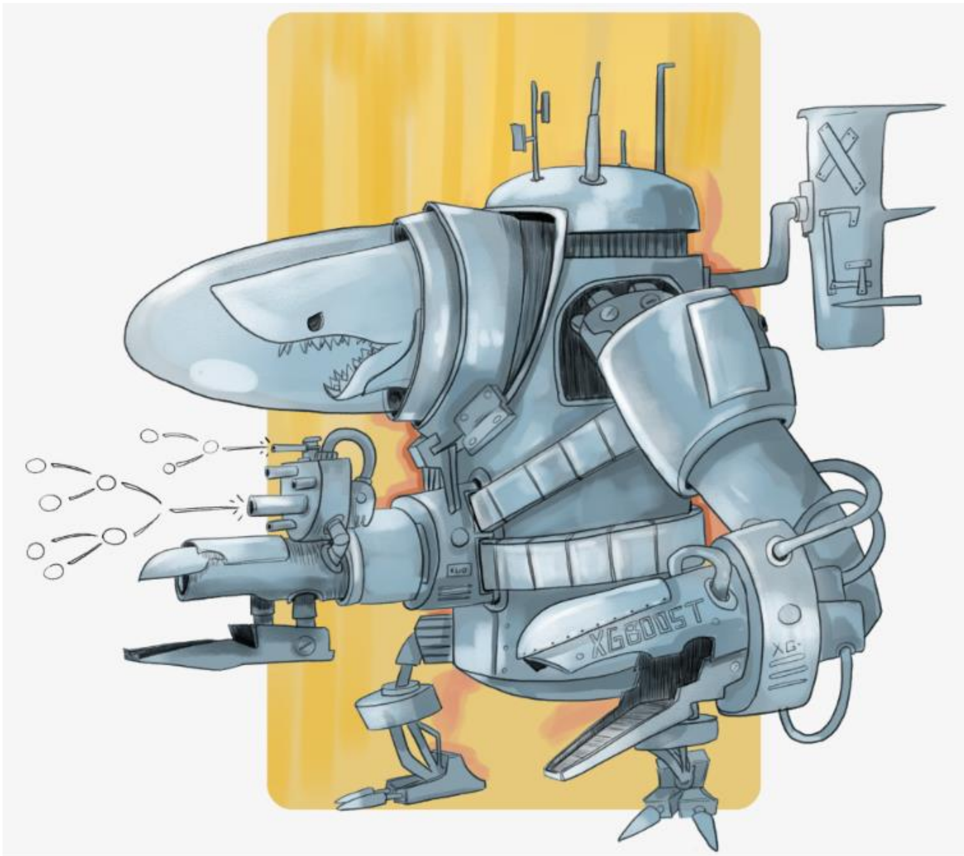
Hydrological Modeling for the Wally project

Contract IS21IIT049

Version 0.5 (Oct 6, 2021)



(Artist's Rendition of XGBoost by Noah Carson)

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Executive Summary

Fathom Scientific Ltd. (FSL) has been contracted by the Province of British Columbia Ministry of Environment (MoE) to provide expert hydrological advice and support the MoE in the development of Wally – a decision-support tool that will assist water authorization staff in making robust, defensible water allocation decisions.

FSL began working worked with the Water Digital Services Team on the Wally tool in early 2021. FSL's prior work with regression modeling and optimization formed the basis of the hydrological model employed in the Wally tool. As such, FSL was retained to provide guidance and oversight to the implementation and refinement of the hydrologic model. This guidance included input on the appropriate use of water models, existing data gaps, uncertainty assessment, and the presentation of uncertainty.

The hydrologic model employed in the Wally tool is built on the work performed by FSL for the South Coast Stewardship Baseline (SCSB 2016) project as well as for the Regional Strategic Environmental Assessment (RSEA 2020) project. Those projects built on prior work undertaken for the South Coast Drought Response project (Sentlinger 2015).

The SCSB, RSEA, and Drought Response projects utilized traceable and common-sense approaches to determine monthly and seasonal water allocation, paired with transparent and defensible multivariate regression models using Geospatial statistics and Quality Controlled/Quality Assured (QA/QC) hydrometric data. These studies used a modified k-fold approach to ensure the chosen model was robust to different training sets. The resulting algorithm has been dubbed the Modified k-fold Multivariate Geospatial Regression (MkMGR) model.

The Wally study had an ambitious goal to apply both multi-variate linear regression models (MkMGR) to the entire province of British Columbia, and compare its performance to a Machine Learning (ML) approach to Geospatial Regression Modeling for Hydrological Statistics (Hydro-stats). The XGBoost ML algorithm was engaged for this task and compared with MkMGR results in this study and showed comparable performance

Both algorithms have strengths and weaknesses, outlined in Table 6, and both showed promising results for large scale estimates of hydro-stats with uncertainty estimates. The fully transparent and reproducible methods are described in Section 2, model performance in Section 3, and results, conclusions, and recommendations ins Section 4.

Despite limitations in scope and resources, the team was able to lay down the foundation of a powerful, accurate, and transparent method to generate any hydro-stat based on regional predictor variables, with uncertainty estimates. Due to limited resources, the team stopped short of generating all hydro-stats presented in SCSB and RSEA (i.e., mean monthly discharge, etc.) and conducting the associated validation exercise found in those earlier reports, but this work could be easily performed in the future.

The value of the work in this project for watershed delineation and hydrological estimation in ungauged basins cannot be understated. With Wally, the team was able to:

- Generate watershed GIS catchments for 534 WSC stations in the province, each with more than 10 years of data, based on Lat-Long and DA of the station alone, including watersheds that cross provincial and national boundaries.
- Generate hydro-stats for those stations with FASSTR from Hydat alone.
- Filter and QA/QC hydrostats based on upstream water allocation data
- Automatically generate independent hydro-stat MkMGR models for all 29 Hydrologic Zones in the province
- Automatically train XGBoost ML models for any hydrostat for the entire province and generate the associated uncertainty.

If the Wally tool can be made available to water professionals in the province, 1000's of hours of needless work can be avoided, robust and standardized Geospatial statistics and watershed boundaries can be quickly generated, and preliminary estimates from two independently developed regression models can be utilized, along with defensible water allocation estimates.

With pressure on water resources at a historic high, and uncertainty due to climate change a constant threat to habitat and water rights, the timing and approach the Water Digital Services Team has taken with WALLY is critical for responsible stewardship of our shared resource. The Wally project shows tremendous potential for widescale (Province-wide) estimation in ungauged basins. It is a transparent, reproducible, and defensible model that is easily understood and the mechanics that have gone into delineating watersheds accurately and autonomously are the state of the art and represent a culmination of decades of work from individual practitioners. The tool is accurate, faster, and aligns with an ethos of a public good, when compared to the alternatives, as it was in RSEA (2020). For posterity, and to support the triumph of the commons, we hope this important work can be continued beyond the borders of this contract.

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ACRONYMS AND ABBREVIATIONS

GIS	Geographic Information System
MFLNRORD	Ministry of Forests, Lands, Natural Resource Operations, and Rural Development
MkMGR	Modified k-fold Multivariate Geospatial Regression
MOECCS	Ministry of Environment & Climate Change Strategy
POD	Point of Diversion
RISC	Resources Information Standards Committee
SC	South Coast
WSC	Water Survey of Canada

1 INTRODUCTION

The Wally project is an ambitious and commendable attempt to bring cutting edge and transparent water modeling to the Province of British Columbia under the umbrella of publicly owned web services. Gabe Sentlinger of Fathom Scientific was retained as an expert advisor under this contract to provide guidance and advice in the modeling of various Hydrological Statistics (hydro-stats), as well as user experience feedback. The Fathom Scientific team provided additional support in water demand modelling and Geographic Information Systems (GIS) processing for watershed delineation.

The project has been challenging partly due to the sheer size of the task (the entire Province including drainage areas extending outside of the Province), and partly because a new data training model employing a Machine Learning algorithm called XGBoost was initially employed to develop unsupervised models for the hydro-stats of interest. The general approach is the same as used in "South Coast Stewardship Baseline (Brem, Fraser Valley South, Toba, Upper Lillooet) REV 1.0" (Sentlinger & Metherall 2016), hereafter referred to as the SCSB. In that study, we built relationships between GeoSpatial Stats (GeoStats) and hydro-stats, and employed a modified k-fold approach to regression modeling which determined the most robust model using limited dataset sizes (from 5-30 training datasets). This modeling technique is hereafter referred to as Modified k-fold Geospatial Regression Model (MkMGR).

The full details of that study are described in the SCSB report and generally not repeated here. The approach was further refined in "RSEA Hydrology and Allocation Baseline REV 1.0." (Sentlinger & Metherall 2020 hereafter referred to as RSEA). In this later study, we added more hydro-stats to the models, and combined Hydrological Zones (HZ) to increase the training dataset size in data-sparse regions.

The significant improvement of this current study over past studies, is the revolutionary approach to watershed delineation and model training dataset extraction and auditing that the Wally team, led by Stephen Hillier (GIS) and Alex Zorkin (Data modeling) have implemented. We have created a dataset of WSC data from recent Hydat training datasets (2021) with appropriate filters to perform automated QA/QC to the dataset. Unlike the SCSB, which relied on BC Watershed Atlas Fundamental Watersheds, and pre-processed Upstream Drainage Areas (UDAs), Wally can process UDAs "on the fly", derive all necessary Geo-Stats, and calculate modeling results based on underlying models. This can be done anywhere in the Province, including transboundary watersheds. This, again, is a significant step forward that will support the Province in water management.

2 METHODOLOGY

This section outlines the three main components of Wally, the Watershed Delineation, the Water License Allocation and Return coefficients, and the hydro-stat modeling.

2.1.1 GIS Data

Beyond having the flow statistics derived from Hydat using FASST, we need GIS-derived statistics to complete the analysis, which required having drainage area polygons. The drainage area polygons were generated using Wally, in the method described below.

Note that the Geospatial stats used in the current study are essentially the same as used in SCSB and RSEA, however the base data from which it is derived has changed slightly, namely the DEM and PET.

The spatial data sources used to derive catchment characteristics are as follows:

1. Digital Elevation Model (DEM): In Sentlinger (2016) we used elevation data primarily provided by GeoBase and the 1:50k Canadian Digital Elevation Data (CDED). This data is very good quality in BC: we have found that elevation contours are within 10m of BC Terrain Resource Inventory Mapping (TRIM) contours. For most areas of the Province in the current study, 90m pixels were used to derive DEM stats. However, when delineating drainage lines in more populated areas with more terrain modification, 20m pixels were used. For this study, we chose to use the 90m CDEM to derive DEM-based geospatial stats:

    a. The hillshade image (using an azimuth of 180° and altitude of 45° with shadows, a.k.a. Solar Exposure),

    b. Slope in % (rise/run),

    c. Median Elevation, and

    d. Drainage Area.

    Because this dataset is a higher resolution than the 500m pixels in SCSB and RSEA, the coefficients and intercepts (model parameters) from that study cannot be directly employed to the geospatial stats derived in this study.

2. Glacier coverage: We used the 1:50k NTS glacier coverage database

3. PRISM Annual Precipitation: Produced by the Oregon Climate Center (Daly 2002). This regression model uses data from local long-term meteorological stations along with DEM data to estimate the local (1km² pixels) precipitation. We only considered annual precipitation since Sentlinger & Metherall (2016) found no significant predictive power was gained going to monthly precipitation estimates.

4. Annual Potential Evapo-Transpiration (PET) (Trabucco 2019): This variable is globally available and takes into account solar radiation and temperature. It's an updated model from PET (Trabucco 2009) used in SCSB and RSEA. In all cases checked, it's a larger value than Trabucco 2009. Therefore, again, the models derived in SCSB and RSEA cannot be directly applied to the estimates of PET in this study.

2.2 Upstream Drainage Areas using Freshwater Atlas and CDEM

(This section written by Stephen Hillier)

The Wally Surface Water Analysis feature collects and outputs a variety of water and climate data for users. The search area for this feature is the upstream catchment area, or basin, originating from a point on a stream that the user selects.

The Freshwater Atlas (FWA) is the primary source for the catchment areas used by Wally. However, the FWA fundamental watershed polygons (1:20000) are not small enough to accurately delineate a catchment from an arbitrary stream point, as there will always be downstream area included (see below example). This document presents a method for using the catchment areas defined by the Freshwater Atlas fundamental polygons, with a refinement/correction for the area that the point of interest was placed in.

In addition to the Freshwater Atlas fundamental watersheds, the method relies on catchment delineation using a Digital Elevation Model (DEM) and the WhiteboxTools program. WhiteboxTools is an open source GIS analysis program developed at the University of Guelph's Geomorphometry and Hydrogeomatics Research Group (GHRG) that is well suited for integration with other software.

The Digital Elevation Model used in this example is the CDEM 3s (90m) data. Future plans include integrating the CDEM 0.75 arcsecond (25m) digital elevation model.

Freshwater Atlas: https://www2.gov.bc.ca/gov/content/data/geographic-data-services/topographic-data/freshwater

CDEM: https://open.canada.ca/data/en/dataset/7f245e4d-76c2-4caa-951a-45d1d2051333

WhiteboxTools: https://jblindsay.github.io/ghrg/WhiteboxTools/index.html

2.2.1 Point of Interest

The user selects a point of interest along a stream. The catchment area generated will be the area that drains to this point (i.e., is "upstream").

Figure 1: Arbitrary Point Selection

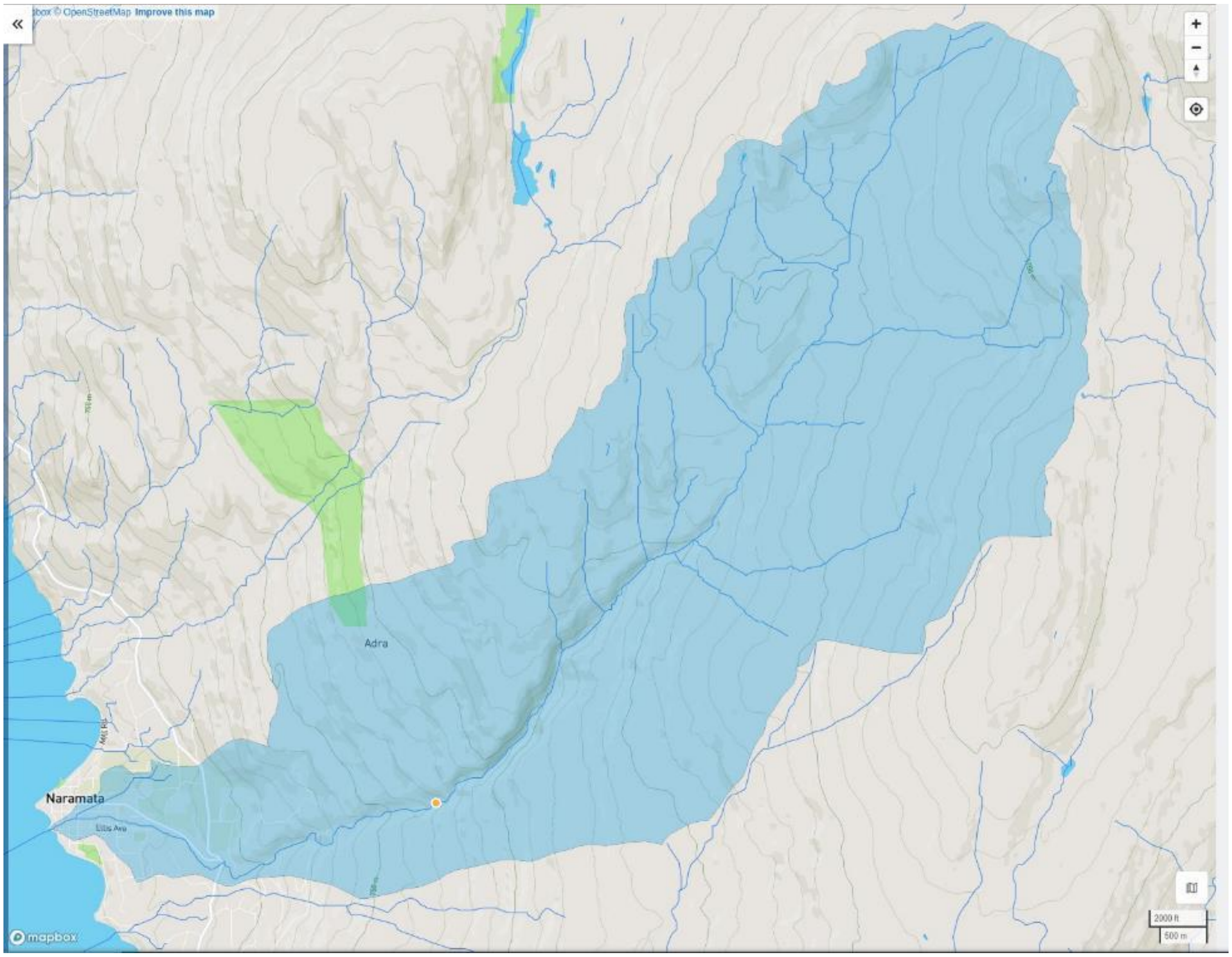
2.2.2 Define working area for the catchment

The Freshwater Atlas datasets and CDEM data files are too large to process all at once. We can speed up calculations and queries by defining a manageable sized "working area".

The working area is found by combining Freshwater Atlas polygons that are associated with the stream (using the FWA_WATERSHED_CODE property), starting from the next downstream tributary of the selected stream (using the LOCAL_WATERSHED_CODE property). Because we start downstream, this will always be an overestimate of the actual upstream catchment area.

Figure 2: Freshwater Atlas Catchment Selection including Downstream Catchment

When selecting FWA fundamental watersheds, both the FWA catchment where the point exists and the next downstream polygon boundary is selected.



2.2.3 Retrieve a pre-processed DEM raster

A DEM raster file is retrieved from Wally covering the working area. This raster has been preprocessed by burning streams using WhiteBoxTools using the FillBurn method described in Lindsay (2016) and Saunders (1999). The purpose of burning streams is to force flow into known, mapped streams (in our case, using the Freshwater Atlas Stream Networks dataset) to correct for any discrepancies between the DEM data and the Freshwater Atlas linework.

The Freshwater Atlas provides the vector stream source (seen below, as applied to the DEM)

Figure 3: Freshwater Atlas Vector Streams overlaid on Raster Image

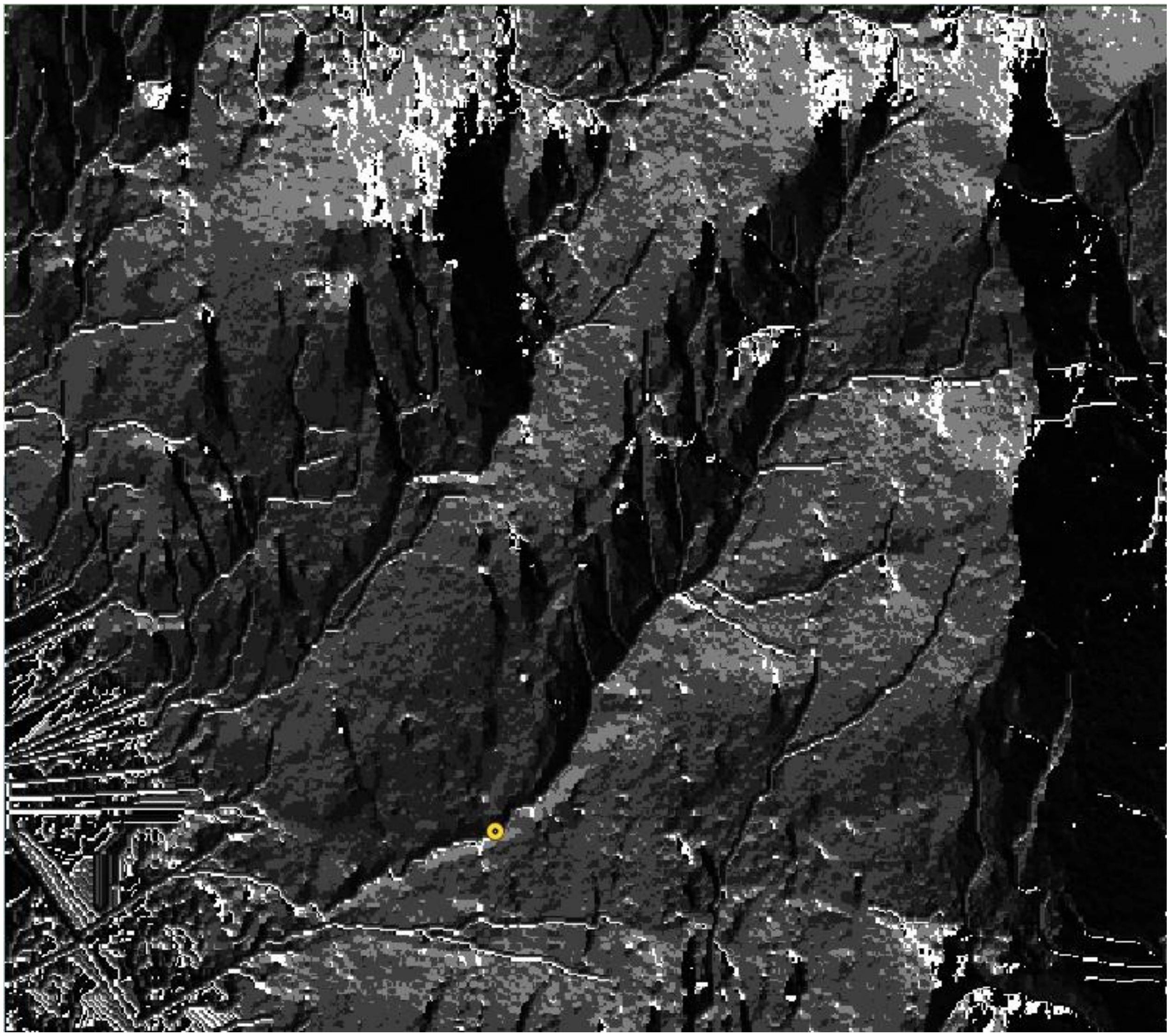
These stream vectors are burned into the underlying DEM to force flowpaths into known streamlines.

2.2.4 Flow Direction raster

A Flow direction (or "pointer") raster is produced using the D8 flow algorithm as implemented in the WhiteboxTools D8Pointer routine.

Figure 4: Flow Direction Raster.

Once streamlines are burned into the DEM, the direction (8 possible) of flow base on slope is calculated for every cell.

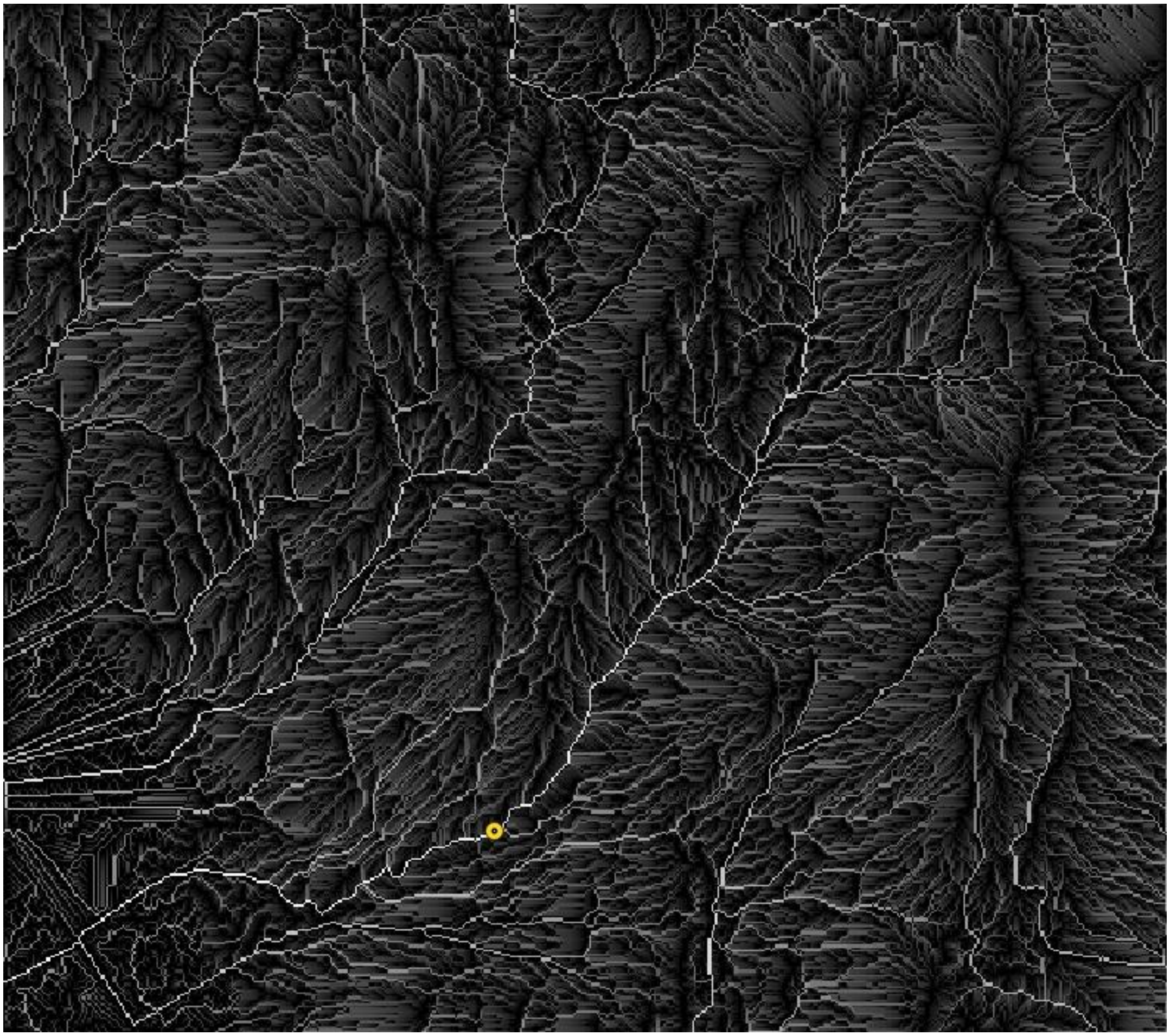


2.2.5 Flow Accumulation raster

A Flow Accumulation raster is produced, also using the D8 algorithm as implemented in the WhiteboxTools D8FlowAccumulation routine.

Figure 5: Flow Accumulation Raster

Using the FDR layer, the number of cells which flow into a downstream cell are added up. Brighter cells have more upstream cells than darker cells, in this image.



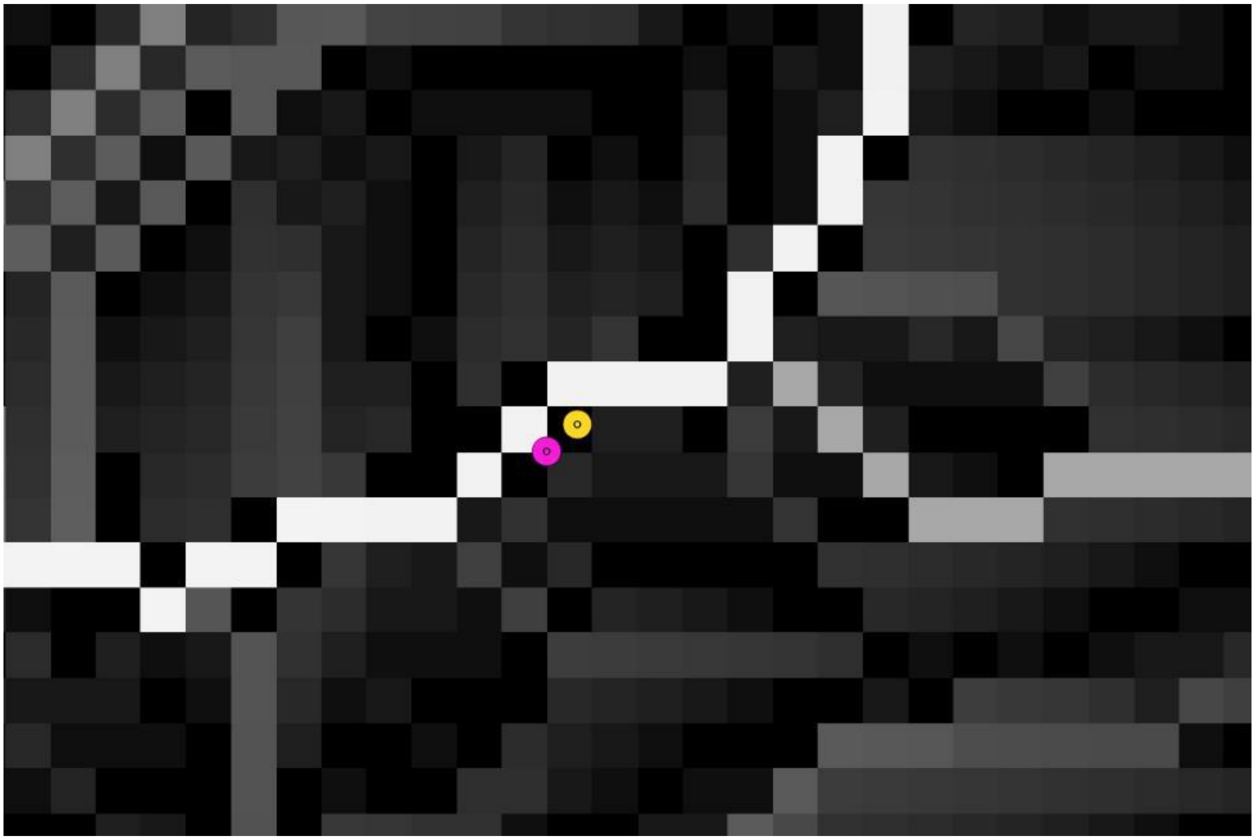
2.2.6 Snap point to Flow Accumulation Streamline

Although the user selected a point on or near a stream, it's important that the DEM delineation function start from a grid cell containing the flow accumulation corresponding to that stream (in other words, it has to hit the exact pixel that the stream flows through). In the below example, the user point (yellow) is corrected to touch the accumulation area (purple) using the SnapPourPoints routine.

Note: the snapped pour point always tends to be downstream of the selected point. More info is at the above link.

