QUINTE CONSERVATION

Salmon River Upper Lakes Flood Hazard Mapping

Hydrology Report

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Limitations

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1.0 INTRODUCTION

1.1 Objectives of the Study

KGS Group was retained by Quinte Conservation (QC) to prepare regulatory floodplain mapping for the Salmon River Upper Lakes Watershed, from Kennebec Lake to the outlet of Crotch Lake (Figure 1-1). The study includes collection of topographic data through site inspection and surveying, hydrologic analyses to assess the magnitude of recurrent flood events ranging from 2 to 500-year return periods (events with annual exceedance probability, AEP, ranging from 50% to 0.2%). The study includes hydraulic modeling and mapping to define the regulatory flood lines in the study area.

The analyses for this project have been conducted in accordance with the requirements outlined in the guidance provided by Ontario Ministry of Natural Resources and Forestry (MNRF), and the Project Eligibility and Requirements for the Flood Hazard Identification and Mapping Program (FHIMP). The following technical guidelines have been applied:

- Natural Resources Canada Federal Flood Mapping Guidelines Series
- MNRF (2011) Technical Bulletins associated with the Lakes and Rivers Improvement Act (LRIA)
- MNRF Technical Guide – River & Stream Systems: Flooding Hazard Limit (2002)
- MNRF Technical Guide – River & Stream Systems: Erosion Hazard Limit (2002)
- USACE HEC-HMS and HEC-RAS User’s Manual and Technical Reference Manual

This report provides an overview of the hydrologic analysis, encompassing statistical analysis and hydrologic modeling, carried out as parts of the floodplain mapping study. It must be noted that the approach adopted in the hydrologic analysis corresponds to the overall strategy proposed and adopted for the preparation of the floodplain maps. In this respect, to fit the characteristics of the study area, the Kennebec Lake and Big Clear Lake were included in the hydrologic model as individual separate sub-catchments, to capture the rapid reaction to direct rainfall, and the flood routing that naturally occurs in those lakes was not included in the hydrologic model. Instead, it was envisioned that the hydrologic model would be used to obtain the natural runoff inflows and that the flood routing was to be included in the hydraulic models that are being prepared as part of the study.

It is recognized that this is a different approach from other studies in which the routing that occurs in the lakes is included in the hydrologic model (using a stage-storage-discharge curve). One reason for the adopted approach is that the outlet of Kennebec Lake is a natural channel, for which there is not a well-defined stage-discharge rating curve (which is a necessary input to simulate the flood routing in the hydrologic model). More details of the proposed approach are provided in the description of the hydrologic model in this report and in the description of the hydraulic model, in a separate hydraulic analysis report.

Following guidance from Environment and Climate Change Canada (ECCC), in this study, recurrent events are referred to using both return periods and AEPs. The purpose is to provide clarity to users of the report and to the public regarding the likelihood of a given event. For instance, the event referred to as the 100-year flood has a 1% probability of occurring or being exceeded on any given year (i.e. 1% AEP).The correspondence between return periods and AEPs is provided in Table 1-1. The two approaches are interchangeable.

TABLE 1-1: RETURN PERIODS AND AEPS

Return Period	Annual Exceedance Probability (AEP)
2 years	50%
5 years	20%
10 years	10%
25 years	4%
50 years	2%
100 years	1%
200 years	0.5%
500 years	0.2 %

1.2 Criteria For Floodplain Mapping

1.2.1 REGULATORY FLOOD

The study area is located within Zone 2, in Ontario. Based on the “Technical Guide – River and Stream Systems: Flood Hazard Limit” (MNRF 2002), the Regulatory Flood for this watershed is the 100-year Flood (i.e. the flood with 1% AEP).

