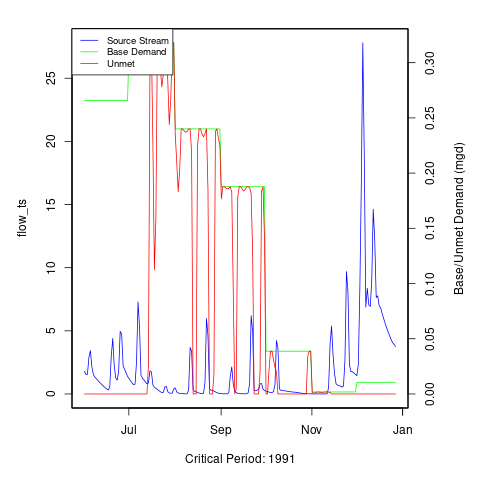
## Reservoir Storage: Current Permit (w/36.37MGY)



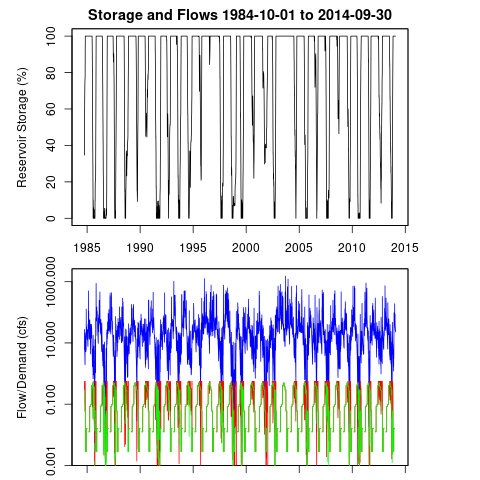
## Heatmap: 90% Flow-by (w/36.37MGY)



## Hydrograph: 90% Flow-by (w/36.37MGY)



## Reservoir Storage: 90% Flow-by (w/36.37MGY)



# Ecological Impacts Assessment:

## Elfgen:

In response to a need for better environmental flow metrics, DEQ has developed a new framework for characterizing relations between streamflow and aquatic organism species richness. Part of an evolving approach to managing environmental flows for maintaining aquatic life; this methodology builds on existing minimum instream ow approaches, allowable withdrawals as a percentage of flow, and extensive flow-habitat studies. For the first time this new framework may allow quantification of potential species loss resulting from flow change, and may offer an improved understanding of aquatic life risk variability due to geographic location, stream size and local scale.

In order to calculate river segment-level richness change, elfgen is first used to produce relations between stream flow and species richness at the HUC 8 scale (See plot below). This is achieved using long term datasets for both ecological and hydrologic data. Ecological data (Fish species richness) is sourced from the VAHydro-EDAS dataset. Hydrologic data (Average Annual Flow) is sourced from the National Hydrography Dataset Plus. The Richness Change values presented in the 6.1. Stats Comparison Table are derived from this flow-ecology relation.

*No elfgen plot available for this model*

## Habitat (If Applicable):