Figure 6: Snap to Pour Point

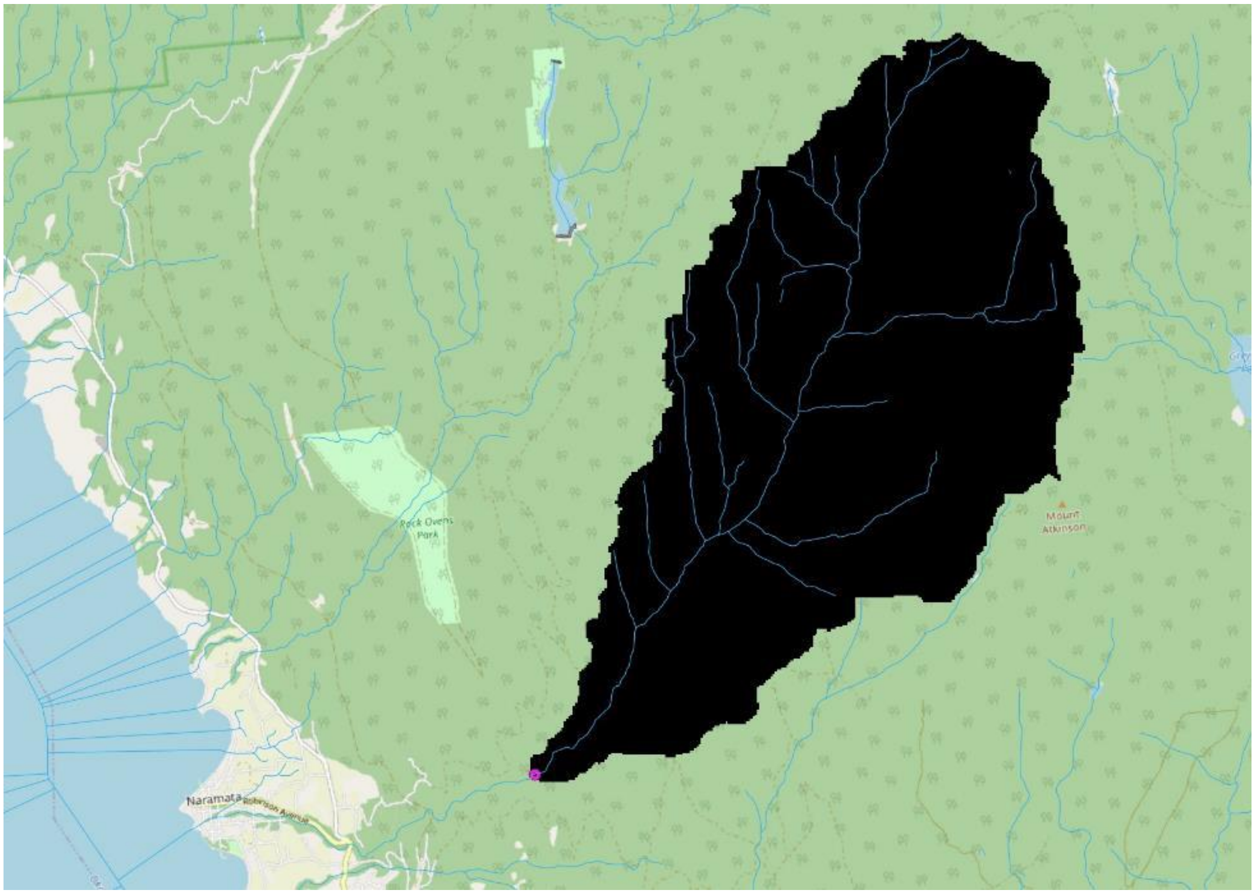
Although every cell is both downstream and upstream from another, the algorithm chooses the highest FAC value within a specified radius to snap to (purple point). This will always be downstream from the arbitrarily chosen point (orange).



2.2.7 Delineate watershed

Using the Flow direction raster and the snapped point, the watershed can be delineated with WhiteboxTools Watershed.

Figure 7: Watershed Delineation

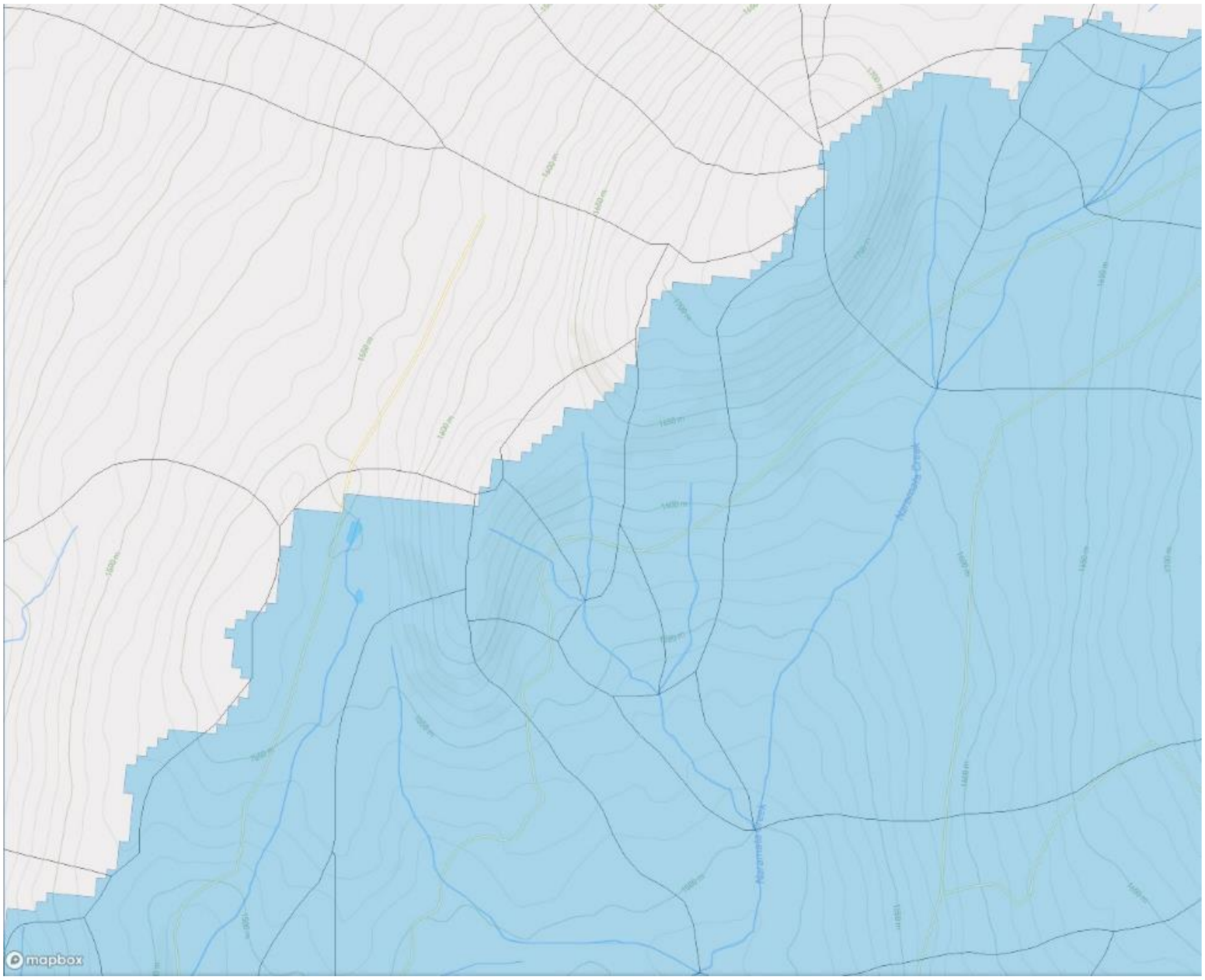


2.2.8 Apply DEM delineated watershed to Freshwater Atlas

The polygon may not correspond exactly to the Freshwater Atlas linework. We want to use the Freshwater Atlas linework everywhere upstream of the point.

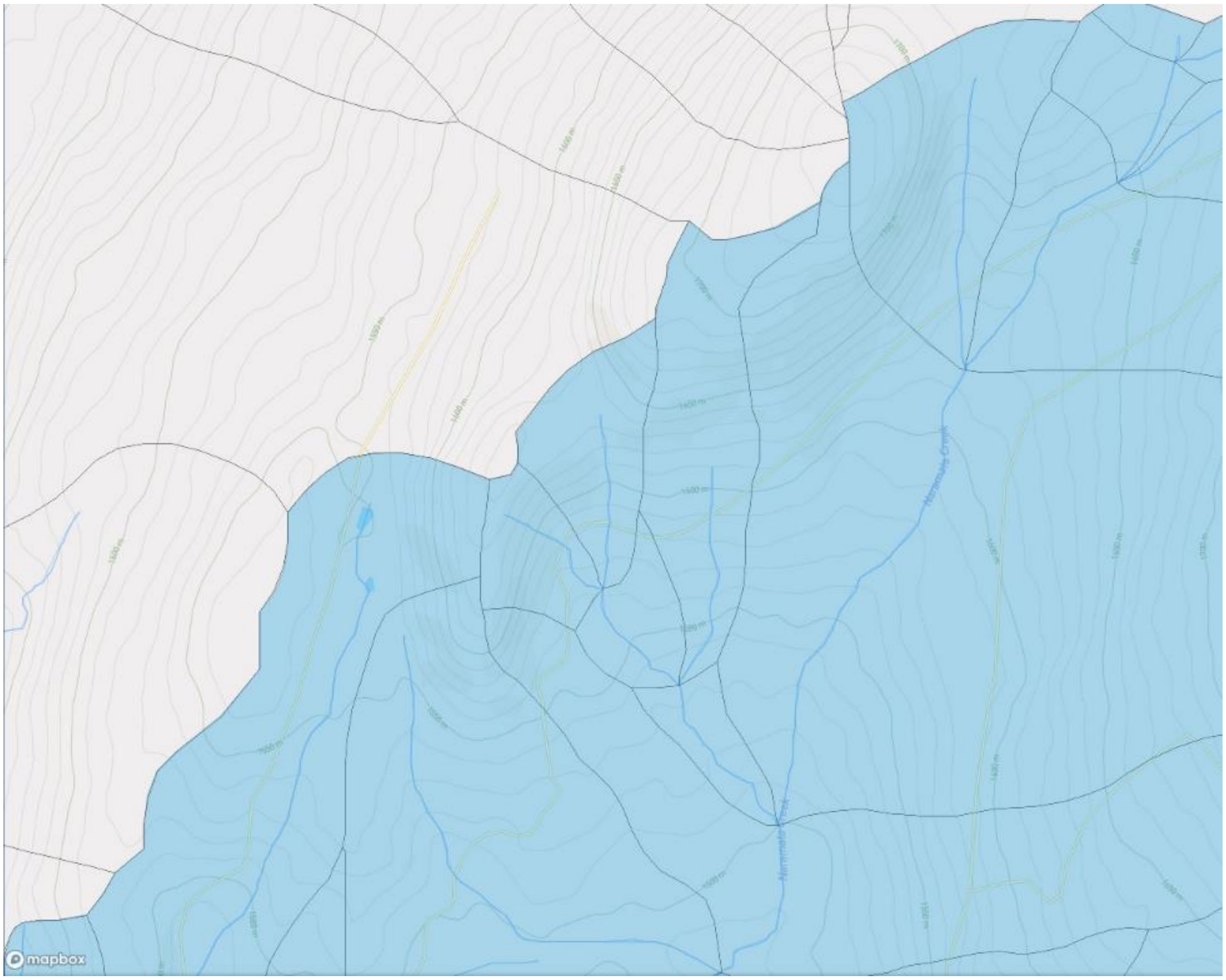
Figure 8: DEM-Based Watershed Boundary Compared to FWA

The fundamental FWA boundaries are shown in gray and Whitebox Tools boundary shown in blue. While the boundaries are close in this example, there are many situations where the two do not agree as well. It's important to use the provincial standard (FWA) in those cases.



To achieve this, we again use the Freshwater Atlas fundamental watersheds, but this time we exclude the polygon that the user's point of interest is within (or is very close to, as some large rivers have several side-by-side polygons covering the river width as well as face unit polygons). We can then fill in the missing area from the point of interest to the first upstream fundamental watershed polygon using the DEM delineated catchment (**note**: need a screenshot showing this "hybrid" watershed clearly).

Figure 9: FWA Boundary

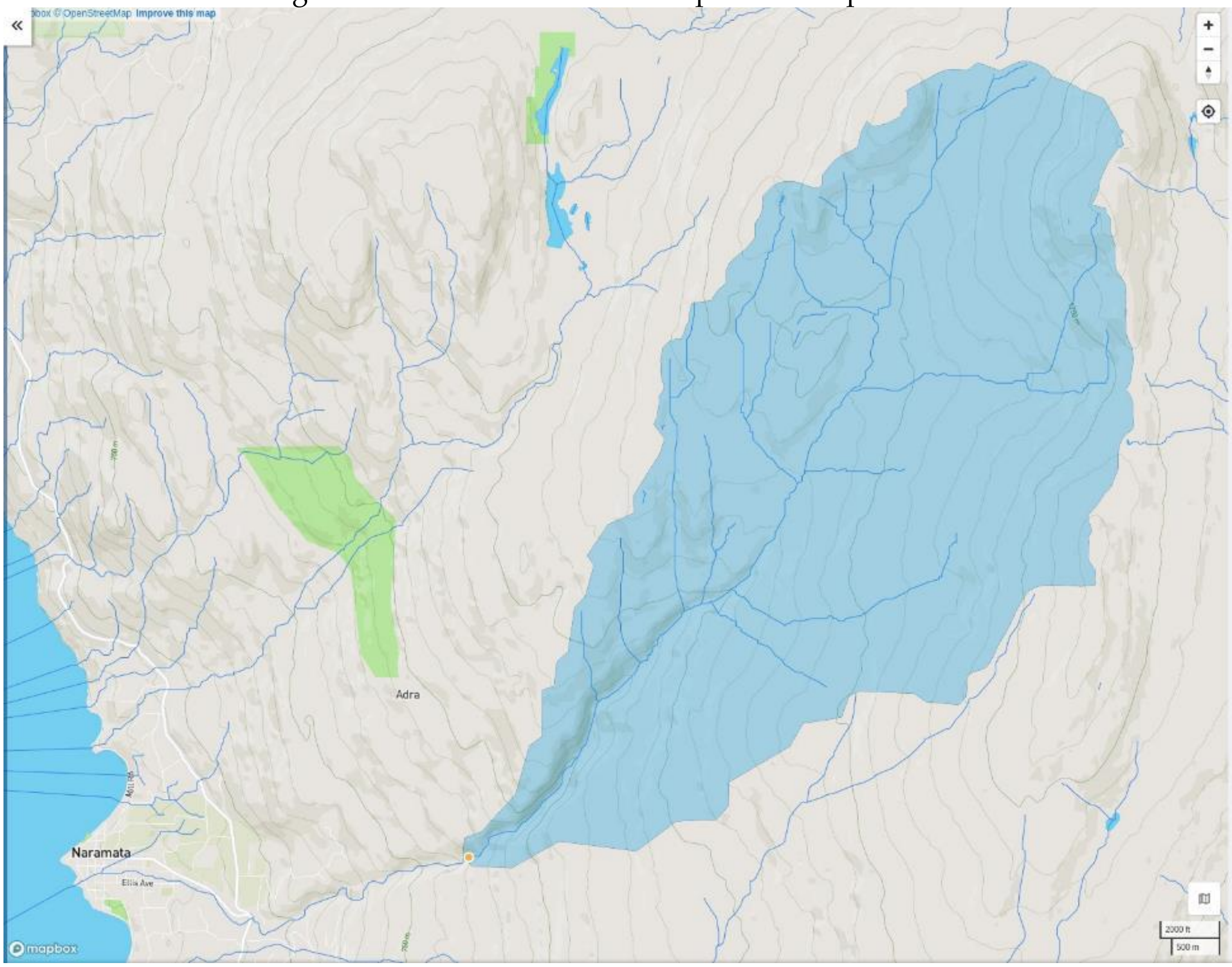


2.2.9 Final result

The final result is the upstream catchment area based on the Freshwater Atlas but refined around the point of interest using the result of the DEM delineation technique.

Figure 10: Hybrid FWA and DEM-Based Watershed Boundary

The final Watershed is based on combining the DEM based boundary near the drainpoint with the upstream FWA boundary. In Wally, we've given the user the option to use any of the 3 outputs generated from the model to explore discrepancies.



This approach is a fast and accurate method to calculate drainage area anywhere in the Province.

2.3 Naturalization/Water License Consideration

Naturalization of long-term flow series was not attempted given the difficulty and complexity of the task. The first step undertaken was to derive all the upstream licenses for the WSC stations (see Section 2.6), then calculate the total gross allocated water, the return flows, and the net allocated water. Two stats were found to be particular useful in flagging/excluding WSC records:

1. the Gross Allocation (disregarding return flows) expressed as %MAD, and
2. the Net Allocation.

We found that by filtering stations by <200%MAD Gross Allocation or Net Allocation = Zero, we could achieve a balance between keeping stations that have MAR and S-

7Q10/MAD close the QA/QC'd values in Obedkoff/Ptolemy/Ahmed, while filtering out stations that did not. In RSEA, we note:

> *"Ahmed and Obedkoff used only Non-Regulated WSC data as indicated in the WSC record. Ahmed states:*
>
> > *The hydrometric stations (data) included in the analyses met the following criteria:*
> >
> > *• natural flow (or flow with minor regulation);*
> > *• minimum 12 years of substantially complete monthly flow data (with a few exceptions); and*
> > *• Measured instantaneous discharge.*
>
> *Dave Hutchinson (2020) provided this definition of regulated: "The record designation Natural (or non-regulated) is applied only if the monthly mean value and/or the maximum instantaneous value is increased or decreased by 10% from that of the natural regime". Based on this definition, we can assume that the flow records used in this report have not been modified by more than 10% of mean monthly flow. If they have been reduced by this much or more, then the model results are conservative (i.e. lower than natural)."*

In the current study, we are not using Ahmed or Obedkoff as training data, and cannot rely on the QA/QC they implied. Instead we have used their studies to ensure our Hydat derived hydro-stats are within a tight error bound to those QA/QC'd values.

We acknowledge that there is work to be done on naturalization. However, we believe the foundation is in place to undertake such work. This first pass at the model is simply meant to flag those WSC records which do not pass the Quality Control filters employed in Obedkoff/Ptolemy/Ahmed.

2.4 Derivation of Long-Term Hydro-stats

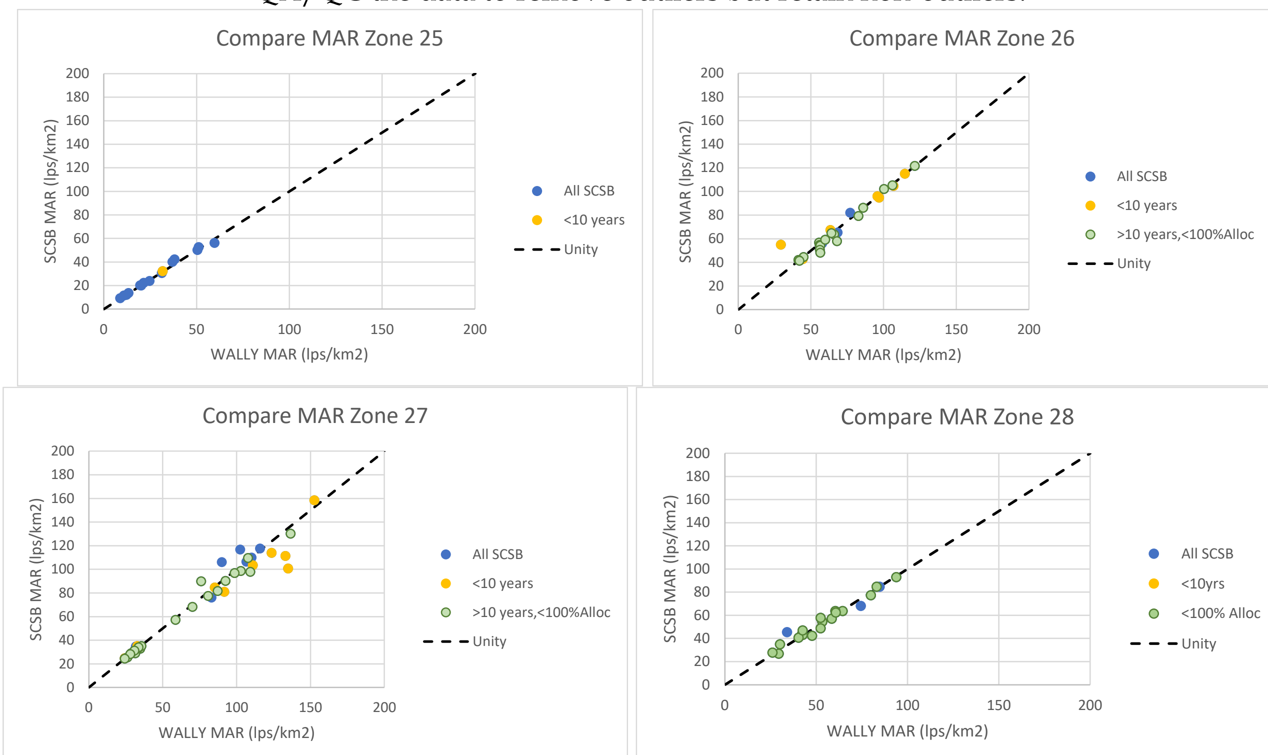
We used the FASSTR library from the BC Government to derive hydro-stats from the Hydat Database.

2.4.1 Mean Annual unit-Runoff (MAR)

The Mean Annual unit-Runoff is the Mean Annual Discharge divided by drainage area, and multiplied by 1000 to get litres/s/km^2. MAR is often presented as mm/year, as it is in Obedkoff (2009) and Ahmed (2015). To go from mm/year to litres/s/km^2, simply divide by 31.536. We compare the derived MAR values in the figures below for several Hydrological Zones considered in SCSB and RSEA (Zones 25, 26, 27, 28).

Figure 11: Comparison Between MAR Derived in SCSB (Obedkoff/Ptolemy) and Wally (Hydat)

Because we are deriving both the WSC Watershed boundaries and the Mean Annual Discharge (MAD) from primary sources, there is QA/QC that needs to be completed. Obedkoff had the highest QA/QC standards (>20 years data, Natural or Naturalized flows) while Ptolemy included many more stations (5<N<20 years data) which is also valuable to consider. Limiting the nYears to >10 years reduces the number of outliers, but also removes non-outliers. Removing those stations that have >100%MAD Gross Allocation also removes some outliers. We aim to find filters to automatically QA/QC the data to remove outliers but retain non-outliers.

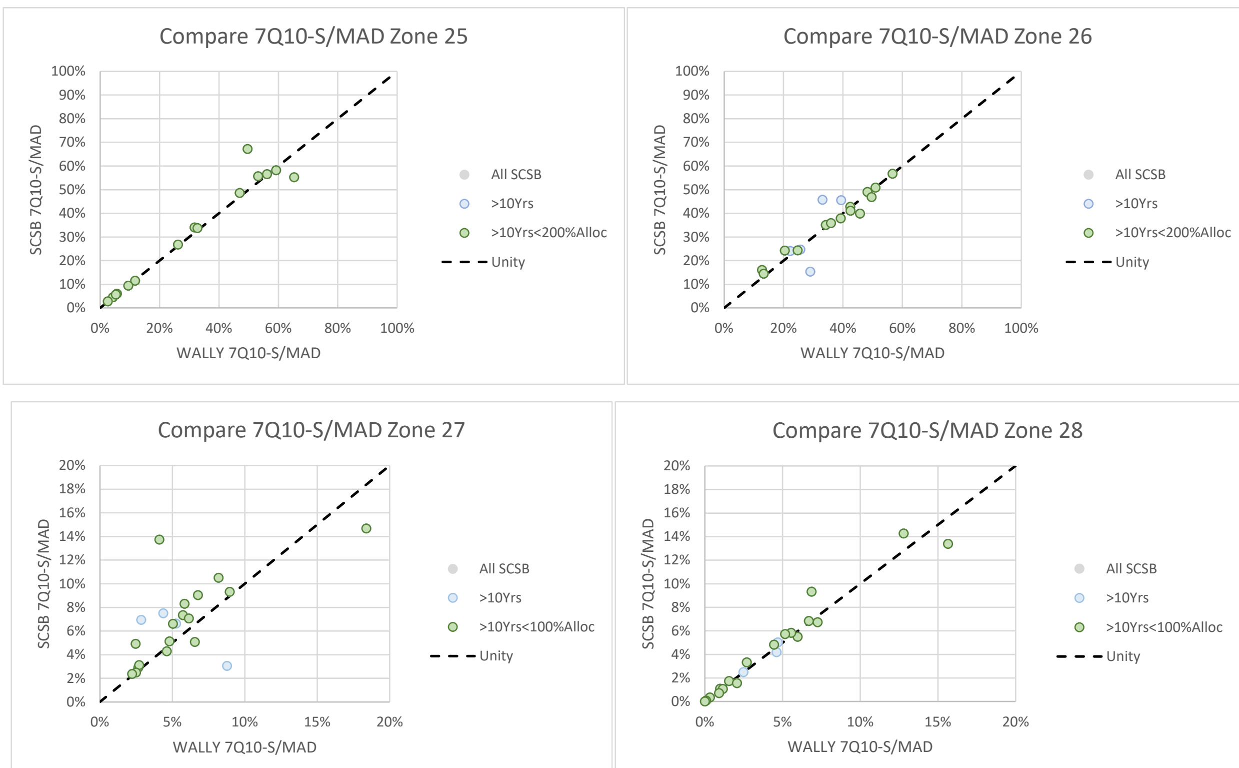


2.4.2 S-7Q10/MAR

The Summer (June-September) 7-day low flow with a 10 year return period (S-7Q10) is calculated from the Hydat database using FASSTR. We then divide by the MAD, and compare to those values from Obedkoff/Ptolemy in SCSB in Figure 12. These figures show that by limiting the minimum number of years to 10 and the %Allocation to <200%MAD the scatter is reduced.

Figure 12: 7Q10-S/MAR Derived in SCSB (Obedkoff/Ptolemy) and Wally (Hydat)

The 7Q10-S measurements from Wally (Hydat-FASSTR) are very close to that derived in Obedkoff, besides a few outliers, in Zone 25 and 26. Investigation into the outliers in Zone 25 suggest that the Wally derived values are correct. There are many more outliers in Zone 27. Note that the scales are smaller. The largest outlier at (4,14) is at Seymour River above Lakehead. SCSB used Ptolemy at this site, and those estimates seem too large i.e. the value from Wally seem correct.



The same exercise was undertaken for the zones in the RSEA study area, Zones 3,4,6,7,8 and 12, with similar results.

2.4.3 A-30Q5

The SCSB and RSEA studies, which use Obedkoff/Ptolemy and Ahmed respectively, did not contain estimates for the Annual 30-day minimum average Q with a 5 year return period (A-30Q5).

2.5 Hydro-stat Modeling

This study employed two independent models to estimate hydro-stats. 1. XGBoost, a Machine Learning framework, and MkMGR, which is the same multi-variate regression model used in SCSB (2016) and RSEA (2020). The rationale for two independent models is as follows:

1. MkMGR has been developed and used to make accurate prediction of hydro-stats in ungauged basins for 5 years and across a large swath (South Coast and Northeast) of the Province. It is well behaved, has defined limits and uncertainty bounds, and is easily reproducible. It serves as a benchmark and reference point to evaluate the Machine Learning approach.
2. While the MkMGR approach is the same as in SCSB and RSEA, this study started from fundamentally raw input datasets, ie Hydat for hydro-stats and DEMs to delineate the WSC training watersheds. In order to properly assess the quality of those training datasets, we needed the insight provided by multiple regression modeling.

Using conventional regression and covariance analysis helped us to

- QA/QC the input training data, as well as identify outliers in the datasets.
- Determine thresholds for QA/QC filters such as number of years of data and water license types and limits.

2.5.1 Modified k-fold Multivariate Geospatial Regression Model (MkMGR)

Using the filters determined in Section 2.4, we retrained the multi-variate regression models using the filtered dataset. For each Hydrological Zone, 30 iterations of a 70-30 Training-Test split was run and the minimum, average, and best R2 was calculated on the Test data. However, in many cases (Zone 2, 4, 5, for example) the N was too small, and the robustness of the model could not be adequately tested against a test set of only 2-3 stations. Therefore, we opted to calculate the R2 on the entire Train+Test dataset. This will necessarily be a higher R2 but will also capture the fit against the entire dataset. This is the same approach used in the SCSB and RSEA and validation results showed good agreement with test data and other metrics.

The chosen model is that which had the highest Minimum R2 of the 30 random iterations. It was never the 7-variable model, i.e. using all geo-stats "over-fit" to the training dataset and gave a poor performance against the test dataset. We noted that the particular model chosen varied from run to run, but always contained key geo-stats, such as precipitation for MAR.

2.5.2 Extreme Gradient Boosting (XGBoost) Machine Learning Model

The machine learning framework used is XGBoost. The Python implementation is used because of its integration with our codebase and its fast execution which allows for quick model building and iteration. The other benefit of using this framework is that it can directly export the saved state of a trained model in the form of a json file, which allows us to load the trained model state later in production for live estimates. Information on the Python implementation we used can be found here:

https://xgboost.readthedocs.io/en/latest/python/index.html

The framework is an ensemble machine learning technique that uses gradient boosting. This technique produces a prediction model from an ensemble of weak prediction models, typically decision trees. More information on gradient boosting can be found here:

https://en.wikipedia.org/wiki/Gradient_boosting

XGBoost stands for extreme gradient boosting, which came from how the framework uses more accurate approximations by using second-order gradients and advanced regularization. The technical paper outlining the framework can be found here:

https://arxiv.org/pdf/1603.02754.pdf

Here is a brief explanation of the model taken from the documentation page.

"**XGBoost** is an optimized distributed gradient boosting library designed to be highly **efficient**, **flexible** and **portable**. It implements machine learning algorithms under the Gradient Boosting framework. XGBoost provides a parallel tree boosting (also known as GBDT, GBM) that solve many data science problems in a fast and accurate way. The same code runs on major distributed environment (Hadoop, SGE, MPI) and can solve problems beyond billions of examples."

XGBoost was developed by Tianqu Chen and Carlos Guestrin.

https://tqchen.com

https://homes.cs.washington.edu/~guestrin/

2.6 Assessing Upstream Water Demand

(This section written by Christina Metherall)

The Fathom team provided guidance in the assessment of upstream water demand, including:

1. **Input on the utilization of available datasets for water demand modelling**

Guidance was provided for the two different types of types of authorizations:

A. Water Rights License data, available in the 'Water Rights Licenses – Public' dataset from the BC Data Catalogue.[1]
B. Short-term use approval (STUA) data, available from two sources:

[1] ttps://catalogue.data.gov.bc.ca/dataset/water-rights-licences-public

- Water approvals issued by the MFLNRORD, as shown in the 'Water Approval Points' dataset available on the BC Data Catalogue[2],
- Water approvals issued by the OGC as shown in the 'Short Term Use of Water (Permitted)' available on the BC Oil and Gas Commission Open Data Portal.[3]

2. Input on monthly variations in water use and return flows, by water license purpose
This guidance was provided in the form of *monthly allocation coefficients* and *monthly return coefficients*. Monthly allocation coefficients represent the fraction of flow being consumed, and monthly return coefficients represent the fraction of flow being returned to the river. Coefficients were assigned based on the license purpose. These could then be used to calculate net upstream withdrawals by month.