1.3 General Description of Watershed and Study Area

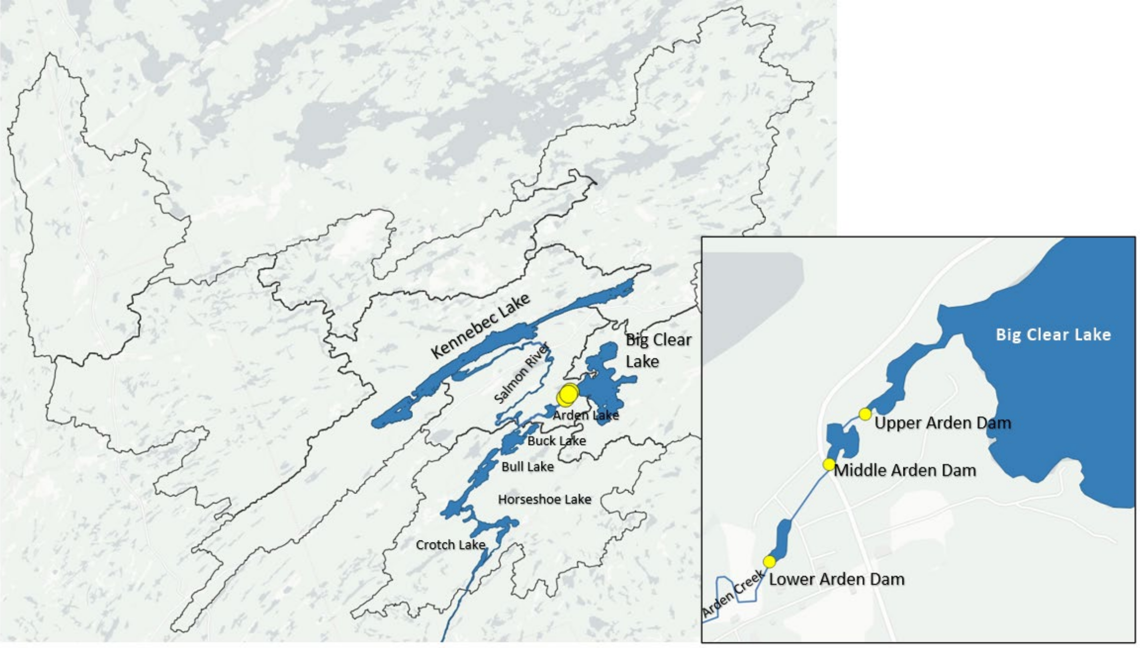
The Salmon River Upper Lakes are situated in the Township of Central Frontenac, including Kennebec Lake, Big Clear Lake, Arden Lake, Buck Lake, Bull Lake, Horseshoe Lake, Crotch Lake, and several other smaller lakes. The study area watershed (404 km^2) is shown in Figure 1-1.

Kennebec Lake (to the north of the study area) receives the runoff from the upstream most portion of the watershed, approximately one-half of the watershed area (297 km^2). It drains through the Salmon River, which generally runs in the south direction, through flat terrain, to find, in that order, Buck Lake, Bull Lake, Horeshoe Lake and Crotch Lake.

Big Clear Lake receives the runoff from an eastern portion of the watershed (approximately 33 km^2 of drainage area) and drains through Arden Creek, a tributary of the Salmon River. The outflows from Big Clear Lake are controlled at the Upper Arden Dam. From there, Arden Creek flows towards the west, passing through the Middle Arden Dam, the Lower Arden Dam, and Arden Lake, to join the Salmon River (from the east) at Buck Lake.

The study area for this floodplain mapping project is from the shores of Kennebeck Lake and Big Clear Lake, along the Salmon River and Arden Creek, to the outlet of Crotch Lake.

FIGURE 1-1: STUDY AREA



2.0 DATA COLLECTION AND BACKGROUND REVIEW

2.1 Previous Studies

KGS performed a background review of the data provided by QC which included:

- Previous Dam Safety Review (DSR) Studies:
    - Lower Arden Dam DSR (Hatch, 2009)
    - Upper Arden Dam DSR (Hatch, 2009)
    - Upper Arden Dam Break Analysis (Ahydtech Geomorphic, 2017)
    - Middle Arden Dam DSR (Hatch, 2009)
- Dam Operations Manual (NRCA, 1994)
- 2019-2022 Arden Dams Inspection Photos
- Arden Dams Drawings
- Floodplain Maps (CCL, 1981)
- Ortho-imagery (Dated 2019)
- Elevation (Based on the Eastern Ontario LiDAR Acquisition Project, Dated 2021-2022)

Floodplain maps for certain lakes within the study area were created by CCL in 1981; however, the associated studies or reports for these maps are currently unavailable.

KGS Group reviewed this background data to obtain useful information for developing the floodplain maps of the study area.

3.0 HYDROLOGYIC ANALYSIS

3.1 Development of 2 to 500 Year Design Storms

3.1.1 PRECIPITATION DATA

Multiple databases were investigated to identify locations with precipitation data available for this study. The first three databases were obtained from Environment and Climate Change Canada (ECCC), and one tool developed by the University of Western Ontario.

- The first source is "Climate Data for a Resilient Canada", accessible at https://climatedata.ca, which provides short duration (5 minutes to 24 hour) rainfall intensity-duration-frequency (IDF) curves with 2, 5, 10, 25, 50 and 100 year return periods.
- The second source is Environment and Climate Change Canada (ECCC) Climate Data Extraction Tool. Historical hourly and daily precipitation are available to retrieve from ECCC Climate Data Extraction Tool (https://climate-change.canada.ca/climate-data/#/).
- The third source is ECCC Engineering Climate Datasets archive, which provides IDFs for return period storms with longer durations than the first source listed above (e.g., 1 day and longer).
- The fourth source is the IDF-CC[1] Web Based Tool. The IDF-CC tool derives IDF curves for ungagged watersheds by extracting IDF values from a gridded dataset obtained through the interpolation of IDF values collected from various meteorological stations. Further information can be found in Gaur et al. (2020).

Table 3-1 lists the meteorological stations located within and in the vicinity of the study area watershed. Figure 3-1 shows the location of the precipitation stations and the watershed.