By improving the understanding of the relationship between supply and demand, the Wally tool supports water allocation staff in make making robust, defensible decisions that reduce the risk to environmental health, the water supply of existing users, and the potential for water use conflicts. The assessment of upstream demand also supports hydrologic modelling activities by identifying watersheds where there is significant alteration of flow, and data from WSC stations may be less suitable for modelling natural flows.

2.6.1 Approach

The following actions were taken to support this work:

1) **Initial project meeting:** To begin, the Fathom team met with Wally developers and MFLNRORD MOE staff to better understand the state of water demand modelling in Wally at the time of project initiation. In this meeting, the following was found:
    a) The Wally development team had made an effort to incorporate water demand modelling work from the RSEA and SCSB projects into the Wally tool. However, it was not unclear if team correctly translated the approach utilized in the SCSB and RSEA projects into the Wally context. In addition, the SCSB and RSEA projects used slightly different approaches to demand modelling, and it was unclear if those differences had been considered.
    b) It was also unclear if the water allocation and return coefficients utilized in the SCSB and RSEA projects could be used on a Province-wide basis in Wally. Further work was needed to assess this.
    c) Existing demand modeling in Wally did not differentiate between consumptive and non-consumptive water use and return flows to the stream were not considered. Further work was needed to differentiate between consumptive and non-consumptive uses and incorporate returns flows. This was identified as a critical area for improvement.

[2] https://catalogue.data.gov.bc.ca/dataset/water-approval-points

[3] https://data-bcogc.opendata.arcgis.com/datasets/fcc52c0cfb3e4bffb20518880ec36fd0_0

In this meeting, the Fathom team also asked questions to better understand the water demand modelling approach used in Wally, so that project deliverables could be provided in a format that would be compatible with the existing Wally water demand modelling tool.

2) **Review draft monthly allocation coefficients:** To better understand the work to-date, the team reviewed the draft monthly allocation coefficients that had been developed by the Wally development team, based on the RSEA and SCSB projects. It was discovered that the allocation coefficients had not been correctly translated from the SCSB and RSEA projects, in part due to small errors, and in part, because the different approaches to water demand modelling used in each project had not been considered.

   In addition, there were also many water license purposes for which there had not been water allocation or return coefficients provided in the RSEA and SCSB projects, and in the draft Wally table, default coefficients had been assigned for these purposes. The reason that coefficients had not been assigned for these purposes in the RSEA and SCSB projects is that these projects had very focused study areas in northeast and southwest BC, and all not all provincial water use purposes existed in these study areas. The provincial water license dataset contains a much broader range of water licenses purposes (e.g., there are certain types of mining that only occur in northwest or southeast BC) and so further work was recommended to:

   a) Correctly assign the water allocation and return coefficients from the RSEA and SCSB projects, considering the varying approaches utilized in those projects.
   b) Assess whether these allocation and return coefficients could be applied provincially (e.g., Could the coefficients and return flows used for irrigation in southwest BC be applied Province-wide in regions with different climates?).
   c) Determine the most appropriate allocation and return coefficients for water license purposes that were not included in the RSEA and SCSB projects.

3) **Conduct research on water allocation and return coefficients:** Next, research was conducted to assign/update water allocation and return coefficients. Details on the approach for this work are provided below, under '*Assigning Monthly Water Allocation and Return Coefficients*'.
4) **Summarize approach to utilization of datasets:** Then monthly water allocation and return coefficients were provided, along with a summary of the recommended approach to utilizing water demand datasets. This is described in further detail under '*Using Spatial Datasets to Assess Net Monthly Water Demand*'.
5) **Recommendations:** Finally, recommendations were provided for consideration by water managers, to support future water demand modelling efforts. These are described in '*Recommendations'.*

2.6.1.1 Assigning Monthly Water Allocation and Return Coefficients

To assign monthly allocation and return coefficients by water license purpose, the following steps were taken:

- Review prior water supply and demand modelling work, and, where appropriate, update or assign, monthly allocation and return coefficients. Materials reviewed included:
  - The Tsolum Agricultural Watershed Plan: Phase One (Metherall, 2019): in which 10 years of municipal metered data from the City of Nanaimo was utilized to develop estimates of monthly allocation coefficients for different types of land uses.
  - The Delta's Future Agricultural Water Supply and Demand (Integrated Sustainability, 2020 [water demand work completed by Elucidate Consulting as a sub-contract]): in which metered data was used to develop monthly coefficients of use for greenhouses. In addition, the Agricultural Water Demand Model (AWDM) was run on a monthly basis to obtain estimates of monthly variations in use for field crop and nursery irrigation.
  - The Okanagan Water Supply and Demand Project - Okanagan Water Management & Use Data Report (Dobson Engineering, 2008): in which monthly water use data for several municipalities was provided, identifying monthly variations in use.
  - Koksilah Water Supply Feasibility Assessment (Metherall, 2021): in which BC Agriculture Water Calculator runs were utilized to estimate monthly variations in irrigation demand.
  - Tsolum River Agricultural Watershed Plan: Phase Two (Metherall, 2021): in which results of AWDM models runs were used to obtain estimates of monthly variations in use.
  - Okanagan Water Tool Plan (OWAT) (Western Water and Associates, 2014): in which recommendations were provided on the use of water demand modelling to support water allocation decisions. It was observed that many of the recommendations in this report are proposed to be implemented in Wally.
  - Sunshine Coast Regional District Water Demand Analysis (Integrated Sustainability, 2018): in which water demand details are provided monthly, for different water use purposes.

When/if assigning coefficients from prior work, additional research was done, and professional judgement applied, to assess the applicability of the coefficient on a Province-wide basis. See examples #1 and #2 below.

Example #1 – Irrigation Purpose:

When estimating coefficients for irrigation use, the following approach was taken:

- Monthly water use coefficients from prior projects in three areas of the Province with a relatively high irrigation demand were averaged. These areas include: the Okanagan, Fraser Valley, and Vancouver Island.
- Subject matter experts were then consulted to provide input on whether these averages should be updated prior to use on a provincial scale. The values were updated to address the feedback (personal communications, Stephanie Tam, Ted

van der Gulik, July 9, 2021). The subject matter experts noted that it is difficult to provide monthly coefficients of water demand for irrigation on a provincial basis and suggested that local data is used wherever possible, and particularly in areas of potential water scarcity/stress.

Example #2 – Waterworks Purpose:

When updating coefficients for the Waterworks purpose water demand coefficients metered data was considered from different regions. This is because the largest use of water for a Waterworks purpose is for summer irrigation, and so the way in which the water demand fluctuates monthly may vary by climate. Metered data was reviewed from communities on Vancouver Island, the Okanagan Valley, and the Sunshine Coast, to better understand how water demand varies monthly and professional judgement applied to develop estimates on a monthly basis that would be suitable Province-wide.

- In cases where there was still some uncertainty regarding the most suitable monthly allocation and return coefficients, interviews were conducted with subject matter experts, representative water license users, and water authorizations staff. Further details are on these groups are provided below. A list of all ***identified*** interview contacts is provided in Table 9.
  - *Subject matter experts:* In cases where it was unclear how water use varied for a particular water license purpose, subject matter experts were contacted. An example of a subject matter expert is the Ministry of Agriculture, Fisheries, and Foods (MAFF) Water Resource Engineer (Stephanie Tam), who, with Ted van der Gulik (previous MAFF Water Resource Engineer), provided input on water use and return coefficients for several agricultural purposes (Irrigation, Crop Harvesting, Crop Protection, Compost, Flood Harvesting, Crop Suppression).
  - *Water license holders:* In cases where subject matter experts were not available, representative water users were contacted. Representative users were identified using the water license dataset. To select representative users, the water licenses for a select purpose were sorted by size, and both a large and small water user were contacted. If it was difficult to find a respondent for a particular type of water use, then larger users were prioritized, as larger users have the potential to create a greater impact. Examples of water license holders contacted include a Hatchery Manager (Jordan Uittenbogaard, Tenderfoot Hatchery) who provided guidance on water allocations and returns for Hatcheries purposes, and Land Based Salmon Aquaculture Specialist (Gary Robinson, Kuterra), who provided guidance on water use for Ponds and Aquaculture purposes. When interviewing users, the following questions were asked:
    - Does your water use fluctuate throughout the year? If so, approximately what percentage is used each month?

   - How much of the water that is used do you think goes back to the environment? Can you provide an estimate monthly? Also, when does it go back? Is there a delay in when that water is returned, (e.g., settling ponds)?
   - Do you think your use is typical for the industry? Province-wide? If you understand use in other areas, can you comment on how it might vary in other regions of the Province?

  When contacting water license holders, the majority of respondents requested to remain anonymous. Many users were hesitant to share the details of their water use with the Province. Also, in large organizations, the person who best understood how water use varied throughout the year, was typically an operational staff person, who did not feel that they had the decision-making authority to share details about their company with the Province. These interviewees had an in-depth understanding of water use in their industry and provided invaluable feedback. For this reason, most interviews with water license holders were recorded on an anonymous basis.

- *Water authorizations staff*: In cases where it was difficult to contact a subject matter expert or a representative user for a particular water license purpose, a regional water authorizations specialist was contacted. Suitable water authorization staff were identified, by identifying the region where the largest number of a particular water use purpose existed, and then calling authorization staff to ask who had the most tenure or experience reviewing applications for that purpose. An example of a water authorizations staff person is Jeremy Roscoe, based out of Smithers, who had significant experience with water use for mining and industrial purposes and provided input on the variations in water use for different mining purposes. When regional water authorizations staff were contacted, they were asked to comment on the applicability of their feedback to other regions of the Province and if they felt they could not comment on water use variations for that purpose Province-wide, additional were contacted in other regions of the Province.

Based on the above research, water authorization allocation and coefficient purposes were updated. Results are shown in Tables and 8 and 9.

Note: If the water license was in m3/day or m3/s, the allocation coefficients was kept as 1. In cases where the use was unlikely to occur in certain months (e.g., Crop Suppression), then the allocation was left at 0 in those months. However, in cases where the water use was predominantly in the summer, but there was a chance that use may occur in a month and the water licenses for that purpose were typically for the full year (e.g., Road Maintenance), the coefficient was left as 1.

It is important to note that the coefficients and water demand calculations provide a very coarse estimate of water use. In any areas of potential stress, further work is required to assess demand and risk to environmental health.

2.6.1.2 Utilizing Spatial Datasets to Assess Net Monthly Water Demand

The Fathom team provided guidance on the approach to utilizing available datasets for modelling water demand. Guidance was provided separately for:

1. Water Rights License data[4]
2. Short-term use approval (STUA) data:
    a. Water approvals issued by the MFLNRORD[5],
    b. Water approvals issued by the OGC[6]

2.6.1.2.1 Estimating Net Monthly Water Demand Using Water Rights License Dataset

The following steps were recommended when utilizing water rights license data to estimate monthly water use on an instantaneous basis:[7]

1. Select surface water licenses (consideration of groundwater licenses recommended as a next step).
2. Check quantity flag and adjust volume accordingly.[8]
3. Select licenses where the License Status is "Current" or "Pending".

1) Convert water license quantity into a standard flow rate units of m^3/s (referred to as: *Q_M3S*).
2) Categorize water licenses into consumptive and non-consumptive based on licensed purpose (see Table 7 : Monthly Allocation Coefficients, Table 9Monthly Return Coefficients)
3) For each water license, assign monthly allocation and return coefficients for each month of the year, based on license purpose and units (see Table: Monthly Allocation Coefficients, Monthly Return Coefficients).
4) Calculate the 'instantaneous' *mean monthly allocation* for each month, expressed in m3/s for each license, by multiplying *Q_M3S* by monthly allocation coefficient.
5) Identify the 'instantaneous' *mean monthly return* for each month, expressed in m3/s.
6) Identify the 'instantaneous' *mean monthly **net** allocation* by subtracting the *mean monthly return* from the *mean monthly allocation*.

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[4] ttps://catalogue.data.gov.bc.ca/dataset/water-rights-licences-public
[5] https://catalogue.data.gov.bc.ca/dataset/water-approval-points
[6] https://data-bcogc.opendata.arcgis.com/datasets/fcc52c0cfb3e4bffb20518880ec36fd0_0
[7] MFLNRORD/MOE staff indicated that steps 1 and 2 were already occurring in Wally.
[8] The 'Quantity Flag' attribute which identifies how the total quantity is assigned across multiple points of diversion for a particular licence and purpose use (e.g. T – Total demand for purpose, one POD; M - Maximum licensed demand for purpose, multiple PODs, quantity at each POD unknown; D – Multiple PODs for purpose, quantities at each are known, PODs on different aquifers; P - Multiple PWDs for purpose, quantities at each are known, PODs on same aquifer). To adjust the Quantity based on the Quantity Flag, a Quantity_Divisor can be calculated as follows: T: Quantity_Divisor=1, M: Quantity_Divisor=the count of the number of PODs for consumptive water license purposes with the same license number, P: Quantity_Divisor=1, D: Quantity_Divisor=1. The adjusted quantity at each POD was calculated as: Adjusted_Quantity = Quantity/Quantity_Divisor. The Adjusted_Quantity can be converted to standard units by multiplying the adjusted volume allocated ("Adjusted_Quantity") by a unit conversion factor (based on the "Units" field) to convert the volume allocated to m^3/s.

7) Once all water licenses are expressed as a mean monthly allocation in m3/s, sum upstream licenses.

The following suggestions were also provided:

- When matching water license purposes, match by number, not name, because there are several misspellings of the names in the dataset.
- Where a water license cannot be matched with the allocation or return coefficient table (e.g., no matching purpose and unit combo), assume allocation coefficient of 1, return coefficient of 0.

2.6.1.2.2 Estimating Net Monthly Water Demand Using Short Term Water Use Approval (STUA) Datasets

The following steps were suggested to be taken when utilizing STUA data from MFLNRORD and OGC sources to estimate monthly water use on an instantaneous basis:[9]

1) Select current allocations:
   - MFLNRORD Short Term: Select approvals where APP_STATUS=Current
   - OGC Short Term: Select approvals where STATUS = Active
2) Select surface water sources:
   - MFLNRORD Short Term: Select all approvals as there is no attribute to differentiate groundwater from surface water sources. The 'Source' attribute is blank for many records and the remainder appear to be surface water sources (it is reasonable to assume that most are surface water sources, as it makes less sense to drill a well for short-term use).
   - OGC Short Term: Select approvals where WATER_SO_1= Lake/Pond OR WATER_SO_1= Water Source Dugout OR WATER_SO_1= Water Source Dugout= Stream/River.
3) Convert allocation quantities to a standard flow rate units of m^3/s
   - MFLNRORD Short Term: This dataset shows allocated volume (called QUANTITY) in units of m^3/s or m3/day. There is also a QTY_MAX field. In all cases, use the max of QTY_MAX and QUANTITY, converted to m^3/s. (There are several records that have a quantity of 0, but a QTY_MAX that is non-zero. In these cases, use the QTY_MAX.)

[9] MFLNRORD/MOE staff indicated that steps 1 and 2 were already occurring in Wally.

OGC Short Term: This dataset provides allocated volume using two fields: Approved Total Volume and Approved Volume per Day. Where an Approved Volume per Day value is available, then the m^3/s value is calculated as the Volume per Day divided by the number of seconds in a day. In cases where an Approved Volume per Day is not available (e.g., records where the water source is a 'dugout' or 'storage location'), then the m^3/s could be calculated as the Approved Total Volume multiplied by a monthly coefficient. Proposed monthly coefficients are shown in the bottom row of the allocation coefficient table and are based on monthly flows from the RSEA project/study area. It was assumed that it was reasonable to apply to these coefficients to the full dataset, because at this time, records are primarily in the RSEA study area, as shown in Figure 35.

4) Utilize monthly allocation and return coefficients to consider consumptive vs. non-consumptive use. Water purpose categories (PURP_DESC) only exist for OGC STUs. They do not exist for MFLNRORD STUs, and so the category 'Unspecified' can be used.

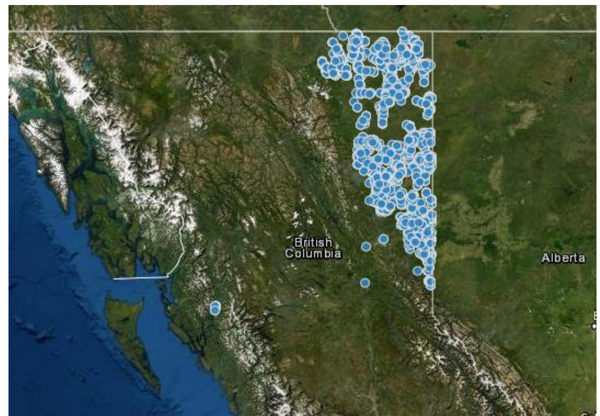


Figure 35: Locations of current active OGC short-term use approvals where the water source is a dugout (storage locations are also primarily in NE BC).

Note: EFN restrictions may be present for some short-term use approvals but are not considered, as the information is not available in the datasets.

3 RESULTS AND DISCUSSION

We have not done significant validation of these datasets for Hydrological Zones outside of SCSB and RSEA study zones. Much of the time on this project was used on QA/QC of the WSC data and deriving geospatial data for input to the models. It must be emphasized how valuable and powerful this dataset is. This dataset alone is a significant achievement of the project and should be made available widely to academia and consulting alike in order to reduce duplication of effort provincewide.

3.1 Hydro-stat Modeling

Two modeling approaches were employed in this study, MkMGR described in Section 2.5.1 and XGBoost described in Section 2.5.2. MkMGR is a modified multivariate, geospatial regression model used in SCSB and RSEA; XGBoost is a new approach to hydrological modeling

Once the best model is chosen using the MkMGR algorithm described in Section2.5.1, i.e. the Geospatial combination that results in the highest Minimum R2, then it is retrained will all available data. As discussed in SCSB and RSEA, this avoids the pitfalls of an overfit model, quantifies the predictive power of the model on test data, but also results in the best model fit.

We have not done significant validation of these datasets for Hydrological Zones outside of SCSB and RSEA study zones. Much of the time on this project was used on QA/QC of the WSC data and deriving geospatial data for input to the models.

In each summary table, we show the MkMGR model for each HZ for a particular hydro-stat. In addition, we've also added two new stats to every model: AVG and STDEV. This is to give the user a sense of the average value of the hydro-stat and the natural standard deviation of the value within the zone. Compare the STDEV to the STEYX value in each model to determine the improvement of the model over simply assuming the AVG value and STDEV within a zone. The reduction in uncertainty of the hydro-stat is directly proportional to the strength of the correlation, and hence the R^2 value. The columns STEYX% and STDEV% convert these values to % of the AVG and are colour coded to show largest (Red) to lowest (Green).

Also note that, based on the work done in RSEA, we've combined the WSC stations in Zones 7,11,12 to increase the sample size in those zones. We expect other Zones can be combined but have not done that analysis.

It should be noted that an effort was made to reconcile the training datasets between Wally, RSEA and SCSB. They remain different for the time being for 3 main reasons

- RSEA and SCSB use Ahmed, Obedkoff/Ptolemy respectively and these authors drew on hydrometric stations from outside WSC, such as BCHydro. They also used apriori knowledge to extend the length of record of some dataset.

- Ahmed (RSEA) was compiled in 2015 and Obedkoff in 2000. Hydat (2021) has an additional 5 and 21 years respectively, and therefore many more long-term (>10years) stations to use in the analysis.
- In RSEA and SCSB, the centroid of the watershed was used to assign a WSC record to HZ. Although it was requested in the current study, we ran out of time before it could be implemented. Therefore, the HZ used in this study is based on the Lat and Lon of the station, which doesn't necessarily represent the bulk of its catchment.
- In RSEA, WSC stations in YT and AB were used to increase the training size for HZ that border those regions. Again, time did not allow this improvement in the current study.

3.1.1 MkMGR Results

Previous studies (SCSB, RSEA) employed a small degree of supervision to maximize both average R2 and minimum R2, as well as retain consistency in the model variables, when results were close. MkMGR was formalized in this study; the current implementation only takes the model with the highest minimum R2. This is a leaner, meaner MkMGR, as depicted in Figure 13.

Figure 13: Artist's Rendition of MkMGR (by Noah Carson)

3.1.1.1 MkMGR for Mean Annual unit-Runoff (MAR)

Modeling of MAR is typically more accurate than other hydro-stats given the large variance within zones (see Table 1, last column) and the predictive power of the geospatial stats. A MkMGR model is generated for each HZ independently. All results have been merged and shown in Figure 14.

These estimates are based on the models in Table 1. Unlike in SCSB and RSEA, we do not present all models for a given Zone within a table. Because we have not had the time to model all hydro-stats, we have chosen to focus only on a few for all HZ within the Province, presented in each table.

We note in this table a few observations

- The "Count" row at the bottom indicates relative importance of a geospatial stat for the particular hydro-stat. In the case of MAR, those important Geospatial stats are Annual Precipitation, Slope, Glacier, PET, and Median Elevation. DA and SolExp do not make much impact.
- The STEYX% is always better than the STDEV%.
- The number of variables of the best model is always less than 7 (number of Geospatial stats) and usually more than 1.
- Where the numVariables is 1, it's usually Precip or Slope, which makes sense (Precip and Slope are highly correlated (SCSB)), except in Zone 9 it is PET. Looking at PET vs MAR in
- The R2 for Zone 6 is very high, R2 of 100%. Shown in Figure 15, this model used 3 variables, Glacier, Median Elevation, and PET, but with only 6 samples. Comparing this to RSEA, which used 10 samples, it also used PET, but SolExp and Precip and achieved an R2 of 0.83. We recommend finding the missing 3 WSC stations in future work.

Figure 14: MAR Derived using MkMGR for all HZ in BC

This figure shows MAR measurements from FASSTR for all 534 WSC stations in the Province (Grey) and filtered 482 (blue). The slope of 0.97 is partly a function of the 0.91 intercept. If a Zero intercept is forced, the slope is 0.98 and R2 is 0.98.

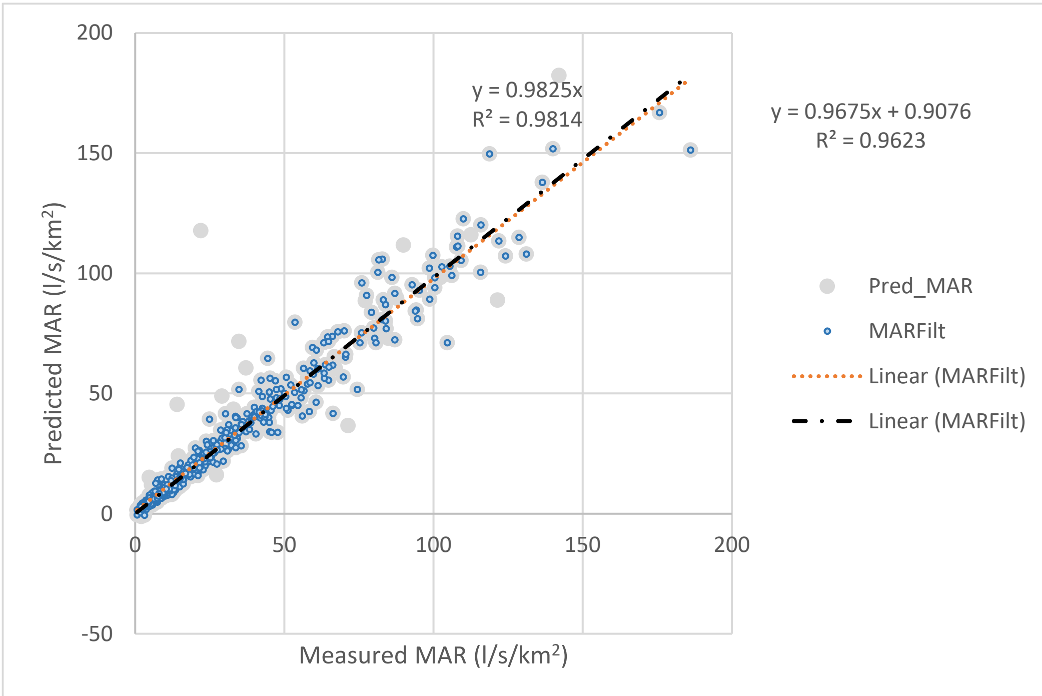


Figure 15: MAR Estimate for Zone 6

This figure shows how tight the estimate of MAR is in Zone 6, but using 3 variables (Glacier, Median Elevation and PET) on 6 samples.

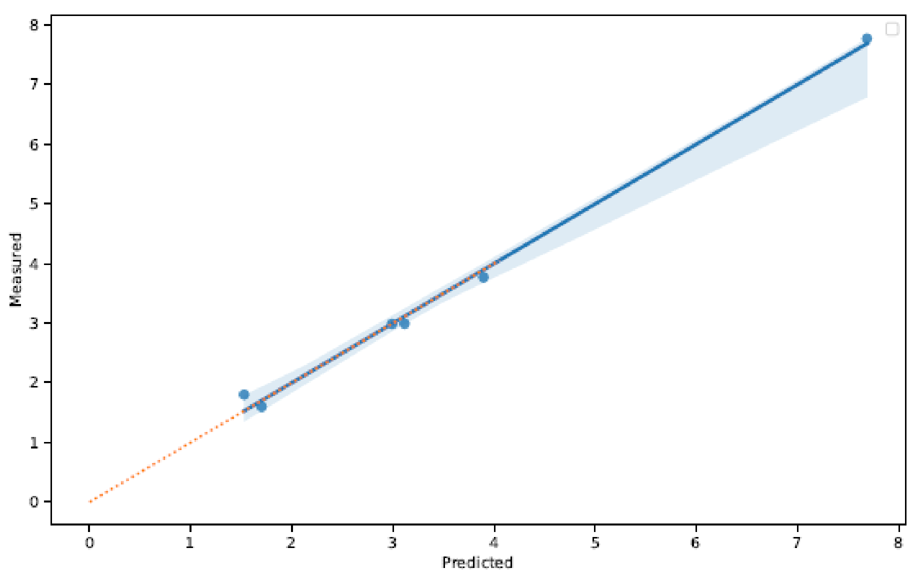
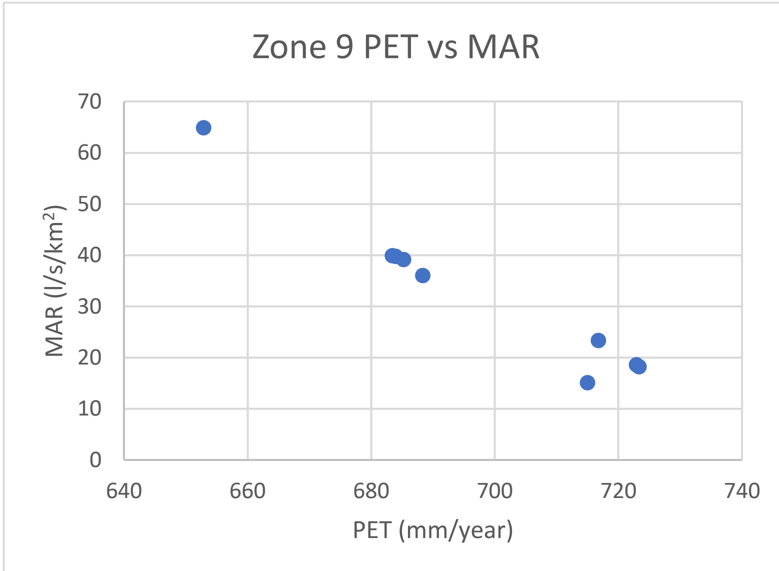


Figure 16: MAR vs PET for Zone 9

This figure shows how highly correlated MAR is to PET in Zone 9. Examination of the HZ again indicates that both PET and Precipitation are highly correlated in this Zone. Probably with more data, Precipitation would become the most important predictor.



3.1.1.2 MkMGR for S-7Q10/MAD

Modeling of the Summer (June-September) 7-day 10 year return period flow statistic has been done in SCSV and RSEA primarily because this stat was included in Obedkoff (2000) and Ahmed (2015). Others have suggested/requested that 30Q5 be modeled as a better estimate of low flows for licensing purposes. We have modeled Annual 30Q5 to meet this request.

We divide by MAD in order to distill the finer features of the dataset. Because we have already modeled MAD (i.e. MAR*Drainage Area) for each HZ, these models can focus more on other factors besides magnitude.

S-7Q10/MAD typically has more unexplained variance than other hydro-stats (except in Zones 2, 3, 5, 18, 25, and 26). For example, in Table 1, the STEYX% in MAR ranges from ±5% to ±27%, but the S-7Q10/MAD STEYX% in Table 2 ranges from ±9% to ±106%. Also note that the lower the S-7Q10/MAD, often the higher the STEYX%. This can partly be explained by the difficulty in measuring very low flows, ie. getting to site during the extreme event, but also a changing hydraulic control at lower flows. The same is true for A-30Q5/MAD, but the latter includes winter low flows, which are often under ice in northern climes, and present an even greater challenge.

A MkMGR model is generated for each HZ independently. All results have been merged and shown in Figure 17 based on the models in Table 2.

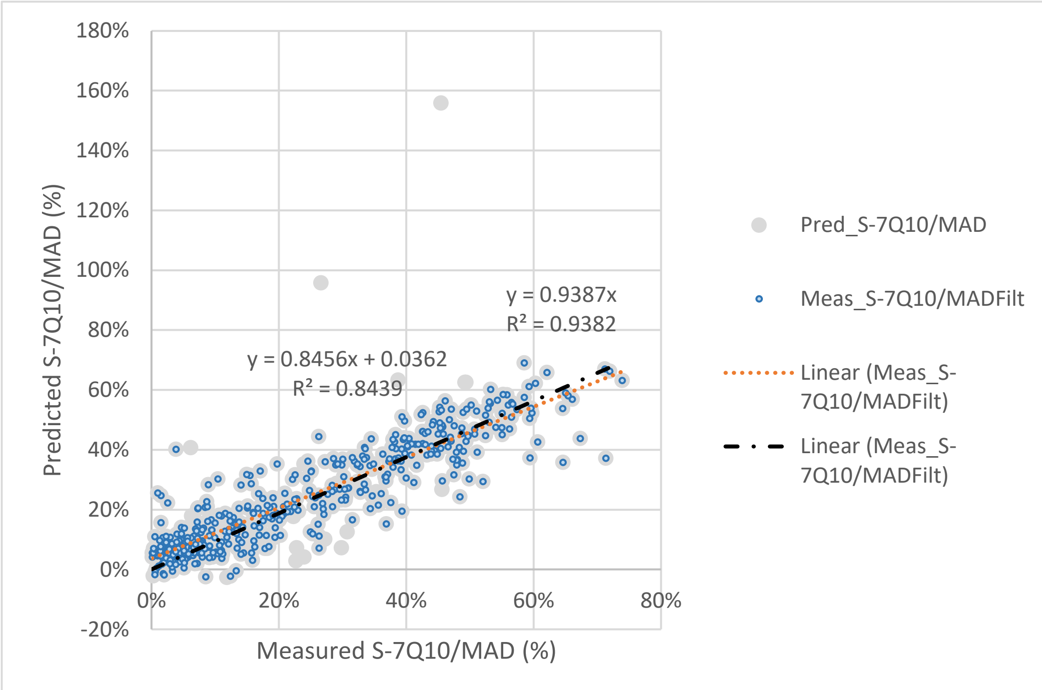
In this table, we note a few observations:

- The “Count” row at the bottom indicates Median Elevation, Glaciation, and Solar Exposure are important geospatial states. Secondary are all other geospatial stats.
- When a single predictor variable is used, it tends to be Glacier, Median Elevation, or Slope. The Glaciation predictor variable is not a strong predictor because most sites in a region do not have glacier content, but when they do, they have a very strong influence on the S-7Q10/MAD. We recommend these HZ be revisited to derive a better model (HZ-10, 13, 19, 28).
- Interestingly, where precipitation is a predictor variable (HZ-3, 5, 18, 25, 27, 29) it’s a negative slope. This implies the more it rains (in the winter) the lower the summer low flow *WRT to MAD*. Perhaps this is the rub; MAD is relatively larger than in other HZ.

It should also be noted again, that the 30-iteration model was run several times, and while some predictor variables remained the same for the “Best Model” others changed depending on the random sample. We did not fully explore this slight variability, and indeed looking at previous runs in RSEA and SCSB, the Best Model was not always a clear choice and often other factors were considered. For example, the author tended to favour 2-4 variable models over 1 or 5 variable models, although the algorithm in the current study to choose the model with the highest Min R2, is more defensible. In future studies, **we recommend running the models a much larger number of times, i.e. >100, until the Best Model is consistent. However, before doing that, we recommend increasing the sample size of every HZ**. And that is assuming the MkMGR model is used rather than, or in combination with, the XGBoost model.

Figure 17: S-7Q10/MAD Derived using MkMGR for all HZ in BC

This figure shows S-7Q10/MAD measurements from FASSTR for all 497 WSC stations in the Province (Grey) with S-7Q10 stats and filtered 454 (blue). The slope of 0.84 is partly a function of the 0.036 intercept. If a Zero intercept is chosen, the slope is 0.94 and R2 is 0.93.



3.1.1.3 *MkMGR for A-30Q5/MAD*

While there is no Annual 30Q5 statistic within Obedkoff/Ptolemy or Ahmed, this hydro-stat was requested by hydrologists that we consulted with prior to beginning the work. There are fewer stations to work with in each zone for this hydro-stat because finding a significant number of years with 30 days of data, especially in the winter, is rarer than 7-day averages in the summer.

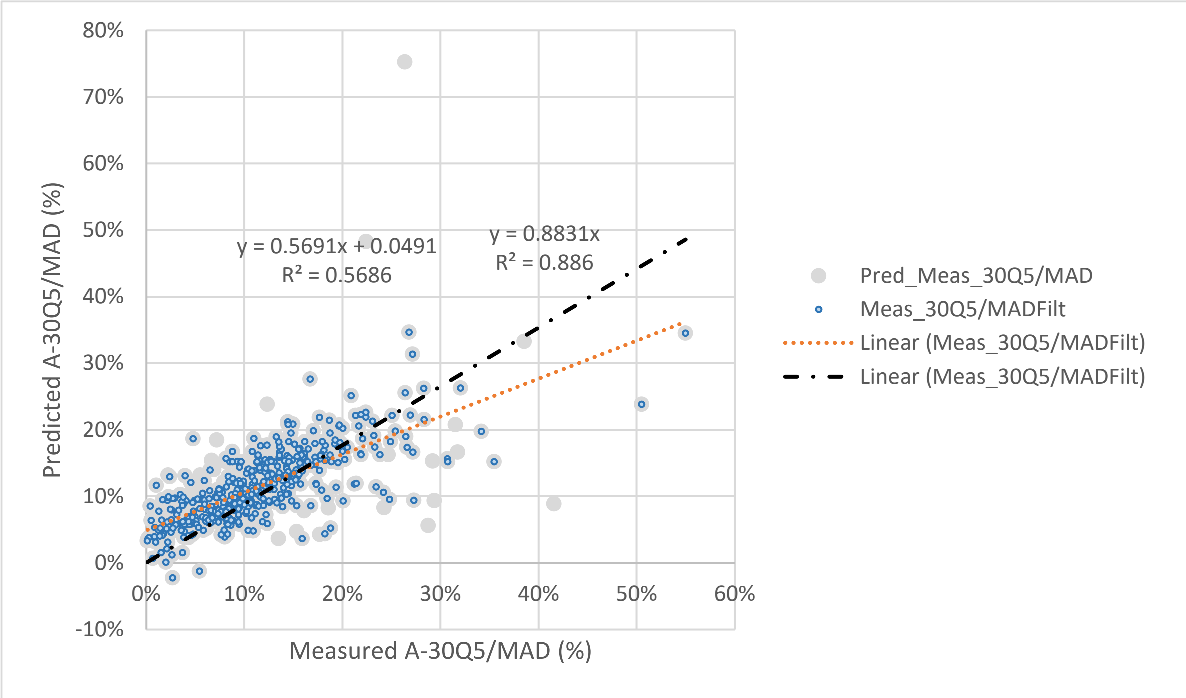
Figure 18 shows the results of the modeling. There appears to be a positive bias in the predicted A-30Q5/MAD, which is not present in the S-7Q10/MAD results, that is influencing the result. **We recommend this hydro-stat be revisited in future iterations of the model.**

From Table 3, we can see that:

- There are several HZ with single variable predictors, but the variable changes between DA, Slope, Median Elevation, PET, and SolExp.
- DA is the most predominant Geospatial Stat used.
- HZ 4 and 6 have less than 5 samples, and therefore the R2 values are unreliable.
- Model STEYX% is always less than STDEV%, but the values are generally quite large compared to MAR STEYX% values.

Figure 18: A-30Q10-S/MAD Derived using MkMGR for all HZ in BC

This figure shows A-30Q5/MAD measurements from FASSTR for all 497 WSC stations in the Province (Grey) with S-7Q10 stats, and filtered (blue). There appears to be a bias in the predicted results, which needs further investigation. If the intercept is set to zero, the R2 is 0.89.



3.1.1.4 *MkMGR for Mean Monthly Discharge (MMD)*

In SCSB and RSEA, we modeled %Monthly Distribution (%MD). This is an odd variable because it must be converted to Q by the number of days within a given month. We used this variable in those studies because both Obedkoff and Ahmed used it. In those studies, to convert the %MD to monthly average flow, in m³/s, we use:

$$MeanMonthlyQ_i = \%MD_i * MAD * \frac{365}{Days_i} \qquad (1)$$

where $Days_i$ is the number of days in the *i*th month. However, **we recommend that this variable be superseded by an easier to manage variable MMD/MAD.** This is the Mean Monthly Discharge (MMD) as a percent of the MAD. This variable is in line with the other low flow stats and much easier to convert to m³/s.

$$MeanMonthlyQ_i = MMD/MAD_i * MAD \qquad (1)$$

While the slopes and intercepts derived using this new variable differ from RSEA and SCSB, the relative values can still be compared.

We have not run MkMGR and XGBoost for all months, given the time restrictions in this project. We have, however, run a few key months to get a sense of the relative performance of the two models.

May has been processed, which tends to be an early freshet month. In RSEA, May%MD was influenced by SolExp in HZ-3, 6, and 13 and by DA in HZ-3, 7-12, 8, and 13. In SCSB, SolExp was not a key predictor variable in any zone. Rather Glc, Precip, and PET were key variables in several 25-26 and Med.Elev, Precip. and DA in HZ-27. In the current study, SolExp was key in HZ-3, 4, and 8, while DA was key in HZ-8 only. This is quite different than RSEA, but the R2 are in the same range of ~30% to ~90%. The values for R2 in the current study for MayQ/MAD are higher than in the SCSB. Figure 19 shows an excellent match when all HZ are compiled, with an R2 of 0.95.

Figure 20 shows the same results for January, based on models compiled in Table 5. Note that in the SCSB HZ-25, 26, and 27, Precip is a primary factor, as it is in the SCSB study. In the RSEA Zones, Median Elevation is a primary factor, as it was in the RSEA study also. Note that January is a low flow month in most northern zones, where the AVG is quite low and the STDEV also relatively low. While the MkMGR STEYX results always improve on the STDEV, STDEV% is relatively low for a given zone, in fact, Obedkoff originally referred to his HZ as Low Flow Zones. HZ are a good predictor of Low Flows.

Figure 19: MayQ/MAD Derived using MkMGR for all HZ in BC

This figure shows MayQ/MAD measurements from FASSTR for all 534 WSC stations in the Province (Grey), and filtered (blue-483). If the intercept is set to zero, the R2 is 0.95. The few outliers may be filtered out with further water license filters.

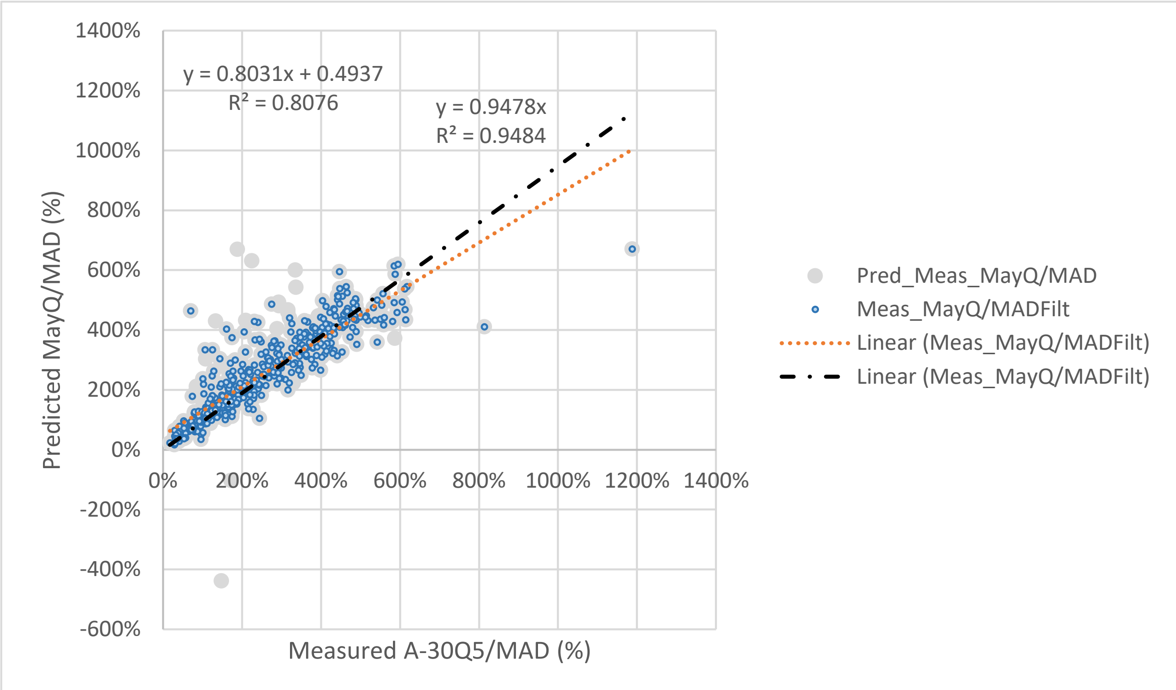
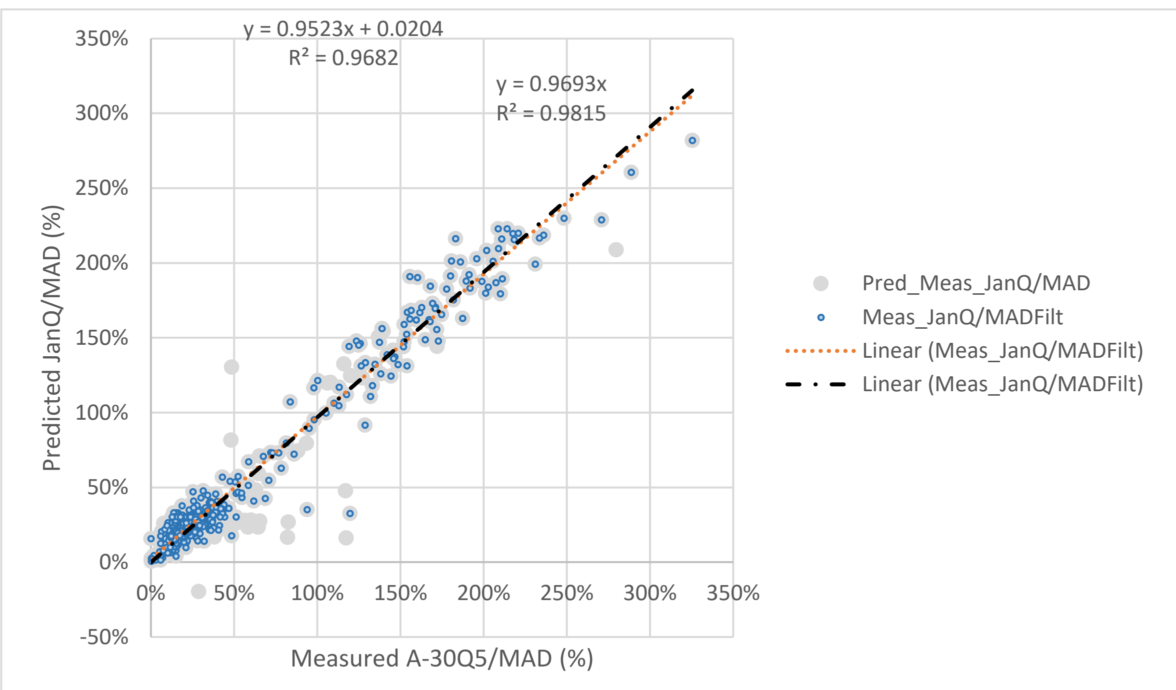


Figure 20: JanQ/MAD Derived using MkMGR for all HZ in BC

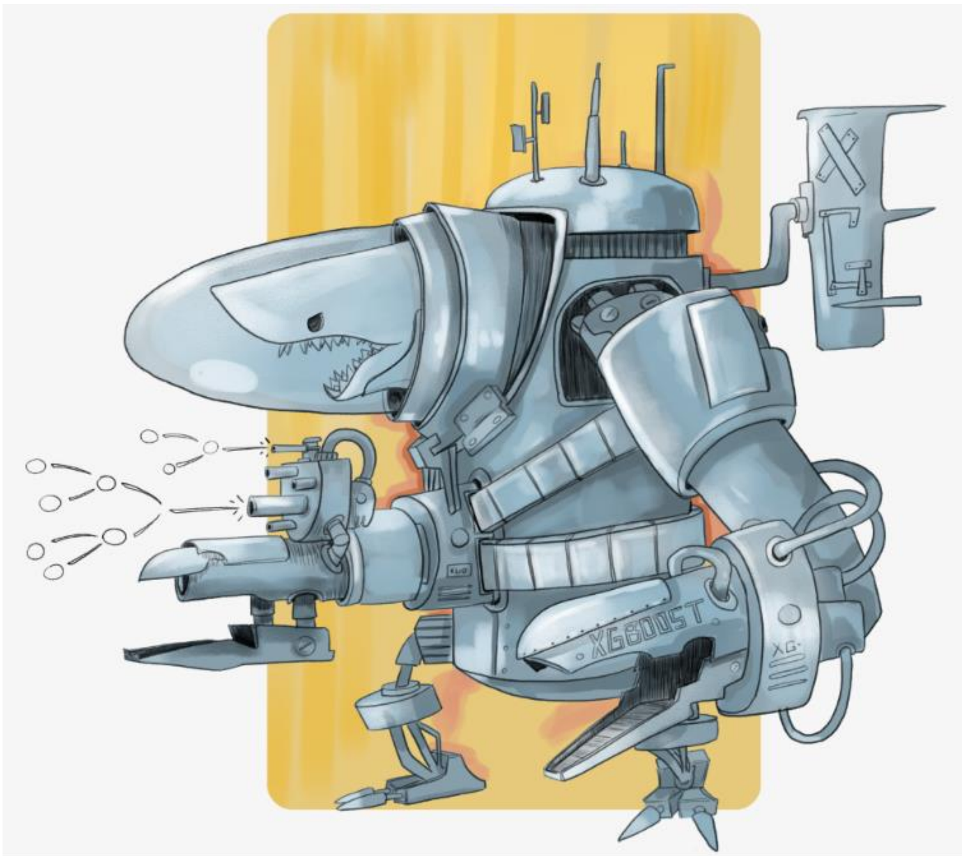
This figure shows JanQ/MAD measurements from FASSTR for all 534 WSC stations in the Province (Grey), and filtered (blue-483). If the intercept is set to zero, the R2 is 0.98. The few outliers may be filtered out with further water license filters.



3.1.2 XGBoost Results

XGBoost is a strange and powerful beast in a hydrologist's menagerie. Its strengths, vulnerabilities, eccentricities, and natural habitat are not fully understood (by the author). Once we have tamed this animal, can feed it appropriate food, understand its language, and have learned and bonded with it in hunting and tracking, we believe it will be a deadly and efficient hydrological modeling asset. Figure 21 is an artist's rendition of XGBoost based on Mariner's tales.

Figure 21: Artist's Rendition of XGBoost (by Noah Carson)



Initial tests in the Wally project divided XGBeast's meals into Hydrological Zones, however the algorithm did not play nicely with the smaller datasets. Feeding the beast larger, quality-controlled datasets, has produced very promising results, shown below. This study uses the entire quality controlled WSC dataset (480 MAR samples, 452 Low Flow samples) as input.

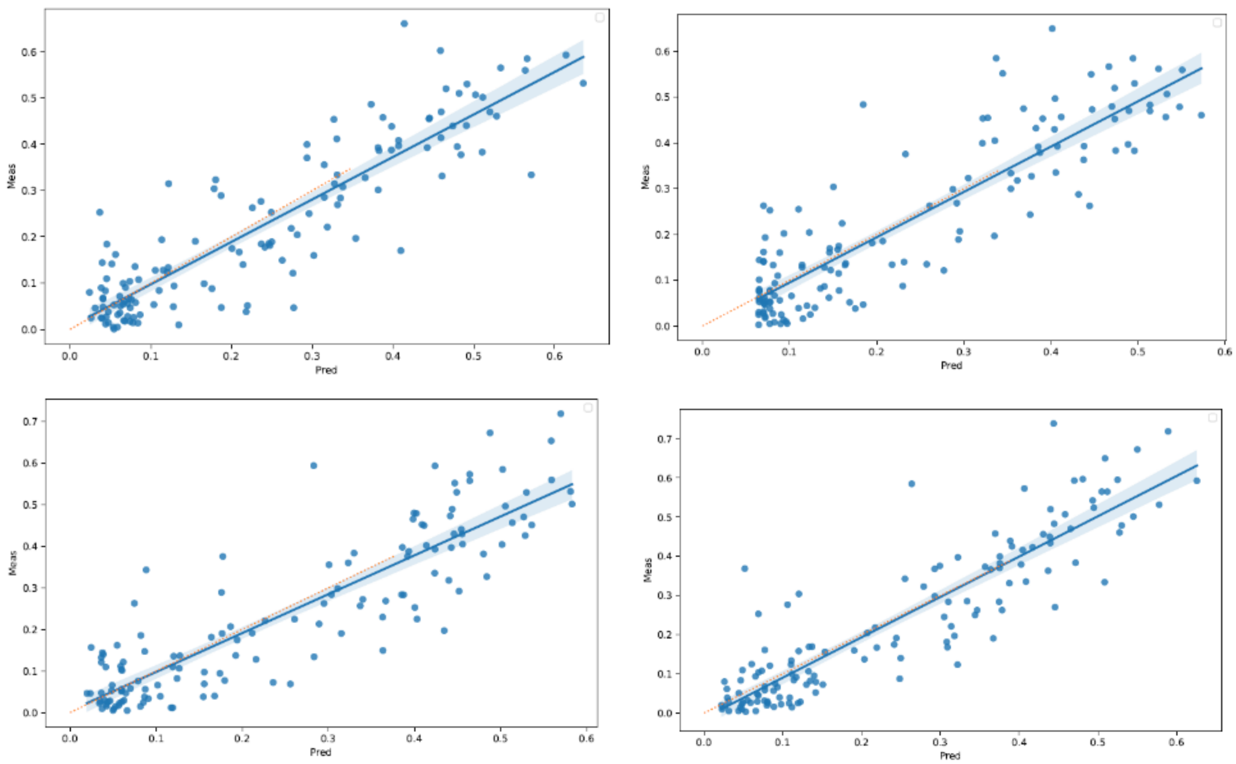
In order to choose the most robust model, we used a modified k-fold approach, as we did for the MkMGR model. The XGBoost is fed 15[10] folds of random train-test datasets with a 70-30 split, and the model that produces the highest Min R2 (or lowest STEYX), is the model chosen to digest the entire dataset as training data. For example, in Figure 22, the first 4 of 15 folds are shown. While there appears to be significant scatter (R2 = 81% for both train:test), the XGBoost results for S-7Q10/MAD are very close to those from the

[10] We have been trying to use 30 folds, but the model is currently crashing for some unknown reason with 30.

compilation of all HZ using MkMGR shown in Figure 17 (R2 = 94%). More on the S-7Q10/MAD results below.

Figure 22: 4 folds from S-7Q10/MAD Derived using XGBoost for all HZ in BC

This figure shows the match of Test data vs Measured data, for the first 4 (of 15) folds, from top left to bottom right, for the S-7Q10/S hydro-stat using a 70:30 Train:Test split. This is data NOT used in the training dataset so we can expect similar results at ANY point for ANY watershed in the Province. While this diagram shows significant scatter, the R2 and STEYX is comparable to the MkMGR results trained on individual HZ.



3.1.2.1 XGBoost for MAR

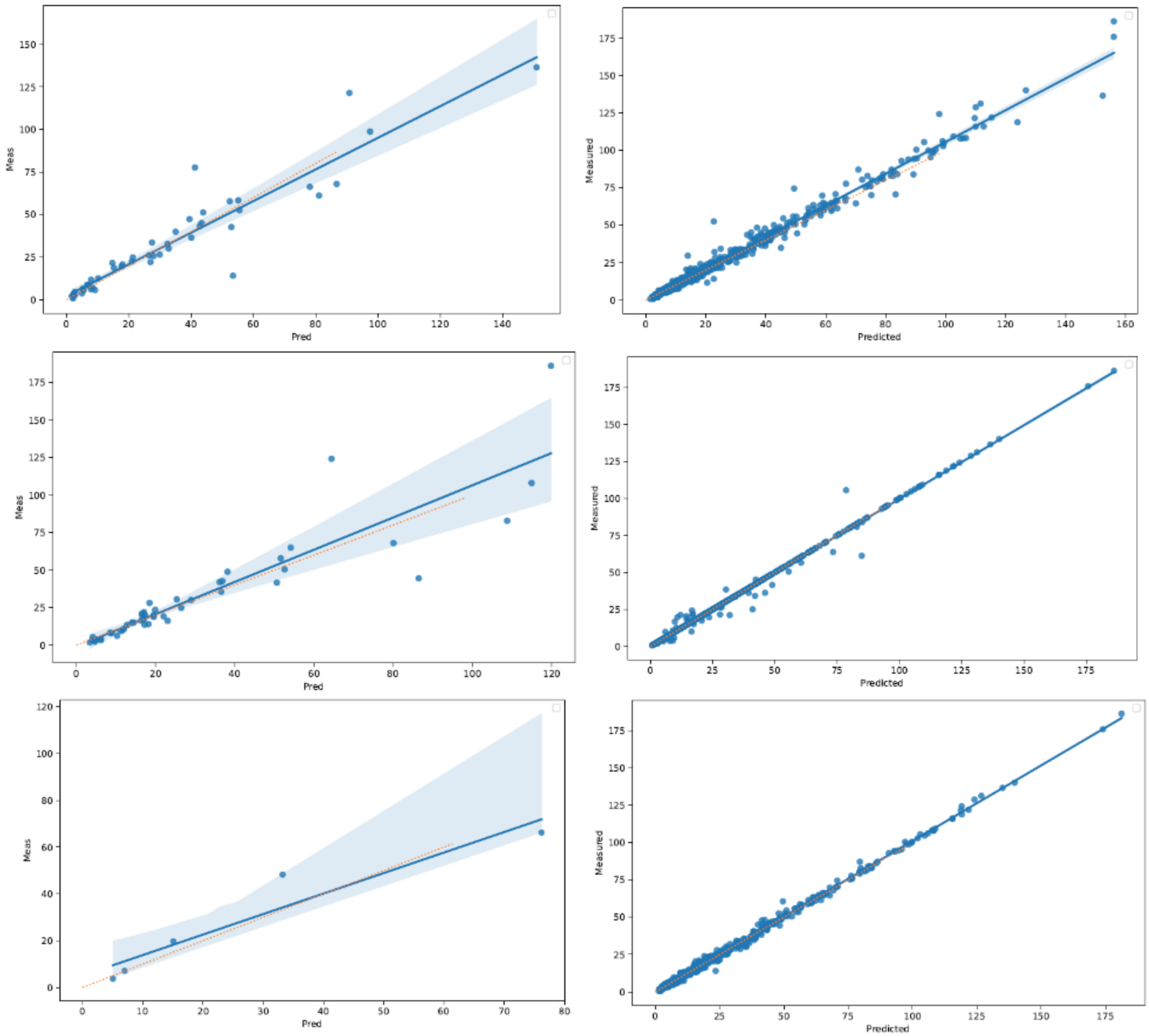
The results, "Gains", R2, and STEYX, have been concatenated onto the bottom of each hydro-stat table. In Table 1, we can see that XGBoost also chose Precipitation as the primary driver for MAR, as expected. The R2 values are similar, 96% for XGBoost and 88% *on average*[11], for MkMGR. There are pros and cons to HZ specific regression equations, i.e. better results in some HZ and worse in others. Another pro is that these regression equations are fairly easily applied with the correct geo-spatial stats. The XGBoost equations require a json model file to execute, but only require a single model for the entire Province. While the model (decision tree, weights, gains, etc) cannot be written down, XGBoost is readily available as a Python plugin and to a moderately skilled python programmer. Although the models will differ from user to user, if trained with a sufficiently large and Quality Controlled dataset, the results should be similar.

[11] The average of all R2 for all HZ, is not the same as the R2 for all samples, as shown for XGBoost.

Suffice it to say, the results between the two models for MAR are very close.

Figure 23: Best Model Fit MAR Derived using XGBoost for all HZ in BC

Below are 3 pairs of plots, top row: left, a typical "fold" containing 30% of the data as "test" data, right, all data processed in the "best" model. Middle row: the same as above for 10% test, bottom row: the same as above for 99%. Strange how more variability is seen in the training data results in the bottom row, than the middle row. Also disturbing is how poor the fit is on the bottom left using 1% of the data. It's almost as if the more data used in the training set, the worse the test data result is.



3.1.2.2 XGBoost for S-7Q10/MAD

For S-7Q10/MAD, the results again are similar, shown in Table 2, although MkMGR has a slight advantage with higher R2 0f 94% (Figure 17). Figure 24 compares all data (Train:Test) for a 70:30 Train:Test split. Compare to the folds in Figure 22 and it again becomes clear that the training data is in a tight distribution along the line of equality. If 99% of the data is used in the training, the result on the right is obtained.

The fold data in Figure 25 gives a good indicator of the model performance with the maximum RMSE (similar to STEYX) being 0.10 which is 10%of MAD uncertainty at 1 sigma. This is approximately 24% of the average measured S-7Q10/MAD of (coincidentally) 24% in the Province. Compare to the MkMGR results which range from STEYX% values of ±9% in HZ-18 to ±105% in HZ-28.

Again, XGBoost trades convenience (a single model for the entire Province) and possible accuracy (±0.06 or 6%MAD in S-7Q10/MAD) for higher granularity in both Hydrological Zones and in fundamental basis for the result. **No hydrologist wants to, or should, simply accept a black-box answer when making critical water used decisions**. It defines us a tribe that hydrologists make a reasonable effort to understand how a number was derived, asks "does it make sense in the context?", and "how was it calculated?". While the power and convenience of XGBoost must be acknowledged, more effort it necessary to understand its applicability.

Figure 26 shows a plot of feature gain, the same values in the bottom row of Table 2. Here, Glacier and Hydrological Zone are the most important factors.

Figure 24: Best Model Fit S-7Q10/MAD Derived using XGBoost for all HZ in BC

After choosing the "best" model, ie the decision tree that produced the lowest STEYX in the value out of all the folds, it was rerun using all data as input data, shown on the left for a 70:30 Train:Test split. If 99% of the data is used as the training data, the version on the right results. This is what is disturbing about XGBoost; it just gives you back your training data. The 4 outliers are the test data.

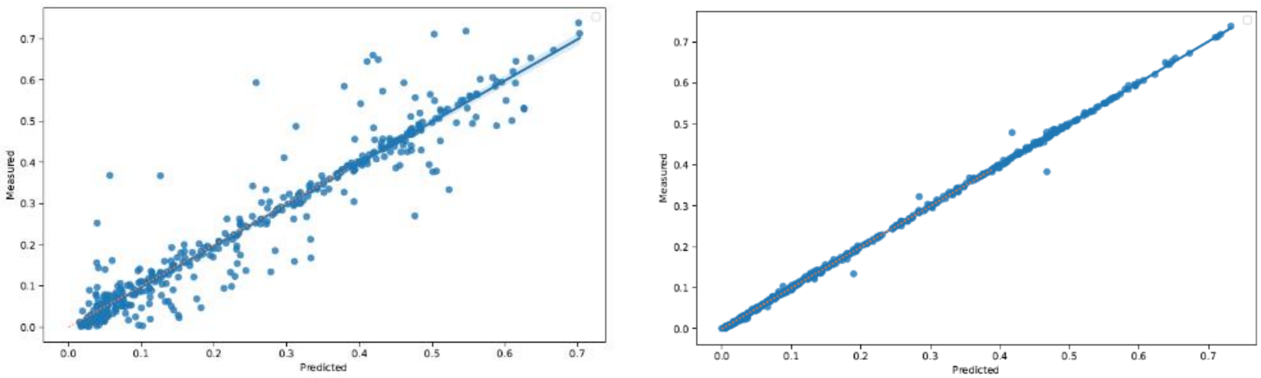


Figure 25: S-7Q10/MAD R2, RMSE, and Fold Number

This is a diagnostic plot showing the RMSE vs R2 of the Test Data (30%) for all of BC and all HZs for S-7Q10/MAD. This suggests the worst case is ±0.10 (±10%MAD).

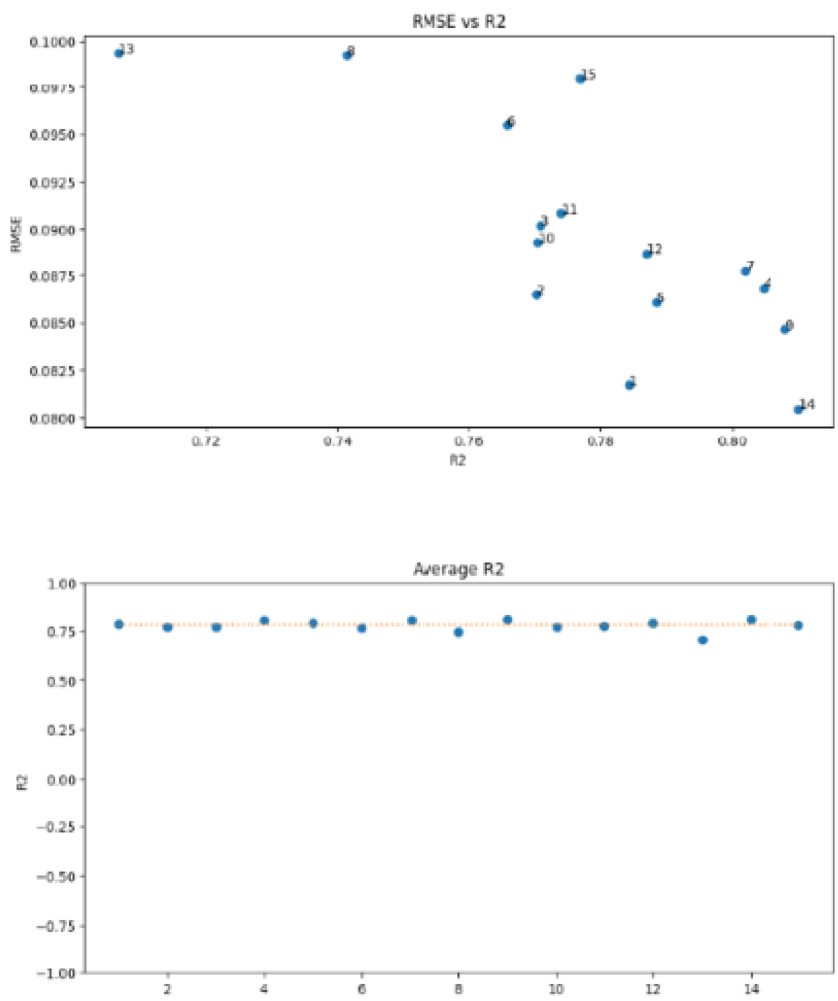
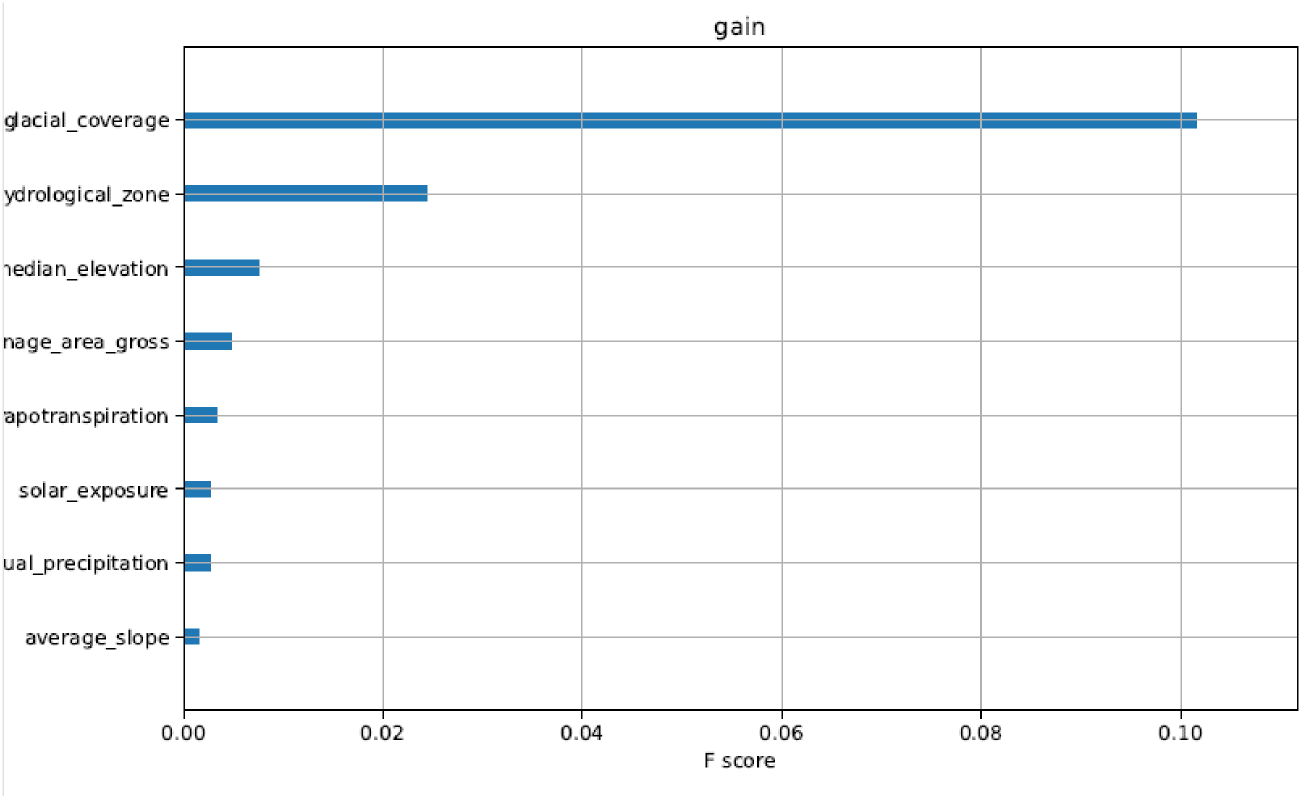


Figure 26: S-7Q10/MAD Gain

This is a diagnostic plot showing the Gain of each Geospatial stat when applied to the S-7Q10/MAD hydro-stat. The gain is the improvement to the model result when that feature is included in the decision tree. The other feature importance metrics are Cover and Weight, but these appear to be less insightful/intuitive than Gain. Note that, like the MkMGR results, XGBoost gives Glc the most weight. Interestingly, HZ is second.



3.1.2.3 XGBoost for A-30Q5/MAD

XGBoost performed as well or better on A-30Q5/MAD as MkMGR did. This may be because there is not much information in the Geospatial stats, and MkMGR is simply taking something slightly better than the average for each HZ. With an R2 of 73%, this is better than the *average R2* of 58% from Table 3, but less than the 89% from Figure 18.

Figure 27 shows a typical fold using 70:30 Training:Test in the left panel and all data in the right. Figure 28 shows the RMSE (STEYX) of the residuals for the 15 folds, peaking at 0.10 (10%MAD). Figure 29 shows the gain, again repeated in Table 3. There is no clear primary predictor variable for this hydro-stat. Slope, SolExp, and PET are the most used Geospatial stats in MkMGR and also have the highest gain, after HZ.

It has been noted that annual low flow stats are the most challenging to predict in SCSV and RSEA given the variability of driving factors. In the same HZ, the A-30Q5 can vary between winter and summer. It is in line with previous studies that HZ is the primary predictor variable, with slope, solar exposure, and PET modifying variables.

Figure 27: A-30Q5/MAD Scatterplot

A typical fold result for test data (30% of data) and all data using the "best" model on the right.

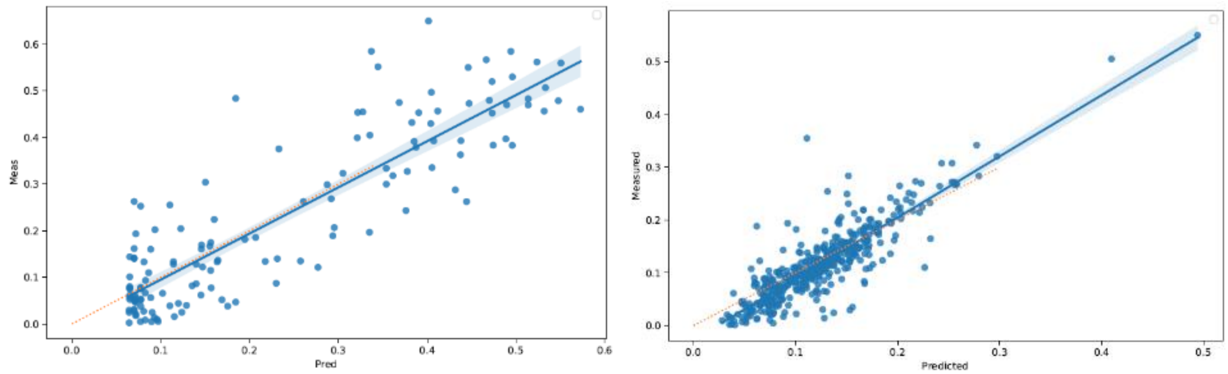


Figure 28: A-30Q10/MAD R2, RMSE, and Fold Number

This is a diagnostic plot showing the RMSE vs R2 of the Test Data (30%) for all of BC and all HZs for A-7Q10/MAD. This suggests the worst case is ±0.10 (±10%MAD).

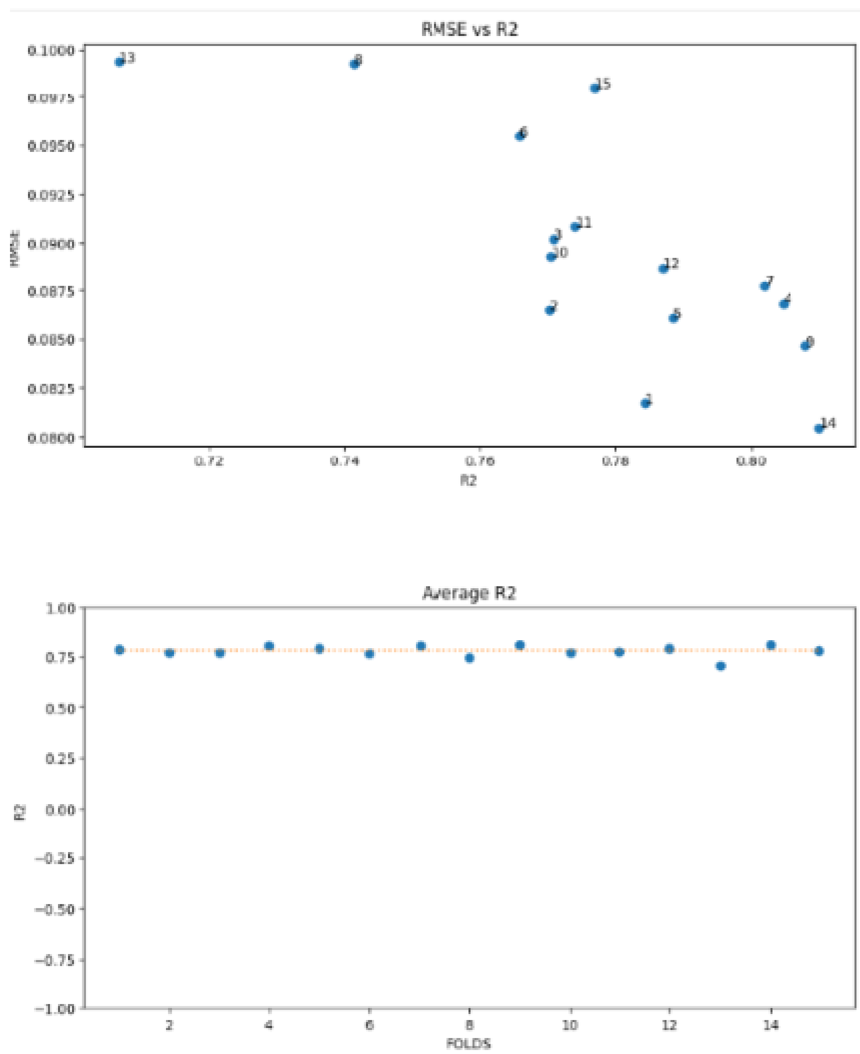
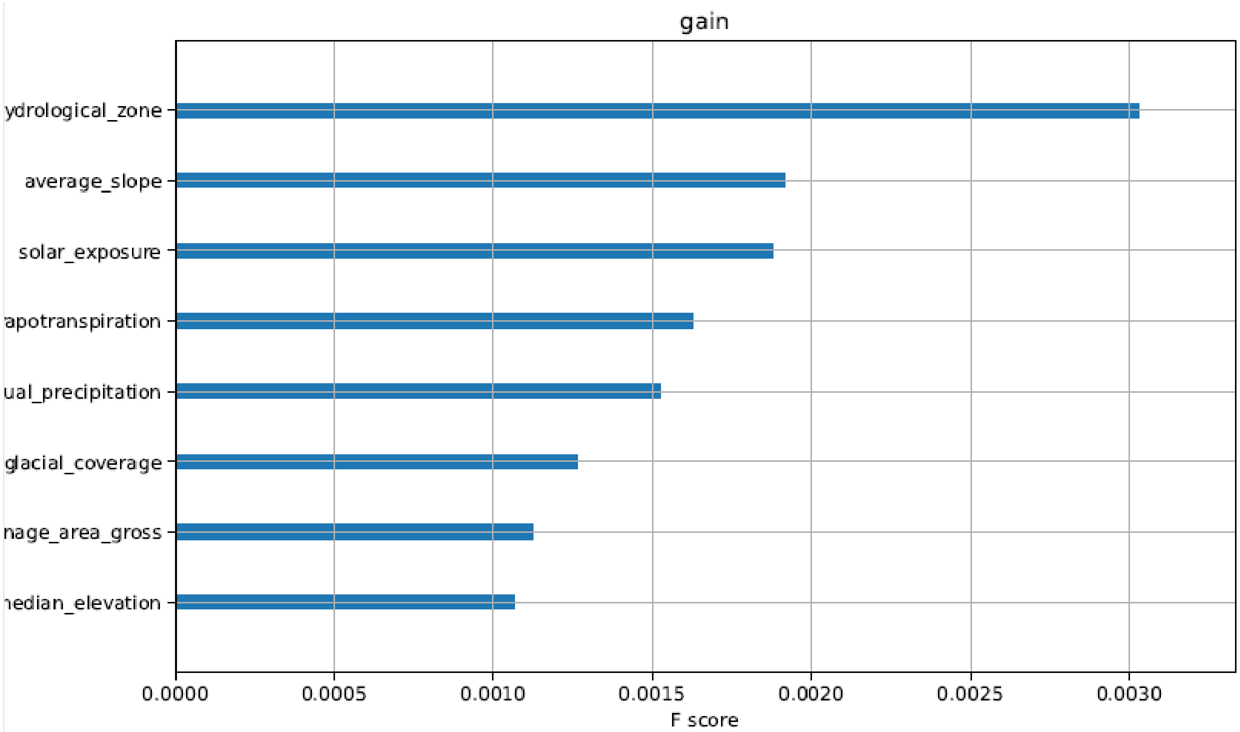


Figure 29: A-30Q5/MAD Gain

This is a diagnostic plot showing the Gain of each Geospatial stat for the A-30Q5. This plot indicates that no particular predictor variable outshines the others in the Province, and HZ is the best predictor.



3.1.2.4 *XGBoost for Mean Monthly Discharge*

The scatterplot and R2 of residuals shown in Table 4 and Figure 30 for May MMD/MAD are encouraging. Like MkMGR, XGBoost considered Precip and PET as strong predictors of MayQ/MAD. HZ and Glacier were also strong predictors.

Results for January are shown in Figure 33. Compare to Figure 20 to see very similar results: a cluster of low flow points and a string of larger flows from southern/coastal watersheds. Figure 34 shows strong results, and Figure 35 indicates that HZ is the strongest predictor of January flows, followed by Median Elevation.

Figure 30: MayQ/MAD Scatterplot

A typical fold result for test data (30%) on the left and all data using the "best" model on the right.

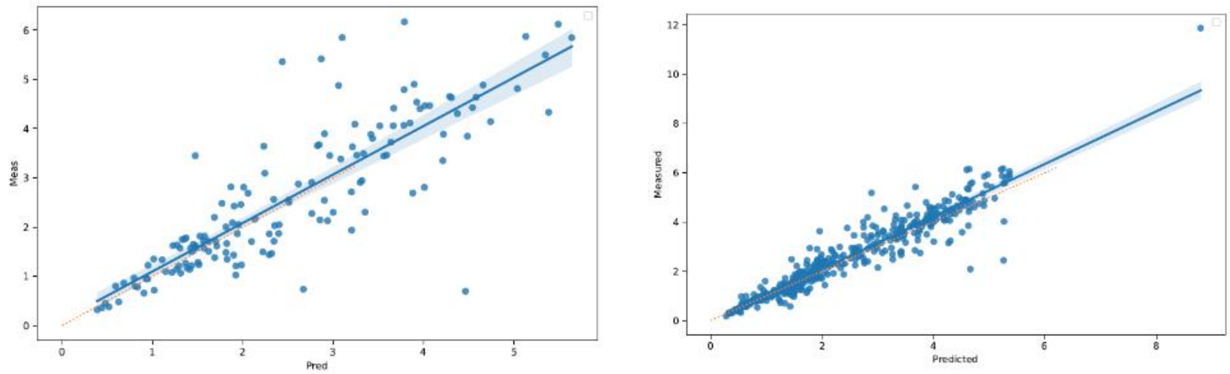


Figure 31: MayQ/MAD R2, RMSE, and Fold Number

This is a diagnostic plot showing the RMSE vs R2 of the Test Data (30%) for all of BC and all HZs for MayQ/MAD. This suggests the worst case is ±1.10 (±110%MAD). This may seem large, but May %MAD values are typically from 1 to 6xMAD.

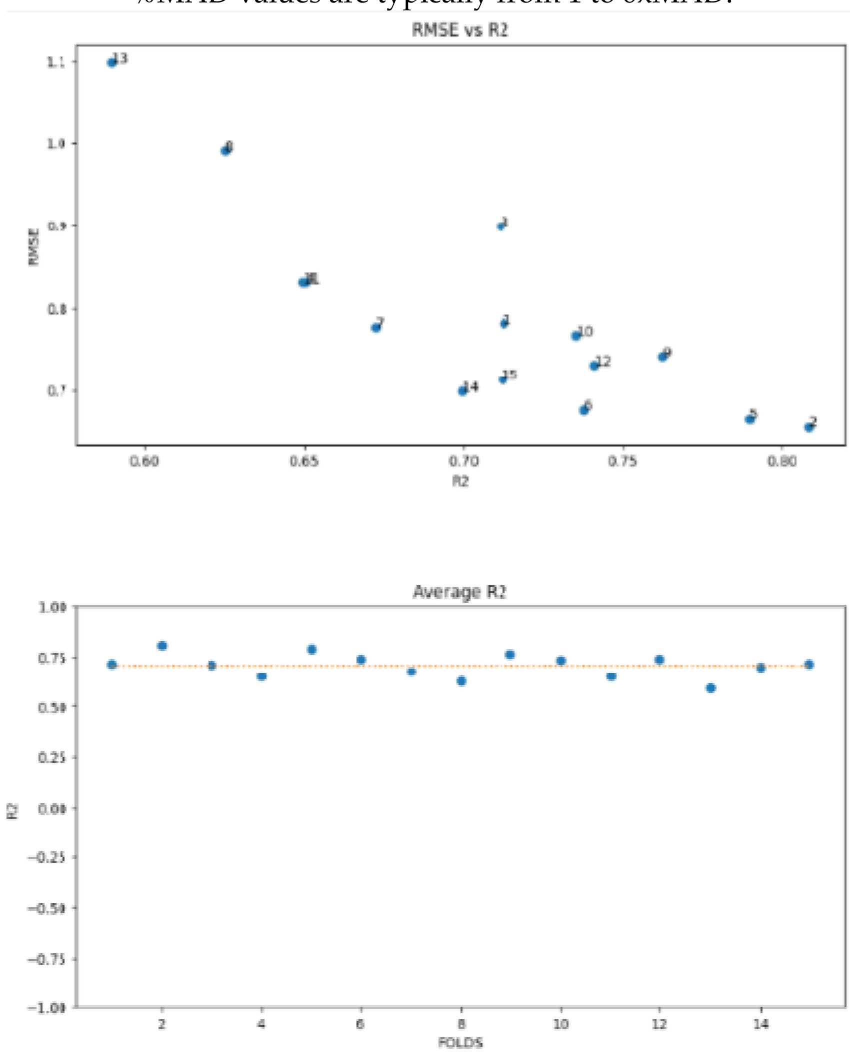


Figure 32: MayQ/MAD Gain

This is a diagnostic plot showing the Gain of each Geospatial stat for the MayQ/MAD. This plot indicates that no particular predictor variable outshines the others in the Province.

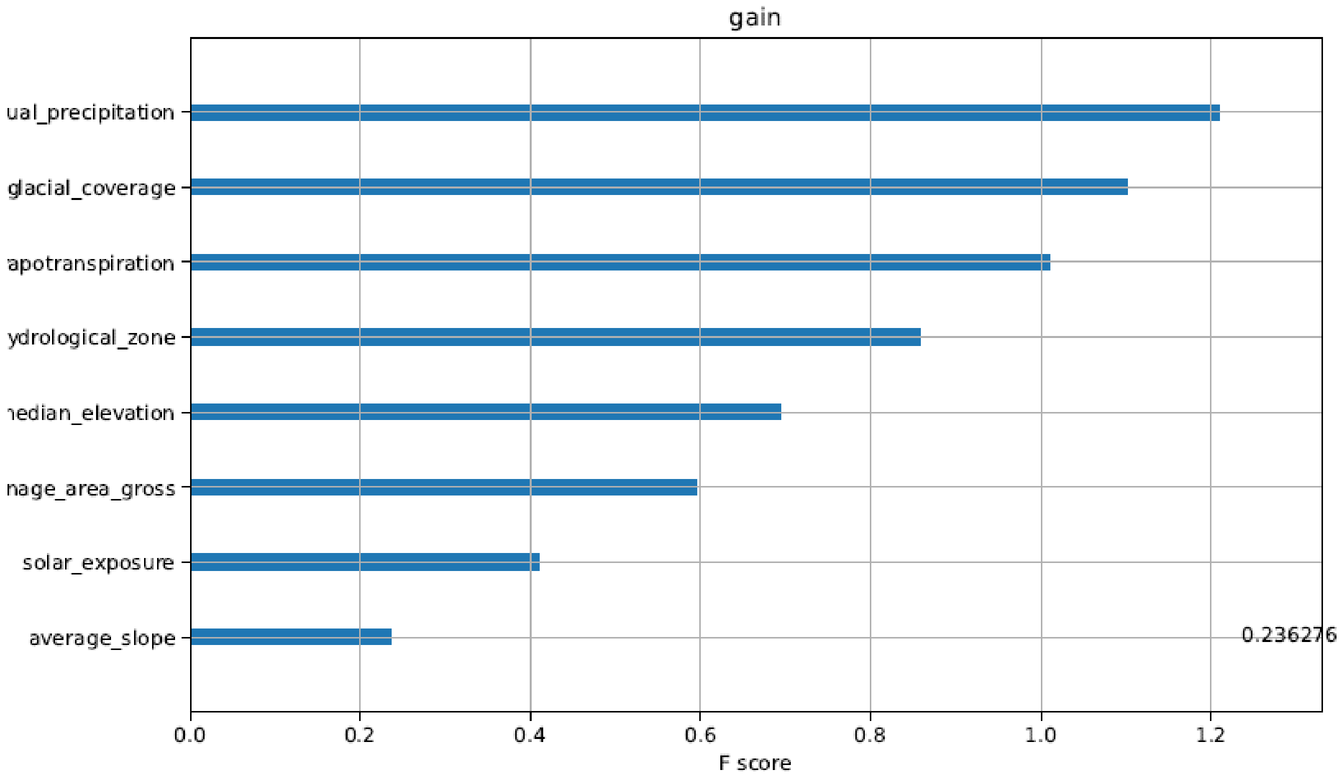


Figure 33: JanQ/MAD Scatterplot

A typical fold result for test data (30%) on the left and all data using the "best" model on the right.

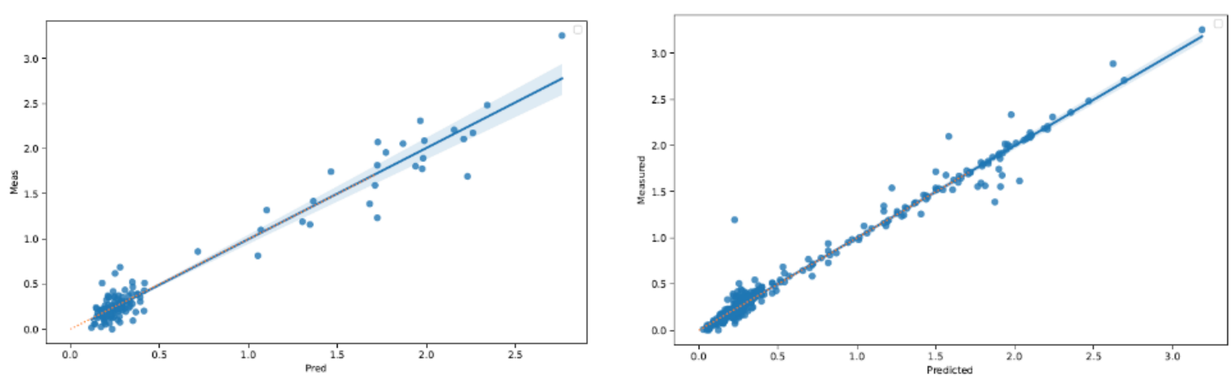


Figure 34: JanQ/MAD R2, RMSE, and Fold Number

This is a diagnostic plot showing the RMSE vs R2 of the Test Data (30%) for all of BC and all HZs for JanQ/MAD. This suggests the worst case is ±0.22 (±22%MAD).

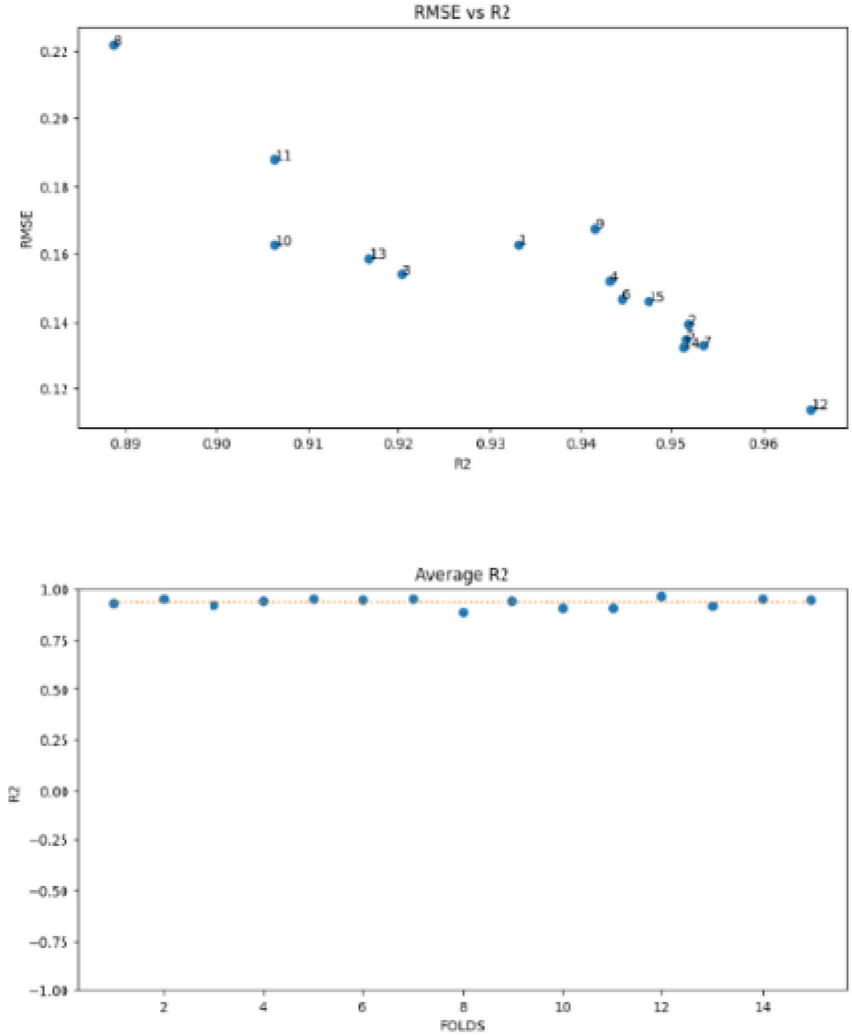
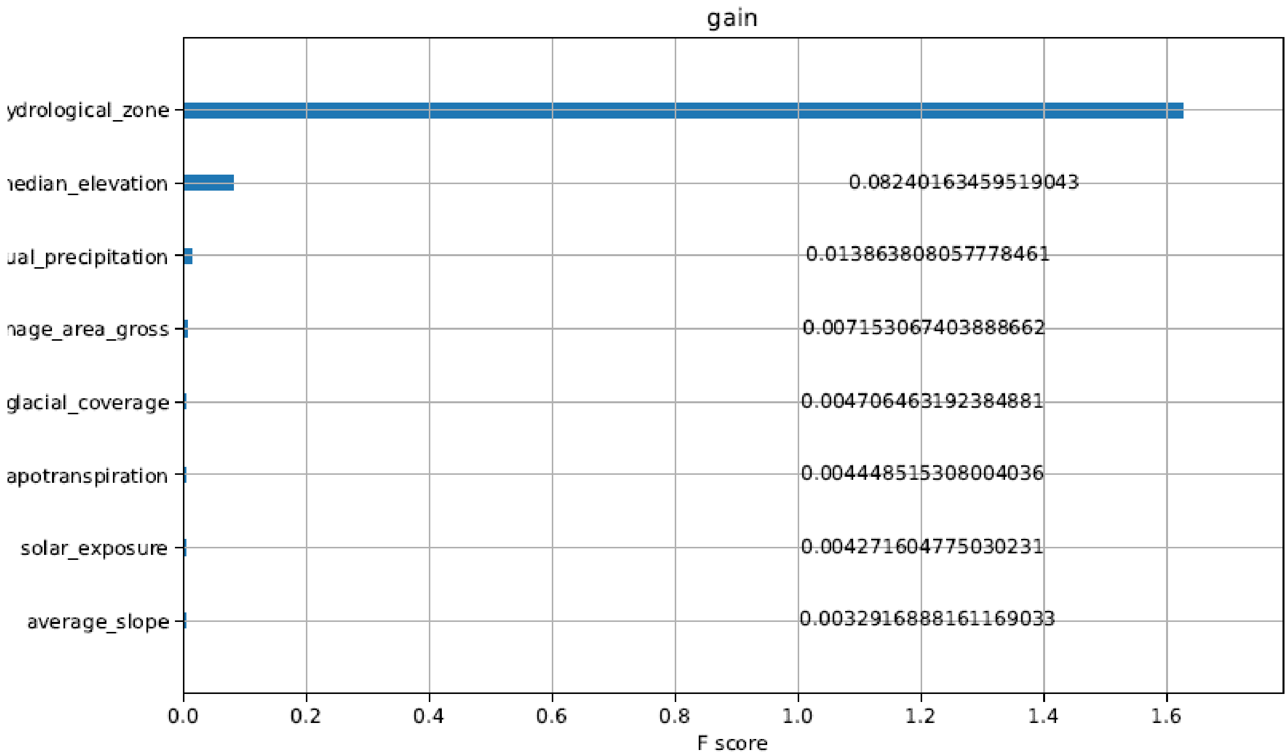


Figure 35: JanQ/MAD Gain

This is a diagnostic plot showing the Gain of each Geospatial stat for the JanQ/MAD. This plot indicates that Hydrological Zone is the strongest predictor, with a small adjustment for Median Elevation.



3.2 Discussion

The work presented here lays the foundation for future iterations of the models. Essentially, both models are Geospatial regression models. MkMGR has been proven out over the last 5 years for the SCSB study area and RSEA has had extensive validation exercises completed. MkMGR must be built for each HZ but can be interpreted physically and easily employed by others.

XGBoost is a new method used to determine the same hydro-stats, using Machine Learning to train a model. While this method has promise, further work is required to refine, understand, and quantify the uncertainty and performance of this algorithm. It appears to be possible to run an entire Province worth of data through a single model, using the Hydrologic Zone as a predictor variable, and generate hydro-stat results on par with those from MkMGR.

At this point, the project has been ended, and so further validation of the results of both new models is postponed until the next stage of development. The foundation built in this project, in watershed delineation, in water license allocation, in filtering of WSC training data, and in linear regression modeling based on Geospatial stats, is very important for the next stage of development, wherever or however that may occur. The database of WSC hydro-stats and Geospatial stats is an invaluable resource for water resource professionals in the Province and we encourage this training table to be shared and refined.

The strengths and weaknesses of the two models is captured in Table 6.

3.2.1 Recommendations for Future Work

We don't recommend relying on XGBoost results alone in the immediate future. The MkMGR models have now been well-established over this third report for the Province of British Columbia and should serve as a baseline for future studies of XGBoost. We recommend continuing the current study to complete the analysis for all months and other low-flow stats.

We recommend re-running both models with 100+folds to completely eliminate the #folds as a factor in decision making.

We recommend increasing the WSC sample size in each HZ. This can be done by considering WSC stations outside of BC, and other long-term records available from BCHydro and the BC MoE. We recommend assigning watershed to HZ by centroid rather than drainage point.

We recommend further work be done on understanding the relationship between training and test dataset in XGBoost, i.e. does a larger training dataset help with model robustness, or does it limit the range of applicability? Does a smaller training dataset of diverse input parameters result in a more robust model? We only just got XGBoost working in a predictable way (tamed the beast) but we do not completely understand it's powers and abilities yet.

3.2.1.1 Water Demand Modelling

The following were noted as areas for further work to refine water supply and demand modelling results:

- *Peak flow rates in water licenses and STUAs:* Currently, information on peak flow rates is not available for several large use types (e.g., Irrigation water licenses, Oil and Gas STUAs). These are potentially significant users and information would be of great value in assessing environmental risk. It is recommended that peak flow rate information for these users is provided/included in future modelling work.
- *Max diversion rate attribute in water license data:* The max diversion rate attribute (QTY_DVRSNE in the Water Rights Licenses) would be an excellent attribute to consider in future water demand modelling. A review of water license data found that there were a significant number of records where this attribute contained inaccurate data, and so the data in this attribute is not reliable for modelling work. It is recommended that this attribute is reviewed, updated, and utilized in future water demand modelling efforts.

- *Max instantaneous rate in STUA data:* Currently, several STUAs identify a max withdrawal over two years. More information is needed regarding daily and/or instantaneous maximums to support better water demand modelling. It is recommended that all STUA authorizations include a max instantaneous rate.
- *Periods of use:* Currently, the windows of time in which a water license can be used are included in the PDF version of the water license, but not in the GIS dataset. It is recommended that this information be included in the GIS dataset for use in water demand modelling.
- *EFN restrictions:* Information on EFN restrictions is not included in the datasets and would be very helpful for modelling demand, especially for large users (e.g., Oil and Gas). While it is recognized that EFN restrictions are often complex, in cases where there is a streamflow threshold, this could easily be utilized in supply and demand modelling.
- *Storage:* Currently, there is no information available in the datasets regarding how and when water that is stored will be released. This information would be very useful for modelling water supply and demand and in the selection of hydrometric stations for hydrologic modelling. It is recommended that this information is included to some degree in the water rights dataset.
- *Water license purpose categories:* Currently, some water license purpose categories combine very different water uses into on category, which makes it impossible to model demand for those categories. For example, the category 'Crop Harvest, Protect & Compost' includes water use that occurs primarily in the fall (e.g., flood harvesting occurs Sep-Nov) and spring (e.g., Flood Protection occurs primarily Feb-Apr). It is recommended that water license purpose categories are updated to reflect uses that share seasonal variations in use. In addition, it is recommended that purpose categories are better defined.
- *Incorrect license data:* Several water licenses were reviewed for this project and it was several licenses had been improperly classified or quantities incorrectly entered. This was observed more commonly in the older licenses that were reviewed.
- *Groundwater use:* Currently groundwater use is not considered in the Wally tool. However, there are many areas of the Province where groundwater use significantly impacts streamflow. Further work is required to incorporate use of groundwater when modelling water supply and demand and assessing risk when making water allocation decisions.

4 CONCLUSIONS AND RECOMMENDATIONS

We have concluded the first phase of the Wally project and it shows tremendous potential for widescale (Province-wide) estimation in ungauged basins. This is an transparent, reproducible, and defensible model that is easily understood. The mechanics that have gone into delineating watersheds accurately and autonomously are the state of the art and represent a culmination of decades of work from individual practiioners. The Wally tool refined and productized this powerful, accurate, and fast tool.

The Modified k-fold Multivariate Geospatial Regression model is a proven workhorse for estimating almost any hydro-stat within the Province, or worldwide for that matter, from readily available GIS datalayers. Much of the work in this project was on quality control for the derivation of both drainage area and hydro-stats for the 534 WSC stations (with >10 years of data) used in this study from all Hydrological Zones (defined in Ahmed 2015) in the Province of British Columbia. This work represents a quantum leap in hydrological basin characterization over existing methods in the public domain.

The project was somewhat delayed working with the rather unknown power of the Machine Learning (ML) algorithm XGBoost. Understanding the diagnostics and ability of the algorithm were a challenge. Pairing the analysis with the MkMGR results to identify QA/QC issues in the training data helped to refine and harness this new algorithmic beast. Once it was realized that XGBoost like large datasets, we were able to generate some very promising results for the entire Province using a single dataset. The concern with this approach is that it's difficult to understand the results, difficult to repeat the results, and the output at this point, just has to be accepted as a black box output, albeit any skilled python developer could install the same packages and run the same analysis and achieve similar results.

Machine Learning approaches to hydro-stats in ungauged basins is a new concept to this investigator, and requires further exploration before it should be adopted. Hydrology is an old field of expertise and the most respected members of the group rely heavily on common sense and an ability to "understand" the datasets and models they work with. Indeed, it's likely what drew them to the field. Replacing rules of thumb, intuition, simple and proven algorithms in favour of a magic-bullet, or black-box solution should always be considered carefully and the behaviour of the tool subjected to heavy scrutiny and peer review. This study represents an important first step along that path.

5 REFERENCES

Ahmed, A. (2015). "Inventory of Streamflow in the Omineca and Northeast Regions", February 2015, Knowledge Management Branch, British Columbia Ministry of Environment, Victoria, B.C.

Beven, K., and P. Young (2013), "A guide to good practice in modeling semantics for authors and referees" Water Resour. Res., 49, 5092–5098, doi:10.1002/wrcr.20393.

Climate Analysis Service at Oregon, (2005). "State University Climate Mapping with PRISM", www.climatesource.com.

Chapman, A. B. Kerr, and D. Wilford. (2012). "Hydrological Modelling and Decision-Support Tool Development for Water Allocation, Northeastern British Columbia" BC Oil and Gas Commission, Victoria, B.C.

Chapman, Allan R., Ben Kerr, and David Wilford. (2018) "A Water Allocation Decision-Support Model and Tool for Predictions in Ungauged Basins in Northeast British Columbia, Canada" Journal of the American Water Resources Association (JAWRA) 1–18. https://doi.org/10.1111/1752-1688.12643

Daly, C., W.P. Gibson, G.H. Taylor, G.L. Johnson and P. Pasteris. (2002). "A Knowledge-based Approach to the Statistical Mapping of Climate." Climate Research, Vol. 22, pp. 99-113.

Dobson Engineer (2008). Phase 2 Okanagan Water Supply and Management and Use Study. Available at: https://www.obwb.ca/wsd/about/project-reports

Hutchinson, Dave. (2020) Personal Communication.

Integrated Sustainability (2020). Delta's Future Agricultural Water Supply and Demand. Available at: https://www.climateagriculturebc.ca/app/uploads/DL12-future-water-supply-2020-report-v1.0.pdf

Integrated Sustainability (2018). Sunshine Coast Regional District Water Demand Analysis. Available at: https://www.scrd.ca/files/File/Infrastructure/Water/ANNEX_H_-_2018-Dec-13_PCD_staff_report_Updated_Water_Demand_Analysis_-_COMBINED.pdf

Metherall, C. (2021). Koksilah Water Supply Feasibility Assessment. Provided to MFLNRORD.

Metherall, C. (2018). Tsolum River Agricultural Watershed Plan: Phase One. Available at: https://www.comoxvalleyrd.ca/sites/default/files/docs/Projects-Initiatives/tsolum_river_agricultural_watershed_plan_-_phase_one_report.pdf

Metherall, C. Metherall, C. (2018). Tsolum River Agricultural Watershed Plan: Phase One. Provided to the Comox Valley Regional District.

Moore, R.D., Trubilowicz, J. and Buttle, J. (2012). "Prediction of streamflow regime and annual runoff for ungauged basins using a distributed water balance model; 61 Journal of the American Water Resources Association. Vol 48, Issue 1, pp 32–42, February 2012

Lindsay JB. 2016. The practice of DEM stream burning revisited. Earth Surface Processes and Landforms, 41(5): 658-668. DOI: 10.1002/esp.3888

Province of BC. Water Authorization Application Assessment and Processing for Applicants. Available at: https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/water-rights/water_authorization_assessment_guidance_for_applicants_signed.pdf

Province of BC. Water Use Purpose Definitions. Available at: https://www2.gov.bc.ca/assets/gov/environment/air-land-water/water/water-rights/water_use_purpose_defns.pdf

Province of BC. Livestock Watering Handbooks. Available at: https://www2.gov.bc.ca/gov/content/industry/agriculture-seafood/agricultural-land-and-environment/water/water-supply-conservation/livestock-watering-handbook

Obedkoff, W. (2000) "Streamflow in the Omineca-Peace Region". Vancouver, Province of British Columbia, Ministry of Environment, Lands, and Parks Sentlinger, G. (2010) "Regression Analysis for Streamflow Hindcasting", Canadian Society of Hydrological Sciences Working Group, Vancouver, B.C.

Okanagan Basin Water Board. Residential Water Use. Available at: https://www.obwb.ca/wsd/water-usage/residential-water-use

Okanagan Basin Water Board. Okanagan Water Demand Model. Available at: https://www.obwb.ca/wsd/models/okanagan-water-demand-model

Sentlinger, G. (2015) “MFLNRO South Coast Drought Response 2015: Prioritization for Monitoring and Mitigation” Presented at CWRA Vancouver Conference, Richmond .B.C.

Saunders, W. 1999. Preparation of DEMs for use in environmental modeling analysis, in: ESRI User Conference. pp. 24-30.

Sentlinger, G.I. and Christina Metherall. (2016). “South Coast Stewardship Baseline (Brem, Fraser Valley South, Toba, Upper Lillooet) REV 1.0 Contract GS16LMN-018 (Nov 16, 2016)” Aquarius R&D Inc. Vancouver, B.C.

Sentlinger, G.I, Christina Metherall, and Adam Valair.(2017) “Stewardship Baseline: Water Allocations for Watersheds in the South Coast Region” Aquarius R&D Inc, Vancouver, B.C.

Sentlinger, G.I. (2017) “Re: Extrapolation of South Coast Hydrology Model” Jun 29, 2017 Letter Report for Ecofish Research Ltd.

Sentlinger, G.I. and Christina Metherall. 2020 “RSEA Hydrology and Allocation Baseline REV 1.0.3 (Feb 10, 2020)” Vancouver, B.C.

Trabucco, A., and Zomer, R.J. (2009) Global Aridity Index (Global-Aridity) and Global Potential Evapo-Transpiration (Global-PET) Geospatial Database. CGIAR Consortium for Spatial Information. Published online, available from the CGIARCSI

GeoPortal at: http://www.cgiar-csi.org/data/global-aridity-and-pet-database.

Trubilowicz, J.W., R.D. Moore, and J.M. Buttle (2013) “Prediction of streamflow regime using ecological classification zones.” Hydrological Processes 27: 1935–1944. Wikipedia, “Verification and validation” Accessed Jan 31, 2020.

Western Water and Associates (2014). Okanagan Water Allocation Tool Plan. Available at: https://www.obwb.ca/newsite/wp-content/uploads/9_13-049-01_OWAT_Final_Report_May1.pdf

Wiley, J. B., Curran, J. H., Alaska. Dept. of Transportation and Public Facilities., Geological Survey (U.S.). (2003). "Estimating annual high-flow statistics and monthly and seasonal low-flow statistics for ungaged sites on streams in Alaska and conterminous basins in Canada." Anchorage, Alaska: U.S. Dept. of the Interior, U.S. Geological Survey.

TABLES

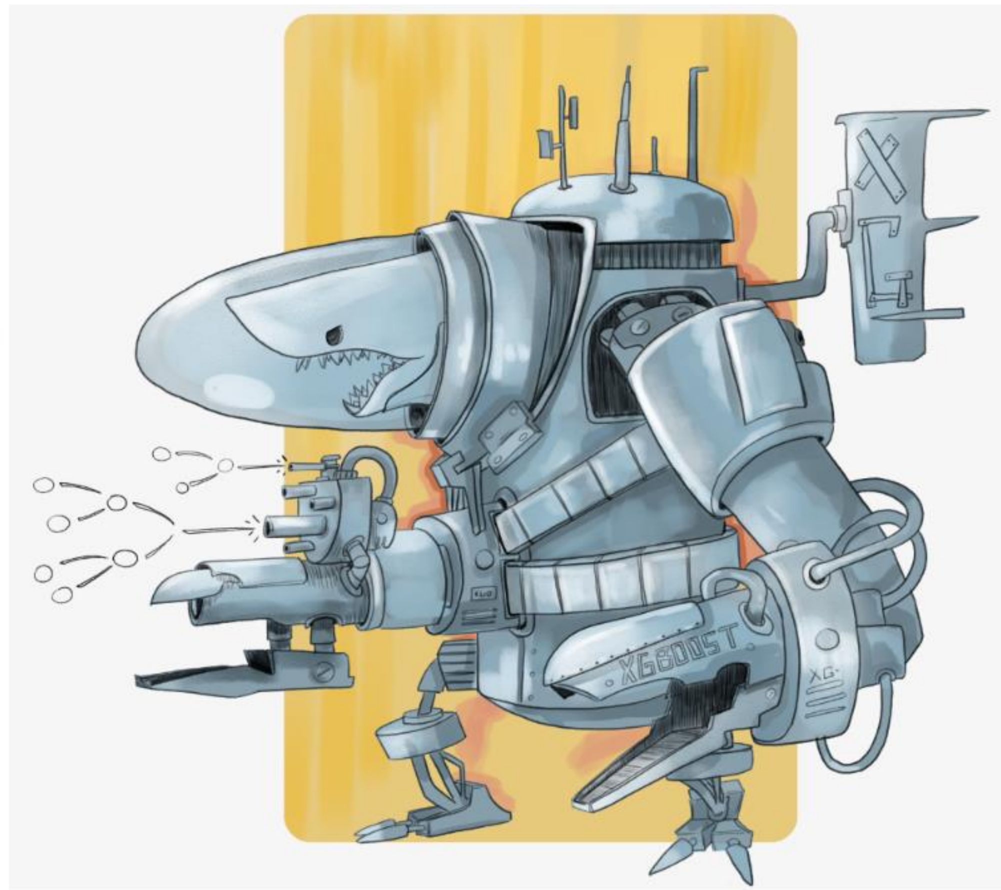


Table 1: Mean Annual Runoff (MAR) Multiple-Regression Hydrological Models

MAR C:\gsentlin\FATHOM_SCI\CUSTOMERS\BCMoe\Projects\WALLE\Data\[WALLY_All_Data_Predict_V0.3.xlsx]MAR zone_summary 2021-10-05 14:29

HZ	Precip (1/mm)	Slope (1/%)	DA (1/km2)	Glc (1/%)	Med.Elev. (1/m)	PET (1/mm)	SolExp (1/%)	Intercept	numVars	N	R2	ADJ R2	MIN R2	STEYX[A] (l/s/km2)	AVG (l/s/km2)	STDEV (l/s/km2)	STEYX%	STDEV%
1	0.0139174			65.9315				17.561925	2	12	89%	88%	83%	6.8	52.8	19.1	13%	36%
2		0.6575049						6.3077619	1	7	62%	55%	62%	2.8	14.7	3.8	19%	26%
3	0.0165891	1.2149078			0.00588157		402.88943	-302.7122	4	19	87%	86%	79%	1.3	13.4	3.5	10%	26%
4		0.4613976						3.7207863	1	7	92%	91%	92%	0.6	6.9	1.9	9%	28%
5	0.0385824				-0.02342039			15.866292	2	7	91%	90%	67%	1.5	19.5	4.3	8%	22%
6				1.7E-12	0.01603453	-0.020897		7.2171322	3	6	100%	99%	97%	0.2	3.5	2.1	5%	59%
7_11_12	0.0296631							-8.509706	1	14	95%	94%	95%	6.4	29.7	25.4	22%	85%
8	2.74E-02	0.3273638			0.01046009			-23.61001	3	23	86%	86%	82%	2.0	11.0	5.1	18%	46%
9						-0.644236		481.76752	1	9	96%	95%	96%	3.5	32.8	14.9	11%	45%
10		2.9105377		-137.891		-0.716665		462.12753	3	8	90%	88%	54%	8.1	77.8	21.7	10%	28%
13	0.0195208	0.6234049						-12.17379	2	8	87%	85%	72%	1.4	29.3	3.4	5%	11%
14	0.0254155	0.5393304		78.5132		-0.088592		63.876085	4	34	95%	94%	94%	3.3	28.7	13.8	12%	48%
15	0.0280974			-81.6295	0.00110522	-0.010901	-34.06498	20.223273	5	43	87%	86%	83%	1.5	5.6	4.0	27%	72%
16				251.705		-0.228466	-241.6055	382.23518	3	14	97%	96%	95%	1.5	15.9	7.3	9%	46%
17	0.0110362							-2.9122	1	9	75%	71%	75%	0.5	2.0	0.9	26%	45%
18				190.401	-0.0339908	-0.072641	-282.7781	326.4955	4	16	95%	94%	88%	3.6	26.7	14.5	13%	54%
19	0.038406	0.5434394	-0.000118	52.4376		0.1397623		-161.7705	5	16	92%	91%	82%	0.9	16.5	3.1	6%	19%
20					0.01934514	-0.06806	-191.3558	177.20749	3	13	89%	88%	76%	2.3	19.2	6.6	12%	34%
21		-0.943468			-0.01163713	-0.341112		373.69242	3	17	91%	90%	86%	2.9	26.5	9.1	11%	34%
22		0.4349858			0.03879515	-0.075759		24.82031	3	18	92%	91%	90%	3.9	32.9	12.8	12%	39%
23	0.0208691	0.2142702		-1.3E-13	0.01949009		54.572822	-72.87323	5	22	90%	90%	84%	1.8	9.8	5.5	18%	56%
24	0.0132972	0.0947976		-1.1E-13	0.00652614		30.284434	-35.05084	5	32	87%	87%	84%	1.1	5.4	2.9	20%	54%
25	0.0113677	1.5121371		93.9385			232.74835	-183.3418	4	23	96%	95%	95%	3.5	30.0	16.0	12%	53%
26	0.0249064			163.882				-13.17485	2	20	78%	77%	67%	12.9	68.3	26.1	19%	38%
27	0.0311505	2.7282834		-4775.21		0.4378022		-437.8335	4	27	94%	94%	92%	9.0	70.6	36.0	13%	51%
28	0.0227473			1752.78				-4.49823	2	35	77%	76%	76%	10.5	50.2	21.1	21%	42%
29		5.3550654	0.0165782		-0.11074974	-0.495089		418.65451	4	20	75%	73%	63%	18.9	101.4	35.7	19%	35%
Count	16	15	2	14	12	13	8	HZ		Average	88%	87%	82%		29.7		19%	35%
XGBoost[C]	1112	33.2	12.3	57.3	25.1	63.1	29.4	19.7	8	480	96%	96%	90%	5.9	30.7	30.3	19%	99%

NOTES

[A] Note that the Standard Error is not %error in the variable. If we are estimating the MAR, the STEYX is the uncertainty in l/s/km ^{2} .

For example if the estimated MAR is 32 l/s/km ^{2} , and the STEYX is 4, then the uncertainty is 32+/-4 l/s/km ^{2} .

[B] The STEYX% and STDEV% are expressed as percent of the AVG value, and intended to show that the STEYX of the model is always better than the STDEV

[C] The XGBoost results ar not slopes, but "Gain" used in the model. R2 results are between predicted value and measured.

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Table 2: S-7Q10/MAD Multiple-Regression Hydrological Models

S-7Q10/MAD C:\gsentlin\FATHOM_SCI\CUSTOMERS\BCMoe\Projects\WALLE\Data\[WALLY_All_Data_Predict_V0.3.xlsx]S-7Q10MAD zone_summary 2021-10-05 14:29

HZ	Precip (1/mm)	Slope (1/%)	DA (1/km2)	Glc (1/%)	Med.Elev. (1/m)	PET (1/mm)	SolExp (1/%)	Intercept	numVars	N	R2	ADJ R2	MIN R2	STEYX (%MAD)	AVG (%MAD)	STDEV (%MAD)	STEYX%	STDEV%
1			1.09E-05			-0.0035825		2.6660504	2	12	86%	84%	82%	7%	41%	18%	18%	44%
2							-5.8428146	4.5008369	1	7	60%	52%	60%	7%	47%	9%	14%	19%
3	-0.000760985	-0.0440978			0.00058561	-0.0022596	-23.077924	18.262274	5	19	89%	88%	76%	5%	49%	14%	10%	29%
4					0.00049263			-0.302963	1	7	92%	90%	92%	6%	18%	18%	34%	101%
5	-0.000459581					-0.0028864		2.8251825	2	7	72%	66%	52%	5%	49%	8%	10%	16%
6			2.39E-06	0				0.0100312	2	5	49%	32%	49%	2%	2%	2%	85%	92%
7_11_12			4.75E-06	6.0345211	0.00010788			-0.0119486	3	13	87%	85%	68%	5%	18%	13%	29%	74%
8		0.0036147	3.44602E-05				-2.3133501	1.6802659	3	22	53%	51%	46%	11%	22%	16%	51%	71%
9				9.1427007	-0.0003751		16.8733914	-10.934655	3	9	71%	67%	42%	7%	40%	12%	18%	30%
10				1.6916378				0.1790462	1	8	80%	76%	80%	5%	28%	10%	18%	35%
13				1.5843574				0.3495266	1	8	32%	20%	32%	9%	40%	9%	21%	22%
14			1.26968E-05	3.2749671			-2.3589166	1.8086263	3	34	68%	67%	64%	10%	33%	17%	31%	53%
15					0.00054342			-0.5529625	1	34	49%	47%	49%	15%	18%	20%	83%	112%
16		0.0073726	7.68249E-06					-0.000835	2	14	84%	83%	82%	8%	21%	18%	35%	83%
17					0.00018734	0.00112656		-1.1725251	2	8	47%	38%	14%	3%	12%	4%	25%	29%
18	-6.83072E-05		8.4338E-06		0.00015432		-1.5900314	1.2486535	4	16	51%	47%	30%	4%	43%	5%	9%	13%
19				4.1628353				0.3524944	1	16	27%	22%	27%	7%	38%	8%	19%	20%
20		0.0255426				0.00136688	7.1098267	-6.4216262	3	13	52%	48%	37%	6%	18%	8%	33%	44%
21					0.00036846			-0.3686224	1	17	24%	18%	24%	14%	28%	15%	51%	55%
22		0.0183432						-0.2729579	1	18	79%	78%	79%	7%	24%	15%	29%	60%
23					-0.0001452			0.2685306	1	20	19%	15%	19%	5%	7%	5%	70%	74%
24		0.0058355						-0.0004932	1	29	21%	18%	21%	5%	8%	6%	71%	77%
25	-0.000105874			0.7804999		-0.0020648	-3.7210034	4.5469708	4	23	95%	95%	93%	5%	28%	22%	18%	76%
26		0.0013972	4.27147E-05		0.00046639	-0.001773		0.9844974	4	20	90%	89%	85%	5%	35%	14%	13%	39%
27	-4.35963E-05			18.427782	5.6118E-05		-0.2536971	0.3164035	4	24	30%	26%	18%	3%	5%	4%	59%	67%
28				7.6892977				0.0553181	1	31	16%	13%	16%	7%	7%	8%	106%	112%
29	-7.12431E-05			26.135705	0.00015046	-0.0009329	-0.6732383	1.4101217	5	19	64%	62%	52%	4%	6%	6%	58%	91%
Count	6	7	8	11	12	8	10	HZ		Average	59%	55%	51%		25%		38%	57%
XGBoost[C]	0.3%	0.2%	0.5%	10.2%	0.8%	0.3%	0.3%	2.4%	8	452	92%	92%	81%	6%	24%	19%	24%	81%

NOTES

A] Note that the Standard Error is not %error in the variable. If we are estimating the S-7Q10/MAD, the STEYX is the uncertainty in the estimate of this value. For example if the estimated S-7Q10/MAD is 5%MAD, and the STEYX is 0.032, then the estimate is 5.0%+/-3.2%.

B] The STEYX% and STDEV% are expressed as percent of the AVG value, and intended to show that the STEYX of the model is always better than the STDEV

[C] The XGBoost results ar not slopes, but "Gain" used in the model. R2 results are between predicted value and measured.

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Table 3: A-30Q10/MAD Multiple-Regression Hydrological Models

A-30Q5/MAD C:\gsentlin\FATHOM_SCI\CUSTOMERS\BCMoe\Projects\WALLE\Data\[WALLY_All_Data_Predict_V0.3.xlsx]A-30Q5MAD zone_summary 2021-10-05 14:29

HZ	Precip (1/mm)	Slope (1/%)	DA (1/km2)	Glc (1/%)	Med.Elev. (1/m)	PET (1/mm)	SolExp (1/%)	Intercept	numVars	N	R2	ADJ R2	MIN R2	STEYX (%MAD)	AVG (%MAD)	STDEV (%MAD)	STEYX%	STDEV%
1					-0.0001037			0.2022204	1	12	68%	64%	68%	1.7%	8%	2.8%	21%	33%
2						0.0026982		-1.6124462	1	7	17%	1%	17%	2.9%	13%	2.7%	21%	20%
3		-0.0138877			-0.0001927		-11.473083	8.4830746	3	19	72%	71%	64%	2.7%	14%	4.9%	20%	36%
4		-0.0002481				-0.0014879	3.0165572	-0.8836718	3	4	100%	100%	99%	0.0%	4%	1.7%	0%	38%
5			1.00223E-06					0.081515	1	7	52%	43%	52%	1.3%	10%	1.6%	13%	16%
6	-2.07E-05	0.0061489						0.001002	2	3	100%	100%	100%	0.0%	2%	1.9%	0%	78%
7_11_12		0.0024038	2.34E-06		1.9936E-05			0.0190752	3	13	61%	57%	45%	2.7%	9%	4.0%	30%	44%
8			1.54104E-05					0.0937475	1	22	35%	32%	35%	7.6%	14%	9.0%	53%	63%
9							2.2066705	-1.3724643	1	9	74%	70%	74%	2.0%	12%	3.4%	16%	27%
10					-0.0001385	0.0006356	0.6866297	-0.6236379	3	8	91%	90%	55%	0.8%	10%	2.5%	8%	24%
13						0.0017573		-1.3445258	1	8	77%	73%	77%	1.4%	10%	2.4%	13%	24%
14	-0.000235183	0.0092282	4.87767E-06	-1.2964415		-0.0009994		1.0713013	5	34	61%	60%	48%	3.8%	14%	5.9%	27%	42%
15	-0.000269299				0.00015308		-2.0604616	1.5028197	3	36	29%	27%	20%	8.1%	11%	9.3%	70%	81%
16		0.0054241		2.2264184	0.0001265	0.0034751	-1.7258386	-2.0217273	5	14	94%	94%	81%	1.4%	12%	5.2%	11%	43%
17				0		0.0006977		-0.4987027	2	8	33%	21%	33%	2.8%	13%	3.0%	21%	22%
18		0.0094535				0.0032474		-2.8210102	2	15	68%	65%	64%	7.2%	15%	11.9%	49%	80%
19	-0.000358027							0.5282761	1	16	58%	55%	58%	3.7%	16%	5.3%	23%	33%
20	7.05012E-05	0.0063533		26.849976	-0.0002492	0.0007597		-0.3713642	5	13	60%	56%	24%	2.9%	12%	4.2%	24%	34%
21			1.47568E-06					0.1517857	1	17	15%	9%	15%	7.7%	16%	7.9%	48%	49%
22	7.83152E-05	0.0095554		-0.8594227	-0.0002738	0.0001872		0.0384913	5	18	71%	69%	54%	3.0%	12%	5.4%	25%	45%
23		0.005113					-0.9585345	0.6893367	2	21	23%	19%	19%	4.8%	8%	5.2%	63%	68%
24		0.0067374						-0.0020039	1	28	42%	40%	42%	3.9%	9%	4.9%	44%	56%
25				-0.2915352	-5.811E-05	-0.000921		0.9558397	3	23	50%	48%	43%	3.3%	10%	4.5%	32%	43%
26			1.53808E-05	-0.4969695		-0.0004911	-0.3969349	0.8329379	4	20	67%	65%	49%	3.3%	16%	5.4%	20%	33%
27	-3.82581E-05			20.99154		-0.0004411	-0.4208537	0.8597228	4	24	27%	24%	18%	3.4%	8%	3.8%	40%	45%
28		0.0007746	7.25353E-05	9.0618081	3.2312E-06			0.0231577	4	32	40%	38%	32%	5.9%	8%	7.4%	77%	97%
29	-8.60291E-05		9.44487E-05		0.00028002	-0.0019073	-1.0436186	2.4082713	5	19	68%	67%	53%	4.3%	9%	7.2%	48%	81%
Count	8	12	8	9	11	14	10	HZ		Average	58%	54%	50%		11%		30%	47%
XGBoost[C]	0.15%	0.19%	0.11%	0.13%	0.11%	0.16%	0.19%	0.30%	8	452	73%	73%	24%	3.6%	12%	6.9%	31%	60%

NOTES

A] Note that the Standard Error is not %error in the variable. If we are estimating the S-7Q10/MAD, the STEYX is the uncertainty in the estimate of this value. For example if the estimated S-7Q10/MAD is 5%MAD, and the STEYX is 0.032, then the estimate is 5.0%+/-3.2%.

B] The STEYX% and STDEV% are expressed as percent of the AVG value, and intended to show that the STEYX of the model is always better than the STDEV

[C] The XGBoost results ar not slopes, but "Gain" used in the model. R2 results are between predicted value and measured.

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Table 4: MayQ/MAD Multiple-Regression Hydrological Models

MayQ/MAD C:\gsentlin\FATHOM_SCI\CUSTOMERS\BCMoe\Projects\WALLE\Data\[WALLY_All_Data_Predict_V0.3.xlsx]MayQ_MAD zone_summary 2021-10-05 14:29

HZ	Precip (1/mm)	Slope (1/%)	DA (1/km2)	Glc (1/%)	Med.Elev. (1/m)	PET (1/mm)	SolExp (1/%)	Intercept	numVars	N	R2	ADJ R2	MIN R2	STEYX (%MAD)	AVG (%MAD)	STDEV (%MAD)	STEYX%	STDEV%
1						0.010507		-5.2848346	1	12	68%	65%	68%	33.9%	144%	54.7%	24%	38%
2							49.951324	-32.811291	1	7	67%	61%	67%	48.2%	167%	71.3%	29%	43%
3		0.1849321			-0.0017733		113.91185	-76.783016	3	19	77%	76%	67%	27.0%	161%	53.3%	17%	33%
4							118.43793	-79.774658	1	7	80%	76%	80%	56.9%	292%	107.8%	19%	37%
5						0.0136406		-7.3554435	1	7	39%	27%	39%	33.0%	164%	35.6%	20%	22%
6					-0.0033002			6.6869028	1	6	86%	83%	86%	19.8%	374%	44.0%	5%	12%
7_11_12						0.0102979		-5.944528	1	14	75%	73%	75%	48.9%	257%	91.3%	19%	35%
8	1.73E-03		-0.000191316				34.386272	-21.455106	3	23	44%	42%	32%	92.0%	304%	117.8%	30%	39%
9	-0.003233049						-89.876096	67.677059	2	9	75%	71%	60%	40.0%	207%	70.3%	19%	34%
10		-0.0335001						2.7406365	1	8	58%	50%	58%	21.8%	172%	29.0%	13%	17%
13				-7.658888				1.9549105	1	8	56%	48%	56%	25.4%	170%	33.0%	15%	19%
14	0.001187598	-0.0971269	-8.63357E-05			0.0152144		-9.5492308	4	34	70%	69%	62%	55.8%	240%	98.2%	23%	41%
15	0.005985972			-72.699389	0.00043602	0.0088502		-8.052215	4	43	39%	38%	32%	117.9%	366%	147.7%	32%	40%
16				-73.557498		-0.0325026	75.169167	-19.993176	3	14	90%	89%	72%	33.9%	304%	98.9%	11%	33%
17		-0.2261678						6.0853399	1	9	52%	45%	52%	78.2%	365%	99.6%	21%	27%
18					-0.0016125			4.7090514	1	16	19%	13%	19%	40.2%	158%	41.7%	26%	26%
19		0.0916417				0.0204322		-18.355812	2	16	65%	63%	57%	28.9%	230%	45.9%	13%	20%
20		-0.0856741						5.4789625	1	13	58%	54%	58%	46.8%	359%	66.2%	13%	18%
21		-0.1319719						6.2535808	1	17	50%	47%	50%	73.3%	262%	97.6%	28%	37%
22	0.000528921	-0.1455714			0.00324398	0.0116961		-9.0235421	4	18	93%	93%	91%	30.5%	291%	110.4%	10%	38%
23	-0.003907236						16.660807	-4.7559507	2	22	44%	41%	33%	58.4%	417%	74.6%	14%	18%
24	-0.000416164	-0.1739241	-0.000517504		-0.003945	-0.0024417		15.602293	5	32	34%	32%	22%	143.4%	479%	170.6%	30%	36%
25			-0.000198834		-0.0027313	0.007587	26.268491	-16.8657	4	23	92%	91%	89%	40.9%	241%	134.4%	17%	56%
26	-0.000168423		-9.39697E-05		-0.0013911	0.0054736		-0.2048198	4	20	81%	80%	64%	20.0%	155%	43.4%	13%	28%
27					0.00092948	-0.0021912		2.3776025	2	27	91%	91%	90%	15.0%	99%	48.4%	15%	49%
28	-0.000247195				0.0019922			0.3104494	2	35	71%	70%	70%	25.4%	97%	46.0%	26%	48%
29	-7.95285E-05				0.00124147			0.3485786	2	20	72%	71%	71%	14.7%	77%	26.5%	19%	35%
Count	10	9	5	3	11	12	8	HZ		Average	65%	61%	60%		243%		19%	33%
XGBoost[C]	120.90%	23.63%	59.48%	110.13%	69.35%	100.93%	40.96%	85.71%	8	480	90%	90%	81%	47.1%	249%	148.9%	19%	60%

NOTES

A] Note that the Standard Error is not %error in the variable. If we are estimating the S-7Q10/MAD, the STEYX is the uncertainty in the estimate of this value. For example if the estimated S-7Q10/MAD is 5%MAD, and the STEYX is 0.032, then the estimate is 5.0%+/-3.2%.

B] The STEYX% and STDEV% are expressed as percent of the AVG value, and intended to show that the STEYX of the model is always better than the STDEV

[C] The XGBoost results ar not slopes, but "Gain" used in the model. R2 results are between predicted value and measured.

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Table 5: JanQ/MAD Multiple-Regression Hydrological Models

JanQ/MAD C:\gsentlin\FATHOM_SCI\CUSTOMERS\BCMoe\Projects\WALLE\Data\[WALLY_All_Data_Predict_V0.3.xlsx]SepQ_MAD zone_summary 2021-10-05 14:38

HZ	Precip (1/mm)	Slope (1/%)	DA (1/km2)	Glc (1/%)	Med.Elev. (1/m)	PET (1/mm)	SolExp (1/%)	Intercept	numVars	N	R2	ADJ R2	MIN R2	STEYX (%MAD)	AVG (%MAD)	STDEV (%MAD)	STEYX%	STDEV%
1					-0.0009744			1.3544553	1	12	88%	87%	88%	8.6%	25%	23.0%	34%	92%
2			-3.40342E-06					0.2519406	1	7	16%	-1%	16%	5.5%	23%	5.1%	24%	22%
3	2.07293E-05	-0.0121039		-1.3217209	-0.000237		-11.60583	8.6724555	5	19	70%	68%	46%	3.3%	21%	5.7%	16%	27%
4					0.00010829			-0.0560308	1	7	79%	74%	79%	2.4%	5%	4.4%	47%	86%
5			1.19736E-06					0.1404319	1	7	55%	46%	55%	1.5%	16%	1.9%	9%	12%
6		0.0169761						-0.0063087	1	6	88%	86%	88%	2.1%	6%	5.1%	34%	81%
7_11_12		-0.0266191				-0.0062711		5.9503514	2	14	96%	96%	94%	10.1%	37%	46.4%	28%	127%
8			2.78928E-05		-0.0004782			0.7679437	2	23	53%	50%	41%	10.6%	30%	14.7%	35%	49%
9							3.2780434	-1.9554043	1	9	37%	28%	37%	6.4%	27%	7.1%	24%	27%
10				-1.7559662				0.4778468	1	8	56%	49%	56%	9.4%	37%	12.3%	25%	33%
13			4.29267E-06	-0.7390246	-7.246E-05		-1.1282621	1.0587452	4	8	99%	99%	81%	0.4%	17%	3.3%	3%	20%
14	-0.000320353	0.0136578	3.18249E-06	-1.5690375				0.342832	4	34	59%	58%	48%	6.0%	26%	9.2%	23%	35%
15	-0.000816892			5.3422787				0.7365092	2	43	25%	23%	23%	12.6%	25%	14.2%	50%	56%
16						0.003777	-3.3117074	-0.7880001	2	14	81%	80%	63%	2.7%	24%	5.8%	11%	24%
17		0.0229189						0.0610683	1	9	55%	49%	55%	7.4%	31%	9.8%	24%	32%
18		0.0162034				0.0038962		-3.4999937	2	16	62%	59%	55%	9.1%	21%	13.8%	44%	67%
19	-0.000329286				-0.0002145			0.9793477	2	16	74%	72%	69%	3.5%	23%	6.5%	15%	28%
20		0.0074442			-0.0002257	0.0014029		-0.8432994	3	13	64%	60%	45%	3.6%	22%	5.5%	16%	25%
21			5.70628E-06					0.3032733	1	17	19%	14%	19%	25.3%	34%	26.5%	75%	79%
22	0.00015408			-1.7582986				0.0614587	2	18	44%	40%	36%	5.0%	23%	6.2%	22%	28%
23				-1.881E-13	-0.0002352		-0.9536663	1.1699538	3	22	45%	43%	43%	5.7%	18%	7.4%	32%	42%
24	0.000240838	0.0062496		-1.576E-13	-0.0002107	-0.0001424		0.4057149	5	32	17%	14%	10%	9.4%	20%	10.0%	46%	49%
25	9.22481E-05		2.53136E-05	-1.0650558			0.2020072	0.0676526	4	23	76%	75%	70%	5.0%	30%	9.9%	17%	33%
26	6.61713E-05			-1.1287054	-0.0005536		-1.6906271	2.2943255	4	20	84%	83%	78%	7.7%	50%	18.3%	15%	37%
27	1.53908E-05				-0.0007553	0.0032911		-0.8864701	3	27	93%	93%	91%	12.5%	159%	46.9%	8%	29%
28	0.000182435	-0.0042568			-0.0010265	0.0057859		-2.6275294	4	35	63%	62%	60%	33.0%	175%	52.7%	19%	30%
29	0.000264232	-0.023786	-0.000291112		-0.0004038	0.0072974		-4.0627329	5	20	64%	62%	49%	15.4%	170%	24.3%	9%	14%
Count	11	10	8	10	13	8	7	HZ		Average	62%	58%	55%		41%		26%	44%
XGBoost[C]	1.39%	0.33%	0.72%	0.47%	8.24%	0.44%	0.43%	162.56%	8	480	98%	98%	97%	8.4%	50%	59.1%	17%	118%

NOTES

A] Note that the Standard Error is not %error in the variable. If we are estimating the S-7Q10/MAD, the STEYX is the uncertainty in the estimate of this value. For example if the estimated S-7Q10/MAD is 5%MAD, and the STEYX is 0.032, then the estimate is 5.0%+/-3.2%.

B] The STEYX% and STDEV% are expressed as percent of the AVG value, and intended to show that the STEYX of the model is always better than the STDEV

[C] The XGBoost results ar not slopes, but "Gain" used in the model. R2 results are between predicted value and measured.

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Table 6: Strengths and Weaknesses of the Two Regression Models

C:\gsentlin\FATHOM_SCI\CUSTOMERS\BCMoe\Projects\WALLE\Data\[WALLY_All_Data_Predict_V0.3.xlsx]Strengths and Weakness 2021-10-06 21:37

XGBoost		MkMGR	
Strength	Weakness	Strength	Weakness
Powerful, i.e. very little supervision required to achieve high accuracy	Difficult to understand the diagnostics and the applicability of results. Training and Test results extremely different and a good training result in no way guarantees a good test result.	Powerful, but better results achieved with supervision and professional guidance	Requires more suprevision, but this also gives the models more meaning and us more confidence in the results. Training and Test data results are much closer than for XGBoost
A hydro-stat for the entire province can be captured in a single model, with HZ as one of the inputs.	Each model is a bit different, and must be saved as a file. Alternately, a user could generate their own XGBoost model using python	The same algorithm, taking the model that results in the highest minimum R2 from 30+ iterations, can be applied to all HZ automatically.	A slightly different "best model" results from each random iteration, although the primary predictor remains constant.
Can be codified and reproduced.	Requires coding skills and knowledge of XGBoost	Can be reproduced from paper records alone	
	Potentially seen as another Black Box generating results that can seem suspicously good for training data.	Based on simple multi-variate regression modeling	

Notes

[A] MkMGR is Modified k-fold Multivariate Geospatial Regression model.

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Table 7: Monthly Water Allocation Coefficients

Code	Consumptive vs. Non-Consumptive	Purpose	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum	Reference/Note
02I47	Consumptive	Heat Exchanger, Residential	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Water use likely higher in winter months than summer months. In BC, water use for heating is more common than water use for cooling.
WSA06	Non-consumptive	Ice & Snow Making	M3/Y	3	1.5	0.5	0	0	0	0	0	0	0	3	4	12	There are more snow-making licenses in this category and they are larger, so uses estimated coefficients for snowmaking. Caution should be taken if upstream licenses are used for icemaking, as diversions for icemaking occur in August, which typically coincides with low flows.
02I36	Consumptive	Processing & Mfg: Wharves	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Processing' (Ecofish, 2015). Water use is relatively consistent throughout year where water is used for commericial activity, but water use typically increases in summer with visitation (5-15% approximately) (Mike Carter, Port Alberni Port Authority). Landscaping irrigation is likely typically very limited at wharves.
WSA01	Consumptive	Domestic (WSA01)	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Domestic' (Ecofish, 2015). Water use likely to double in summer due to irrigation use (irrigation typically occurs May-September, with highest use in June-Aug). Summer use is on average twice winter use. Could potentially use coefficients of 0.5 in the winter.
02I30	Non-consumptive	Ice & Snow Making: Snow	M3/Y	3	1.5	0.5	0	0	0	0	0	0	0	3	4	12	Most significant use is before Christmas (Arthur DeJong, Whistler Blackcomb). Diversion begins at some point in November, based on weather and is highest in December, in preparation for holiday visitation. Use continues (based on season), through Jan, Feb, with some use in Mar based on weather conditions.
02I29	Consumptive	Processing & Mfg: Shipyard	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	No current licenses. Used coefficients for 'Processing' (Ecofish, 2015).
05H	Consumptive	O & G: Drilling	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Varies with market conditions and specific license conditions (e.g. EFN requirements). Use is fully consumptive (Suzan Lapp, BC Oil and Gas Commission).
02I21	Consumptive	Camps & Pub Facil: Institutions	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Camps' (Ecofish, 2015). Monthly use will vary by user. Some users may use more water in the summer (e.g., due to irrigation), whereas others may use more in the winter (e.g. schools with winter attendance). For schools, May, June, and to a lesser extent, September, are likely to have higher use due to high indoor use and irrigation combined (e.g. 25% higher) (source: water license holder for this purpose).
02I12	Consumptive	Misc Indl: Fire Protection	M3/S, M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Fire Protection' (Ecofish, 2015). Most of the water is used for structure fires and motor vehicle accidents (MVAs) and those can happen anytime of year. Assume water use is consistent throughout the year, as structure fires and MVAs may be more likely to occur in the winter, and wildfire is more likely to occur in the summer (Cody, Cariboo Regional District).
02I12	Consumptive	Misc Indl: Fire Protection	M3/Y	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Fire Protection [MY]' (Ecofish, 2015).
02I39	Consumptive	Vehicle & Eqpt: Mine & Quarry	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Water more likely to be used more in spring through fall than winter, but may vary (Jeremy Roscoe).
02I33	Consumptive	Vehicle & Eqpt: Truck & Eqp Wash	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Truckwashing' (Ecofish, 2015).
02I37	Consumptive	Camps & Pub Facil: Work Camps	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Work Camps' (Ecofish, 2015). Water use likely to be higher in summer for some camps due to higher populations in summer, but this is not the case for all camps.
02HU	Consumptive	Marine Export - Used (Inactive)	M3/Y	1	1	1	1	1	1	1	1	1	1	1	1	12	No current licenses
02I24	Non-consumptive	Misc Indl: Overburden Disposal	TF	1	1	1	1	1	1	1	1	1	1	1	1	12	Typically used when a gully is filled and is likely to be more an approach to land and watercourse protection/management, than a diversion (Barry Watson). Likely relatively consistent 'use'.
07C	Non-consumptive	Power: General	M3/S, M3/Y	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Power-General' (Ecofish, 2015).
02I43	Consumptive	Transport Mgmt: Tunnelling/Well Drilling	DNE	1	1	1	1	1	1	1	1	1	1	1	1	12	No current licenses
02I11	Consumptive	Processing & Mfg: Fire Prevention	M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Processing' (Ecofish, 2015). It is likely that the majority of the use (e.g. 80%) would be through summer and fall (e.g, spraying vegetation to reduce fire risk), but it is likely to vary by application (Barry Watson).
02I23	Consumptive	O & G: Oil Fld Inject. (non-deep GW)	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	
02C	Consumptive	Cooling	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Processing' and 'Industrial' (Ecofish, 2015). Water use likely consistent due to challenges of shutting down and starting up processing operations.
02F	Consumptive	Lwn, Fairway & Grdn: Watering	M3/Y	0	0	0	0	1.2	3	3.6	3	1.2	0	0	0	12	Coefficients for Irrigation. Some relatively small volumes may be used in April and October in some locations for some licenses.
01A	Consumptive	Domestic	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Domestic' (Ecofish, 2015). Note: water use likely to double in summer due to irrigation use (irrigation typically occurs May-September, with highest use in June-Aug)r. Because use is up to half of max demand in the winter, coefficients could potentially be 0.5 in the winter in some cases.
02I07	Consumptive	Indl Waste Mgmt: Effluent	M3/Y	0.95	0.95	0.95	0.95	1.05	1.07	1.08	1.08	1.07	0.95	0.95	0.95	12	Coefficients for 'Industrial' (Ecofish, 2015). Water use likely to be consistent througout the year with some increase in summer due to additional maintenance activities and potentially dilution requirements.
02I26	Non-consumptive	River Improvement	TF	1	1	1	1	1	1	1	1	1	1	1	1	12	Generally, the intent is to take water from a stream and place in another location. All existing licenses have units of TF (non-consumptive). In some cases, water may be returned to the same stream and it may be non-consumptive (Barry Watson).
02I41	Consumptive	Livestock & Animal: Kennel	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Stockwatering' (Ecofish, 2015).
WSA04	Consumptive	Crop Harvest, Protect & Compost	M3/Y	0	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	1.2	0	12	This category contains several uses that happen at very different times and have very different returns flows. Given the variability within this category, water use is distributed equally through the months with the greatest likelihood of use (Feb-Nov). In areas that are under stress or places where there are large licenses for this purpose, further investigation is required.
09B	Consumptive	Mineralized Water: Comm. Pool	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Use likely variable, Given that units in M3/day, assume consistent use.
02I16	Consumptive	Indl Waste Mgmt: Garbage Dump	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Industrial' and 'Sewage Disposal' (Ecofish, 2015).
02I35	Consumptive	Waterworks: Water Delivery	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Bottle Sales' (Ecofish, 2015).
12A	Non-consumptive	Stream Storage: Power	M3/Y	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Storage-Power' (Ecofish, 2015).
05B	Consumptive	Mining: Washing Coal	M3/D, M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	Significant volumes of water used without any particularly seasonality to use. Water goes into a tailing pond with a long retention time. Assume fully consumptive (Jeremy Roscoe).
02A	Consumptive	Pulp Mill	M3/D, M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Pulp Mills' (Ecofish, 2015).
02I01	Consumptive	Vehicle & Eqpt: Brake Cooling	M3/D, M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	Use uncommon and likely greater in summer and fully consumptive, as water evaporates (Jeremy Roscoe, Barry Watson).
02I	Consumptive	Industrial - Misc (Inactive)	DNE	1	1	1	1	1	1	1	1	1	1	1	1	12	No current licenses. Used coefficients for 'Industrial' and 'Processing' (Ecofish, 2015).
02E	Consumptive	Pond & Aquaculture	M3/S, M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Water use for this type of use typically does not vary from month to month (Gary Robinson, Kuterra [license holder for purpose])
02I15	Consumptive	Livestock & Animal: Game Farm	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Stockwatering' (Ecofish, 2015).
00B	Consumptive	Waterworks (other than LP)	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Waterworks (Other) [M3/D]' (Ecofish, 2015).

Table 7: Monthly Water Allocation Coefficients (cont.)

Code	Consumptive vs. Non-Consumptive	Purpose	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum	Reference/Note
00B	Consumptive	Waterworks (other than LP)	M3/Y	0.8	0.8	0.8	0.8	1	1.2	1.6	1.6	1	0.8	0.8	0.8	12	Same as Waterworks: Local Provider. Water use typically doubles in peak summer months due to increased use for irrigation, washing and bathing, tourism, etc.
02G	Consumptive	Fresh Water Bottling	M3/D, M3/Y	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Bottle Sales' (Ecofish, 2015).
11C	Non-consumptive	Conservation: Construct Works	M3/S, M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Conserv.-Use of Water' (Ecofish, 2015).
11B	Non-consumptive	Conservation: Use of Water	M3/S, M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Conserv.-Use of Water' (Ecofish, 2015).
05C	Consumptive	Mining: Processing Ore	M3/D, M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Processing' (Ecofish, 2015). Water use consistent through out year (Jeremy Roscoe). The water use would be entirely dependent on how much they were processing, which may change seasonally but shouldn't. Processing plants are expensive so they generally run at full capacity all the time. Mostly consumptive.
WSA13	Consumptive	Industrial Waste Mgmt	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Industrial' and 'Sewage Disposal' (Ecofish, 2015).
02H	Consumptive	Bulk Shipment for Marine Trans	DNE	1	1	1	1	1	1	1	1	1	1	1	1	12	No current licenses.
02I28	Consumptive	Indl Waste Mgmt: Sewage Disposal		1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Sewage Disposal' (Ecofish, 2015). Typically small volumes of water that are used fairly consistently thoughout the year (staff at City of Vernon, District of Squamish [license holders for this purpose]).
05D	Consumptive	Mining: Placer	M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	While there are several water licenses for the whole year, water diversion for this purpose only occurs in summer months (from April-end of October or less) (Jeremy Roscoe). Typically water is taken out of a stream, sprayed on rock nearby, then sent to a settling pond, where sediment settles out, then water infiltrates through the gravel back into the watershed or stream indirectly. Operations typically occur May til end the end of October (Barry Watson, Jeremy Roscoe). Most license periods vary from 6/7 months to a year.
WSA07	Consumptive	Misc Indust	M3/S, M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Industrial' (Ecofish, 2015).
WSA07	Consumptive	Misc Indust	M3/S, M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Industrial' (Ecofish, 2015).
02I02	Consumptive	Camps & Pub Facil: Non-Work Camps	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Camps' (Ecofish, 2015). Likely higher use in summer for many users.
09A	Consumptive	Mineralized Water: Bottling & Dist	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Bottle Sales' (Ecofish, 2015).
08A	Non-consumptive	Stream Storage: Non-Power	M3/Y	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for Storage-Non Power' (Ecofish, 2015).
05A	Consumptive	Mining: Hydraulic	M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	While some licenses are for use for the whole year, this use typically occurs May-end of October. New licenses for this purpose are not allowed in BC anymore and there are only 3 active licenses. Water use involves using water pressure to remove material from high banks to get it lower down to get it into a sluicebox for placer mining purposes. Water would be returned to system in a highly sediment laden form (the use involves hosing water at a hillside and water re-enters the creek) (Jeremy Roscoe).
02I38	Non-consumptive	Fish Hatchery	M3/D, M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	Non-consumptive, most use is in Feb-Apr and use is similar across fish hatcheries (Jordan Uittenbogaard, Tenderfoot Hatchery).
00A	Consumptive	Waterworks: Local Provider	M3/Y	0.8	0.8	0.8	0.8	1	1.2	1.6	1.6	1	0.8	0.8	0.8	12	Water use typically doubles in summer months due to increased use for irrigation, washing and bathing, tourism, etc. In some areas, such as the Okangan, water use can go up by 4 times in the summer. Coefficients are monthly averages, and peak day (day of highest use) is typically much higher.
WSA03	Consumptive	Commercial Enterprise	M3/DAY	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Enterprise [MY]' (Ecofish, 2015).
WSA03	Consumptive	Commercial Enterprise	M3/Y	0.8	0.8	0.8	0.8	1	1.2	1.6	1.6	1	0.8	0.8	0.8	12	On average, use is likely higher in the summer, due to irrigation demand, tourism, higher washing and cooling requirements, etc. For some users such as food and beverage processing plants, use may not peak in the summer months.
05F	Consumptive	O & G: Hydrlc Frctrg (deep GW)	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Varies with market conditions and specific license conditions (e.g. EFN requirements). Use is fully consumptive (Suzan Lapp, BC Oil and Gas Commission).
04B	Consumptive	Land Improve: Indl for Rehab/Remed	M3/Y	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Land Improve' (Ecofish, 2015). Generally, the intent is to take water from a stream and place in another location. In some cases, water may be returned to the same stream and it may be non-consumptive. In other cases, it may be consumptive (classified as consumptive in Rood & Hamilton, 1995 and Ecofish, 2015).
02I17	Consumptive	Grnhouse & Nursery: Grnhouse	M3/D	0	1	1	1	1	1	1	1	1	1	1	0	10	Use often varies, with higher use in summer months and most use between Feb and Nov. Because units are in max M3/D, assume consistent use.
02I31	Consumptive	Livestock & Animal: Stockwatering	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Stockwatering' (Ecofish, 2015, verified with MAFF Livestockwatering Factsheets. Generally, summer water requirements are twice winter requirements. There is generally no return, as the majority of water goes to milk or meat.
WSA02	Consumptive	Camps & Public Facilities	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Camps' and 'Public Facilities (Ecofish, 2015). Water use is likely to be higher in the summer for most users.
WSA10	Consumptive	Well Drill/Transprt Mgmt	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	This category contains a wide range of uses and while water use is likely to go up in the summer and may not occur for some of these purposes in the winter, given that the max units are in M3/D, and the wide range of uses, the coefficents are assumed to be consistent.
02I14	Consumptive	Crops: Frost Protection	M3/Y	0	5	5	2	0	0	0	0	0	0	0	0	12	Based on conversations with Carolyn Teasdale, Stephanie Tam, Ted van der Gulik.
02I08	Consumptive	Transport Mgmt: Dust Control	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	While many licenses are for the full year, the majority of use is likely when there is less precipitation, between April and October.
11A	Non-consumptive	Conservation: Storage	M3/S, M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Conserv.-Constr.Works' and 'Storage-Non Power' (Ecofish, 2015).
02I34	Consumptive	Indl Waste Mgmt: Intake Wash	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	No current licenses. 1 Abandoned license.
07B	Non-consumptive	Power: Commercial	M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Power-Commercial' (Ecofish, 2015).
07A	Non-consumptive	Power: Residential	M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Power-Residential' (Ecofish, 2015).
02I40	Consumptive	Comm. Enterprise: Amusement Park	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Enterprise' (Ecofish, 2015).
01A01	Consumptive	Incidental - Domestic	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Domestic' (Ecofish, 2015). Note: water use likely to double in summer due to irrigation use (irrigation typically occurs May-September, with highest use in June-Aug), and be approximately hal of that in winter. Could potentially use coefficients of 0.5 in the winter.
02I20	Non-consumptive	Ice & Snow Making: Ice	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Water use varies. It is likely greatest in late July, early August (about 25% of yearly water is consumed in this time when the rink is created) and then maintenance use from Sep-Mar for levelling, etc.) (Rob Pakulak, City of Nanaimo). Most arenas remove their ice in March for lacrosse season (March-June) and put their ice back in between June and August because many communities have hockey camps starting in August. (For this reason, water is most likely to be used in late July, early August).

Table 7: Monthly Water Allocation Coefficients (cont.)

Code	Consumptive vs. Non-Consumptive	Purpose	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum	Reference/Note
02I06	Consumptive	Misc Indl: Dewatering	M3/S, TF	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Industrial' (Ecofish, 2015).
02I46	Consumptive	Transport Mgmt: Road Maint.	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	While some water licenses are for the whole year, water use is most likely to happen in the months between Apr-Nov, following precipitation deficits (Barry Watson).
02I19	Consumptive	Hydraulicking (Inactive)	DNE	1	1	1	1	1	1	1	1	1	1	1	1	12	No current licenses.
WSA05	Consumptive	Greenhouse & Nursery	M3/Y	0	0.12	0.12	0.24	1.2	1.68	2.88	2.88	2.04	0.72	0.12	0	12	Use coeffcients for Nurseries. The largest users in this category are nureries, so the coefficients for nursery use are included, as that is a more conservative approach (nurseries use more than greenhouses in summer).
02I32	Consumptive	Swimming Pool	M3/D, TF	1	1	1	1	1	1	1	1	1	1	1	1	12	Use likely varies throughout year.
02I04	Consumptive	Conveying (Inactive)	DNE	1	1	1	1	1	1	1	1	1	1	1	1	12	No current licenses.
WSA08	Consumptive	Livestock & Animal	M3/Y	0.84	0.84	0.84	0.84	0.84	1.44	1.8	1.2	0.84	0.84	0.84	0.84	12	Based on MAFF Livestock Watering Factsheets. Returns are 0 as the water goes to animal/milk/meat.
WSA08	Consumptive	Livestock & Animal	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Stockwatering [MD]' (Ecofish, 2015).
04A	Non-consumptive	Land Improve: General	M3/S, M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Land Improve' (Ecofish, 2015). Generally, the intent is to take water from a stream and place in another location. In some cases, water may be returned to the same stream and it may be non-consumptive. In other cases, it may be consumptive. Identified as consumptive in Rood & Hamilton, 1995.
03B	Consumptive	Irrigation: Private	M3/Y	0	0	0	0	1.2	3	3.6	3	1.2	0	0	0	12	Stephanie Tam (MAFF).
02I27	Consumptive	Misc Indl: Sediment Control	M3/S, M3/Y	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Industrial' (Ecofish, 2015).
02I13	Consumptive	Crops: Flood Harvesting	M3/Y	0	0	0	0	0	0	0	0	3	6	3	0	12	Based on conversations with Carolyn Teasdale, Stephanie Tam, Ted van der Gulik.
02I23	Consumptive	O&G: Oil Fld Inject (non-deep GW)	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Varies with market conditions and specific license conditions (e.g. EFN requirements). Use is fully consumptive (Suzan Lapp, BC Oil and Gas Commission).
02I09	Consumptive	Camps & Pub Facil: Exhibition Grnds	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Camps' and 'Public Facilities' (Ecofish, 2015).
08B	Non-consumptive	Aquifer Storage: NP	M3/Y	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Storage-Non Power' (Ecofish, 2015). This would be associated with a diversion purpose.
WSA12	Consumptive	Vehicle & Equipment	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Truckwashing' (Ecofish, 2015).
02I42	Consumptive	Lwn, Fairway & Grdn: Res L/G	M3/Y	0	0	0	0	1.2	3	3.6	3	1.2	0	0	0	12	Based on variations in use for Irrigation. It is likely that most water use would occur during growing months (May-Sep) but in some areas, may occur in Apr-Oct..
WSA11	Consumptive	Lawn, Fairway & Garden	M3/Y	0	0	0	0	1.2	3	3.6	3	1.2	0	0	0	12	Based on variations in use for Irrigation. It is likely that most water use would occur during growing months (May-Sep) but in some areas, may occur in Apr-Oct..
WSA09	Consumptive	Processing & Manufacturing	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Processing' (Ecofish, 2015).
03A	Consumptive	Irrigation: Local Provider	M3/Y	0	0	0	0	1.2	3	3.6	3	1.2	0	0	0	12	Coefficients obtained from BC Agriculture Water Calculator and Agriculture Water Demand Model runs for several BC watersheds (Delta, Kelowna, Koksilah). Confirmed with Ted van der Gulik and Stephanie Tam (MAFF).
02I03	Consumptive	Camps & Pub Facil: Church/Com Hall	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Camps' and 'Public Facilities' (Ecofish, 2015).
02I05	Consumptive	Crops: Crop Suppression	M3/Y	0	0	0	0	0	0	4.2	6	1.8	0	0	0	12	Crop suppression is not based on crop water demand so it really depends on how it is applied. Suppression would likely not happen until near the end of July, August and September so the breakdown would be approximately July 35%, August 50% and September 15% (Ted Van der Gulik, 2021).
02D	Consumptive	Comm. Enterprise: Enterprise	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Enterprise' (Ecofish, 2015).
02I18	Consumptive	Heat Exchanger	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Water use likely higher in winter months than summer months. In BC, water use for heating is more common than water use for cooling.
02B	Consumptive	Processing & Mfg: Processing	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Processing' (Ecofish, 2015).
05E	Consumptive	O & G: Hydrlc Frctrg (non-deep GW)	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Varies with market conditions and specific license conditions (e.g. EFN requirements). Use is fully consumptive (Suzan Lapp, BC Oil and Gas Commission).
00C	Consumptive	Waterworks: Sales	M3/D	1	1	1	1	1	1	1	1	1	1	1	1	12	Same as Waterworks: Local Provider. Water use typically doubles in peak summer months due to increased use for irrigation, washing and bathing, tourism, etc.
00C	Consumptive	Waterworks: Sales	M3/Y	0.8	0.8	0.8	0.8	1	1.2	1.6	1.6	1	0.8	0.8	0.8	12	Same as Waterworks: Local Provider. Water use typically doubles in peak summer months due to increased use for irrigation, washing and bathing, tourism, etc.
02I22	Consumptive	Grnhouse & Nursery: Nursery	M3/Y	0	0.12	0.12	0.24	1.2	1.68	2.88	2.88	2.04	0.72	0.12	0	12	Based on actual use data from a 25-acre nursery in the Fraser Valley, provided by Dave Woodske, P.Ag. | Industry Specialist, Ornamentals and Greenhouse Vegetables, Ministry of Agriculture
STU	Consumptive	Equipment (02139)		1	1	1	1	1	1	1	1	1	1	1	1	12	Assume same as 'Industrial'
STU	Consumptive	Industrial: Fire Suppression		1	1	1	1	1	1	1	1	1	1	1	1	12	Assume same as 'Industrial'
STU	Consumptive	Industrial: Pressure Testing		1	1	1	1	1	1	1	1	1	1	1	1	12	Assume same as 'Industrial'
STU	Consumptive	Industrial: Road Maintenance		1	1	1	1	1	1	1	1	1	1	1	1	12	Assume same as 'Industrial'
STU	Consumptive	Industrial: Work Camp		1	1	1	1	1	1	1	1	1	1	1	1	12	Assume same as 'Work Camps'
STU	Consumptive	Oil & Gas Purpose: Hydraulic Fracturing		1	1	1	1	1	1	1	1	1	1	1	1	12	Assume same as 'Industrial'
STU	Consumptive	Oil & Gas Purpose: Oil Field Injection		1	1	1	1	1	1	1	1	1	1	1	1	12	Assume same as 'Industrial'
STU	Consumptive	Oil & Gas Purpose: Other		1	1	1	1	1	1	1	1	1	1	1	1	12	Assume same as 'Industrial'
STU	Consumptive	Oil & Gas Purpose: Well Drilling		1	1	1	1	1	1	1	1	1	1	1	1	12	Assume same as 'Industrial'
STU	Consumptive	Other Water Purpose		1	1	1	1	1	1	1	1	1	1	1	1	12	Assume same as 'Industrial'
STU	Non-consumptive	Storage - Non Power		1	1	1	1	1	1	1	1	1	1	1	1	12	Assume same as 'Storage'
STU	Non-consumptive	Storage Purpose		1	1	1	1	1	1	1	1	1	1	1	1	12	Assume same as 'Storage'
STU	Consumptive	Unspecified		1	1	1	1	1	1	1	1	1	1	1	1	12	Assume same as 'Industrial'
STU	Consumptive	Monthly coefficients for dugouts		0.24	0.12	0.24	0.72	2.4	2.88	2.04	1.08	0.84	0.72	0.36	0.36	12	From RSEA project

Table 8:: Monthly Water Return Coefficients

Code	Consumptive vs. Non-Consumptive	Purpose	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum	Reference/Note
02I47	Consumptive	Heat Exchanger, Residential	M3/D	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	9.6	In an open loop system, the majority of water (in many cases, 100%) is returned to the environment, most often by injecting it back into the ground. However, water may also be returned to the surface (staff at Drillwell, personal communications). Water use (and return) is likely higher in winter months than summer months because water is more commonly used for heating than cooling in BC.
WSA06	Non-consumptive	Ice & Snow Making	M3/Y	0	0	3	3	3	3	0	0	0	0	0	0	12	Return coefficients for Snow Making (Ecofish, 2015), supported by discussion with Whistler Blackcomb staff.
02I36	Consumptive	Processing & Mfg: Wharves	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Processing' (Ecofish, 2015), supported by discussions with license holders for purpose (Wharves) (Mike Carter, Port Alberni Port Authority).
WSA01	Consumptive	Domestic (WSA01)	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Domestic' (Ecofish, 2015).
02I30	Non-consumptive	Ice & Snow Making: Snow	M3/Y	0	0	3	3	3	3	0	0	0	0	0	0	12	Return coefficients for Snow Making (Ecofish, 2015).
02I29	Consumptive	Processing & Mfg: Shipyard	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Processing' (Ecofish, 2015).
05H	Consumptive	O & G: Drilling	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Fully consumptive (Suzan Lapp, BC Oil and Gas Commission)
02I21	Consumptive	Camps & Pub Facil: Institutions	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Camps' (Ecofish, 2015).
02I12	Consumptive	Misc Indl: Fire Protection	M3/S, M3/D, TF	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	3	Coefficients for 'Fire Protection [MD]' (Ecofish, 2015).
02I12	Consumptive	Misc Indl: Fire Protection	M3/Y	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	6	Coefficients for 'Fire Protection [MY]' (Ecofish, 2015).
02I39	Consumptive	Vehicle & Eqpt: Mine & Quarry	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Licenses in this category were previously classified as Industrial so the distribution for Industrial was used (Ecofish, 2015). Also, MFLNRORD staff noted that the primary useses in this category were likely related to dust control and equipment washing and so it is likelt that the majority of water would evaporate (Jeremy Roscoe).
02I33	Consumptive	Vehicle & Eqpt: Truck & Eqp Wash	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Truck Washing' (Ecofish, 2015). MFLNRORD staff noted that most of the water for this purpose is used to wash equipment and is sprayed onto the ground where much of it evaporates. Any surface runoff should/would be kept from re-entering a source source (Jeremy Roscoe).
02I37	Consumptive	Camps & Pub Facil: Work Camps	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Work Camps' (Ecofish, 2015).
02HU	Consumptive	Marine Export - Used (Inactive)	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	No current licenses
02I24	Non-consumptive	Misc Indl: Overburden Disposal	TF	1	1	1	1	1	1	1	1	1	1	1	1	12	Non-consumptive, as it is typically not an actual use of water and all licenses are in units TF (Barry Watson).
07C	Non-consumptive	Power: General	M3/S, M3/Y	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Power-General' (Ecofish, 2015).
02I43	Consumptive	Transport Mgmt: Tunnelling/Well Drilling	DNE	0	0	0	0	0	0	0	0	0	0	0	0	0	No current licenses
02I11	Consumptive	Processing & Mfg: Fire Prevention	M3/S	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Processing' (Ecofish, 2015). Water is removed from source and most likely evaporates (Barry Watson).
02I23	Consumptive	O & G: Oil Fld Inject. (non-deep GW)	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Fully consumptive (Suzan Lapp, BC Oil and Gas Commission)
02C	Consumptive	Cooling	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Industrial' (Ecofish, 2015).
02F	Consumptive	Lwn, Fairway & Grdn: Watering	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	Return flows for irrigation are quite low and can be ignored (Ted Van der Gulik). Historical irrigation practices (e.g. flood irrigating) had higher return flows, but those practices are only used in a few select locations in BC now.
01A	Consumptive	Domestic	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Domestic' (Ecofish, 2015).
02I07	Consumptive	Indl Waste Mgmt: Effluent	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Industrial' (Ecofish, 2015).
02I26	Non-consumptive	River Improvement	TF	1	1	1	1	1	1	1	1	1	1	1	1	12	Generally, the intent is to take water from a stream and place in another location. In some cases, water may be returned to the same stream and it may be non-consumptive. In other cases, it may be consumptive. Identified as consumptive in Rood & Hamilton, 1995.
02I41	Consumptive	Livestock & Animal: Kennel	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Stockwatering' (Ecofish, 2015).
WSA04	Consumptive	Crop Harvest, Protect & Compost	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	This category contains several uses that happen at very different times and have very different returns flows. Crop harvesting anf frost protection have 10-80% return flows and composting use should have no returns flows (leachate is not allowed to return to water course) and is most likely to occur after harvest (which varies by crop) (Jake Turek). In areas that are under stress or places where there are large licenses for this purpose, further investigation is required.
09B	Consumptive	Mineralized Water: Comm. Pool	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Bottle Sales' (Ecofish, 2015).
02I16	Consumptive	Indl Waste Mgmt: Garbage Dump	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Industrial' and 'Sewage Disposal' (Ecofish, 2015).
02I35	Consumptive	Waterworks: Water Delivery	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Bottle Sales' (Ecofish, 2015). Water most likely taken out of watershed.
12A	Non-consumptive	Stream Storage: Power	M3/Y	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Storage-Power' (Ecofish, 2015).
05B	Consumptive	Mining: Washing Coal	M3/D, M3/S	0	0	0	0	0	0	0	0	0	0	0	0	0	It is likely that most of the water used would be contact water and would end up in some kind of tailings impoundment area and eventually discharged into the environment with a long retention time. Assume fully consumptive (Jeremy Roscoe).
02A	Consumptive	Pulp Mill	M3/D, M3/S	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Pulpmills' (Ecofish, 2015). Signficant evaporative losses and longer retention times for effluent. Returns likely vary by operation. Newer and updated operations are likely to return more and cleaner water, but there are many older operations (Jeremy Roscoe).
02I01	Consumptive	Vehicle & Eqpt: Brake Cooling	M3/D, M3/S	0	0	0	0	0	0	0	0	0	0	0	0	0	Use is fully consumptive, as water evaporates (Jeremy Roscoe, Barry Watson)
02I	Consumptive	Industrial - Misc (Inactive)	DNE	0	0	0	0	0	0	0	0	0	0	0	0	0	No current licenses
02E	Consumptive	Pond & Aquaculture	M3/S, M3/D, M3/Y, TF	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	3	Coefficients for 'Ponds (Ecofish, 2015). Returns could be as much as 90%, but vary based on operation (Gary Robinson, Kuterra).
02I15	Consumptive	Livestock & Animal: Game Farm	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Stockwatering' (Ecofish, 2015).
00B	Consumptive	Waterworks (other than LP)	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Some water (e.g. 10%) may or may not be returned to the same system.*
00B	Consumptive	Waterworks (other than LP)	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	Some water (e.g. 10%) may or may not be returned to the same system.*
02G	Consumptive	Fresh Water Bottling	M3/D, M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Bottle Sales' (Ecofish, 2015).
11C	Non-consumptive	Conservation: Construct Works	M3/S, M3/D, M3/Y, TF	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Conserv.-Use of Water' (Ecofish, 2015).
11B	Non-consumptive	Conservation: Use of Water	M3/S, M3/D, M3/Y, TF	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Conserv.-Use of Water' (Ecofish, 2015).

Table 8: Monthly Water Return Coefficients (cont.)

Code	Consumptive vs. Non-Consumptive	Purpose	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum	Reference/Note
05C	Consumptive	Mining: Processing Ore	M3/D, M3/S	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Processing' (Ecofish, 2015). While most operations will likely disvcharge water at at some point, it is likely to be taken from the source for some time. In terms of modelling supply and demand, it is most appropriate to assume that water used is taken out of the source/supply (Jeremy Roscoe, Barry Watson).
WSA13	Consumptive	Industrial Waste Mgmt	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Industrial' and 'Sewage' (Ecofish, 2015).
02H	Consumptive	Bulk Shipment for Marine Trans	DNE	0	0	0	0	0	0	0	0	0	0	0	0	0	No current licenses
02I28	Consumptive	Indl Waste Mgmt: Sewage Disposal		0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Sewage' (Ecofish, 2015). Much of the water used is likely to evaporate (City of Vernon, District of Squamish).
05D	Consumptive	Mining: Placer	M3/S	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	9	While some licenses are for the whole year, most license periods vary from 6/7 months to a year and use would typically occur from April through October. Water is likely partially returned after time spent in settling ponds (Barry Watson, Jeremy Roscoe). Estimated average returns are 75-80% with a 1 month delay from time of use.
WSA07	Consumptive	Misc Indust	M3/S, M3/D, M3/Y, TF	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Industrial' (Ecofish, 2015).
WSA07	Consumptive	Misc Indust	M3/S, M3/D, M3/Y, TF	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Industrial' (Ecofish, 2015).
02I02	Consumptive	Camps & Pub Facil: Non-Work Camps	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Camps' (Ecofish, 2015).
09A	Consumptive	Mineralized Water: Bottling & Dist	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Bottle Sales' (Ecofish, 2015).
08A	Non-consumptive	Stream Storage: Non-Power	M3/Y	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for Storage-Non Power' (Ecofish, 2015).
05A	Consumptive	Mining: Hydraulic	M3/S	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	9.6	Water would be returned to system in a highly sediment laden form (the use involves hosing water at a hillside and water re-enters the creek) (Jeremy Roscoe). 80% return flow assumed.
02I38	Non-consumptive	Fish Hatchery	M3/D, M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	Non-consumptive, most use is in feb-apr and use is similar acros fish hatcheries(Jordan Uittenbogaard, Tenderfoot Hatchery).
00A	Consumptive	Waterworks: Local Provider	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	Some water (e.g. 10%) may or may not be returned to the same system.
WSA03	Consumptive	Commercial Enterprise	M3/DAY	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Enterprise' (Ecofish, 2015).
WSA03	Consumptive	Commercial Enterprise	M3/YEAR	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Enterprise' (Ecofish, 2015).
05F	Consumptive	O & G: Hydrlc Frctrg (deep GW)	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Fully consumptive (Suzan Lapp, BC Oil and Gas Commission)
04B	Consumptive	Land Improve: Indl for Rehab/Remed	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Land Improve' (Ecofish, 2015). Generally, the intent is to take water from a stream and place in another location. In some cases, water may be returned to the same stream and it may be non-consumptive. In other cases, it may be consumptive. Identified as consumptive in Rood & Hamilton, 1995.
02I17	Consumptive	Grnhouse & Nursery: Grnhouse	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Water is not returned to source (Ted Van der Gulik).
02I31	Consumptive	Livestock & Animal: Stockwatering	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	No return, as the majority of water goes to milk or meat.
WSA02	Consumptive	Camps & Public Facilities	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Camps' and 'Public Facilities' (Ecofish, 2015).
WSA10	Consumptive	Well Drill/Transprt Mgmt	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	This category contains a wide range of uses and while water use is likely to go up in the summer and may not occur for some of these purposes in the winter, given that the max units are in M3/D, and the wide range of uses, the coefficents are assumed to be consistent.
02I14	Consumptive	Crops: Frost Protection	M3/Y	0	2.5	2.5	1	0	0	0	0	0	0	0	0	6	Assume 50% return. Could be anywhere from 10-80% return (based on conversations with Carolyn Teasdale, Ted van der Gulik, Stephanie Tam).
02I08	Consumptive	Transport Mgmt: Dust Control	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Water lost to evaporation. Use value for Dust Control in Phase 1 (Sentlinger, Metherall).
11A	Non-consumptive	Conservation: Storage	M3/S, M3/D, M3/Y, TF	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Conserv.-Constr.Works' and 'Storage-Non Power' (Ecofish, 2015).
02I34	Consumptive	Indl Waste Mgmt: Intake Wash	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	No current licenses
07B	Non-consumptive	Power: Commercial	M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Power-General' (Ecofish, 2015).
07A	Non-consumptive	Power: Residential	M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Power-Residential' (Ecofish, 2015).
02I40	Consumptive	Comm. Enterprise: Amusement Park	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Enterprise' (Ecofish, 2015).
01A01	Consumptive	Incidental - Domestic	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Domestic' (Ecofish, 2015).
02I20	Non-consumptive	Ice & Snow Making: Ice	M3/D	0	0	3	3	3	3	0	0	0	0	0	0	12	Coefficients for Snow Making (Ecofish, 2015), supported by discussion with icemaking license holders. Most arenas remove their ice in March for lacrosse season (March-June) and put their ice back in between June and August.
02I06	Consumptive	Misc Indl: Dewatering	M3/S, TF	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Industrial' (Ecofish, 2015). Most licenses are in units TF or are very small volumes.
02I46	Consumptive	Transport Mgmt: Road Maint.	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Use value for Dust Control in Phase 1 (Sentlinger, Metherall). It us assumed that much of the use would be consumptive as water would evaporate
02I19	Consumptive	Hydraulicking (Inactive)	DNE	0	0	0	0	0	0	0	0	0	0	0	0	0	No current licenses
WSA05	Consumptive	Greenhouse & Nursery	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	Assume mainly consumptive. Based on personal communications with Dave Woodske, P.Ag. | Industry Specialist, Ornamentals and Greenhouse Vegetables, Ministry of Agriculture
02I32	Consumptive	Swimming Pool	M3/D, TF	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Public Facilities' (Ecofish, 2015).
02I04	DNE	Conveying (Inactive)	DNE	0	0	0	0	0	0	0	0	0	0	0	0	0	No current licenses
WSA08	Consumptive	Livestock & Animal	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	From livestock watering. Returns should be almost 0 as the water goes to animal/milk/meat.
	Consumptive	Livestock & Animal	M3/D	0	0	0	0	0	0	0	0	0	0	0	0		From livestock watering. Returns should be almost 0 as the water goes to animal/milk/meat.
04A	Consumptive	Land Improve: General	M3/S, M3/D, M3/Y, TF	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Land Improve' (Ecofish, 2015). Generally, the intent is to take water from a stream and place in another location. In some cases, water may be returned to the same stream and it may be non-consumptive. In other cases, it may be consumptive. Identified as consumptive in Rood & Hamilton, 1995.
03B	Consumptive	Irrigation: Private	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	Return flows for irrigation are quite low and can be ignored (Ted Van der Gulik). Historical irrigation practices (e.g. flood irrigating) had higher return flows, but those practices are much less common now. If irrigation system is optimized, then all of the water goes into the soil and nourishes plants.
02I27	Consumptive	Misc Indl: Sediment Control	M3/S, M3/Y, TF	0	0	0	0	0	0	0	0	0	0	0	0	0	A review of water licenses associated with this purpose shows that a range of uses were placed in this category when the water license purposes changed under the new Water Sustainability Act. Therefore, it was decided to assume the same as 'Industrial' - or consistent use seasonally. Some of these licenses included tailings ponds so these would be fully consumptive

Table 8: Monthly Water Return Coefficients (cont.)

Code	Consumptive vs. Non-Consumptive	Purpose	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Sum	Reference/Note
05C	Consumptive	Mining: Processing Ore	M3/D, M3/S	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Processing' (Ecofish, 2015). While most operations will likely disvcharge water at at some point, it is likely to be taken from the source for some time. In terms of modelling supply and demand, it is most appropriate to assume that water used is taken out of the source/supply (Jeremy Roscoe, Barry Watson).
WSA13	Consumptive	Industrial Waste Mgmt	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Industrial' and 'Sewage' (Ecofish, 2015).
02H	Consumptive	Bulk Shipment for Marine Trans	DNE	0	0	0	0	0	0	0	0	0	0	0	0	0	No current licenses
02I28	Consumptive	Indl Waste Mgmt: Sewage Disposal		0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Sewage' (Ecofish, 2015). Much of the water used is likely to evaporate (City of Vernon, District of Squamish).
05D	Consumptive	Mining: Placer	M3/S	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	9	While some licenses are for the whole year, most license periods vary from 6/7 months to a year and use would typically occur from April through October. Water is likely partially returned after time spent in settling ponds (Barry Watson, Jeremy Roscoe). Estimated average returns are 75-80% with a 1 month delay from time of use.
WSA07	Consumptive	Misc Indust	M3/S, M3/D, M3/Y, TF	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Industrial' (Ecofish, 2015).
WSA07	Consumptive	Misc Indust	M3/S, M3/D, M3/Y, TF	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Industrial' (Ecofish, 2015).
02I02	Consumptive	Camps & Pub Facil: Non-Work Camps	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Camps' (Ecofish, 2015).
09A	Consumptive	Mineralized Water: Bottling & Dist	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Bottle Sales' (Ecofish, 2015).
08A	Non-consumptive	Stream Storage: Non-Power	M3/Y	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for Storage-Non Power' (Ecofish, 2015).
05A	Consumptive	Mining: Hydraulic	M3/S	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	9.6	Water would be returned to system in a highly sediment laden form (the use involves hosing water at a hillside and water re-enters the creek) (Jeremy Roscoe). 80% return flow assumed.
02I38	Non-consumptive	Fish Hatchery	M3/D, M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	Non-consumptive, most use is in feb-apr and use is similar acros fish hatcheries(Jordan Uittenbogaard, Tenderfoot Hatchery).
00A	Consumptive	Waterworks: Local Provider	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	Some water (e.g. 10%) may or may not be returned to the same system.
WSA03	Consumptive	Commercial Enterprise	M3/DAY	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Enterprise' (Ecofish, 2015).
WSA03	Consumptive	Commercial Enterprise	M3/YEAR	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Enterprise' (Ecofish, 2015).
05F	Consumptive	O & G: Hydrlc Frctrg (deep GW)	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Fully consumptive (Suzan Lapp, BC Oil and Gas Commission)
04B	Consumptive	Land Improve: Indl for Rehab/Remed	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Land Improve' (Ecofish, 2015). Generally, the intent is to take water from a stream and place in another location. In some cases, water may be returned to the same stream and it may be non-consumptive. In other cases, it may be consumptive. Identified as consumptive in Rood & Hamilton, 1995.
02I17	Consumptive	Grnhouse & Nursery: Grnhouse	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Water is not returned to source (Ted Van der Gulik).
02I31	Consumptive	Livestock & Animal: Stockwatering	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	No return, as the majority of water goes to milk or meat.
WSA02	Consumptive	Camps & Public Facilities	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Camps' and 'Public Facilities' (Ecofish, 2015).
WSA10	Consumptive	Well Drill/Transprt Mgmt	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	This category contains a wide range of uses and while water use is likely to go up in the summer and may not occur for some of these purposes in the winter, given that the max units are in M3/D, and the wide range of uses, the coefficents are assumed to be consistent.
02I14	Consumptive	Crops: Frost Protection	M3/Y	0	2.5	2.5	1	0	0	0	0	0	0	0	0	6	Assume 50% return. Could be anywhere from 10-80% return (based on conversations with Carolyn Teasdale, Ted van der Gulik, Stephanie Tam).
02I08	Consumptive	Transport Mgmt: Dust Control	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Water lost to evaporation. Use value for Dust Control in Phase 1 (Sentlinger, Metherall).
11A	Non-consumptive	Conservation: Storage	M3/S, M3/D, M3/Y, TF	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Conserv.-Constr.Works' and 'Storage-Non Power' (Ecofish, 2015).
02I34	Consumptive	Indl Waste Mgmt: Intake Wash	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	No current licenses
07B	Non-consumptive	Power: Commercial	M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Power-General' (Ecofish, 2015).
07A	Non-consumptive	Power: Residential	M3/S	1	1	1	1	1	1	1	1	1	1	1	1	12	Coefficients for 'Power-Residential' (Ecofish, 2015).
02I40	Consumptive	Comm. Enterprise: Amusement Park	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Enterprise' (Ecofish, 2015).
01A01	Consumptive	Incidental - Domestic	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Domestic' (Ecofish, 2015).
02I20	Non-consumptive	Ice & Snow Making: Ice	M3/D	0	0	3	3	3	3	0	0	0	0	0	0	12	Coefficients for Snow Making (Ecofish, 2015), supported by discussion with icemaking license holders. Most arenas remove their ice in March for lacrosse season (March-June) and put their ice back in between June and August.
02I06	Consumptive	Misc Indl: Dewatering	M3/S, TF	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Industrial' (Ecofish, 2015). Most licenses are in units TF or are very small volumes.
02I46	Consumptive	Transport Mgmt: Road Maint.	M3/D	0	0	0	0	0	0	0	0	0	0	0	0	0	Use value for Dust Control in Phase 1 (Sentlinger, Metherall). It us assumed that much of the use would be consumptive as water would evaporate
02I19	Consumptive	Hydraulicking (Inactive)	DNE	0	0	0	0	0	0	0	0	0	0	0	0	0	No current licenses
WSA05	Consumptive	Greenhouse & Nursery	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	Assume mainly consumptive. Based on personal communications with Dave Woodske, P.Ag. | Industry Specialist, Ornamentals and Greenhouse Vegetables, Ministry of Agriculture
02I32	Consumptive	Swimming Pool	M3/D, TF	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Public Facilities' (Ecofish, 2015).
02I04	DNE	Conveying (Inactive)	DNE	0	0	0	0	0	0	0	0	0	0	0	0	0	No current licenses
WSA08	Consumptive	Livestock & Animal	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	From livestock watering. Returns should be almost 0 as the water goes to animal/milk/meat.
	Consumptive	Livestock & Animal	M3/D	0	0	0	0	0	0	0	0	0	0	0	0		From livestock watering. Returns should be almost 0 as the water goes to animal/milk/meat.
04A	Consumptive	Land Improve: General	M3/S, M3/D, M3/Y, TF	0	0	0	0	0	0	0	0	0	0	0	0	0	Coefficients for 'Land Improve' (Ecofish, 2015). Generally, the intent is to take water from a stream and place in another location. In some cases, water may be returned to the same stream and it may be non-consumptive. In other cases, it may be consumptive. Identified as consumptive in Rood & Hamilton, 1995.
03B	Consumptive	Irrigation: Private	M3/Y	0	0	0	0	0	0	0	0	0	0	0	0	0	Return flows for irrigation are quite low and can be ignored (Ted Van der Gulik). Historical irrigation practices (e.g. flood irrigating) had higher return flows, but those practices are much less common now. If irrigation system is optimized, then all of the water goes into the soil and nourishes plants.
02I27	Consumptive	Misc Indl: Sediment Control	M3/S, M3/Y, TF	0	0	0	0	0	0	0	0	0	0	0	0	0	A review of water licenses associated with this purpose shows that a range of uses were placed in this category when the water license purposes changed under the new Water Sustainability Act. Therefore, it was decided to assume the same as 'Industrial' - or consistent use seasonally. Some of these licenses included tailings ponds so these would be fully consumptive

Table 9:: Phone Contacts for Water Demand Research

Name	Organization	Title	References
Cali Seater	MFLNRORD - Northeast Resource Authorizations Fort St. John	Licensed Authorizations Officer-Water	Stream storage: non-power
Barry Watson	MFLNRORD - Land & Water Section Smithers	Authorizations Specialist - Water	Processing and manufacturing, river and land improvement, transport management
Jeremy Roscoe	MFLNRORD - Land & Water Section Smithers	Authorizations Specialist	Mining, vehicle and equipment, industrial, cooling, industrial waste management
Arthur DeJong	Whistler Blackcomb (water license holder)	Senior Manager Planning and Environment	Snowmaking
Suzan Lapp	BC Oil and Gas Commission	Hydrologist	Oil and gas purposes, short term use approvals
Cody Braaten	Cariboo Regional District	Protective Services Assistant	Fire Protection
Stephanie Tam	Ministry of Agriculture	Water Resource Engineer	Irrigation
Ted van der Gulik	Partnership for Water Sustainability	President	Irrigation, Crop Harvesting, Crop Protection, Compost, Flood Harvesting, Crop Suppression
Gary Robinson	Kuterra (water license holder)		Pond & Aquaculture
Bob Smith, staff	District of Squamish, City of Vernon (license holders for this purpose)	Director of Public Works	Sewage disposal
Jordan Uittenbogaard	Tenderfoot Hatchery		Fish hatchery
Dave Woodske	Ministry of Agriculture	Industry Specialist, Ornamentals and Greenhouse Vegetables	Nursery
Rob Pakulak	City of Nanaimo	Zamboni Driver	Icemaking
Mike Carter	Port Alberni Port Authority	Director of Operations	Wharves