TABLE 3-1: PRECIPITATION STATIONS IN THE VICINITY OF THE STUDY AREA

Station Name	Climate ID	Latitude Longitude	Data Duration	Data Availability
ARDEN	6100310	44.7 N -76.95 W	1895-1911	Historical Daily
CROYDON	6151921	44.57 N -77.00 W	1895 - 1908	Historical Daily
KALADAR	6153935	44.65 N -77.12 W	1998-2015	Historical Daily
TWEED	6159010	44.60 N	1957-1970	IDFs

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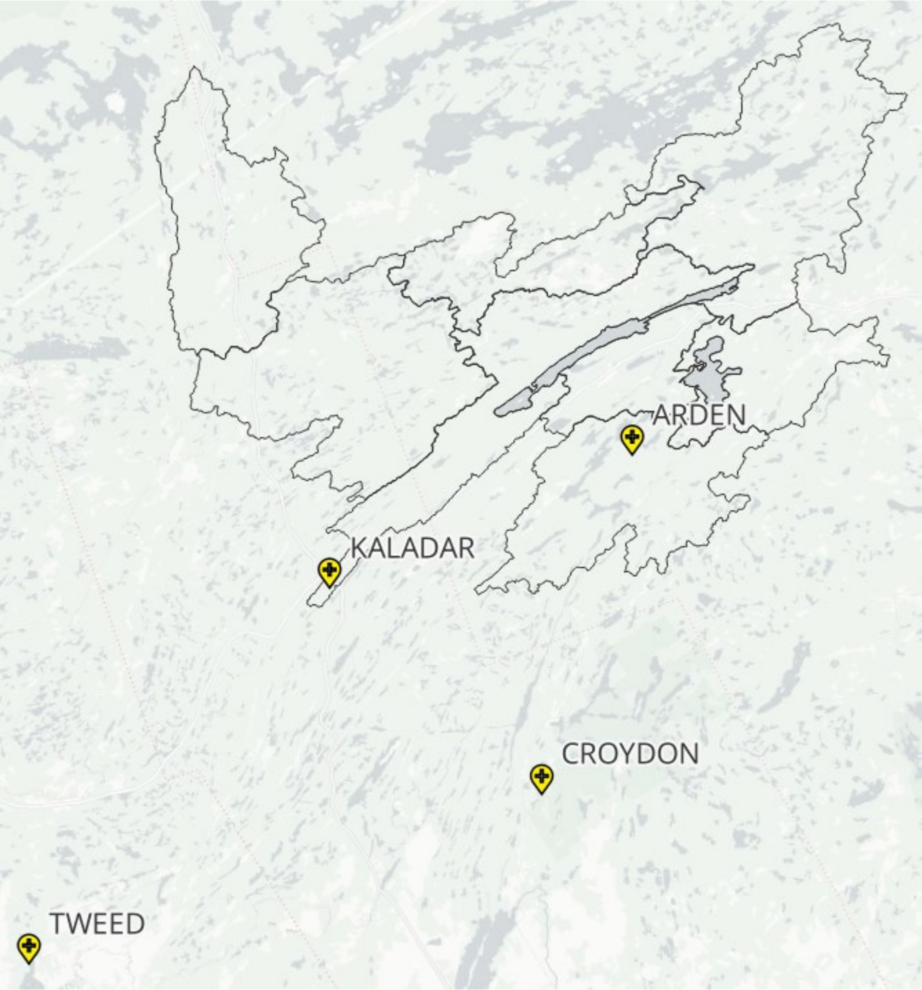
[1] I-D-F Climate Change Tool (IDF-CC) developed by the University of Western Ontario

Station Name	Climate ID	Latitude Longitude	Data Duration	Data Availability
		-77.28 W	1953 - 1973	Historical Daily

The IDFs from the Tweed Station were employed to calculate the input hyetographs to the hydrologic model. Additionally, historical daily rainfall, temperature, and snow on the ground data from the Kaladar Station were utilized to estimate the duration of recurrent design storms. The Kaladar Station was chosen because it had more recent data than the other stations from which historical data was available.

FIGURE 3-1: ENVIRONMENT CANADA METEOROLOGICAL STATIONS WITHIN THE VICINITY OF THE STUDY AREA



3.1.2 SUMMER STORMS

Daily rainfall values at the Tweed and Kaladar climate stations were inspected to choose a proper duration for summer storms. From that inspection it was determined that a 24-hour duration is appropriate, because large storms observed in the historical data, surpassing the total rain depth of a 2-year return period design storm, lasted one day.

To represent recurrent rainfall events, storm hyetographs ranging from 2 to 500 years were developed from Intensity Duration Frequency (IDF) Curves. Two sources of IDF curves were evaluated to select the most appropriate values for summer rainfall events: the IDF curves for Tweed station, available from ECCC, and the IDF curves obtained from the IDF-CC, for a location that corresponds to the centroid of the portion of the Salmon River watershed within the study area.

Total precipitation depths for 24-hour storms and various return periods, from the two sources, are compared in Table 3-2. The values for return periods of 2 to 100 years were obtained directly from the IDF curves, and were used to develop a logarithmic regression equation. The equations showed adequate fit, with coefficient of determination (R^2) of 0.99 for both data sources, and were used to extrapolate precipitation depths for the 200-year and 500-year storm events.

TABLE 3-2: PRECIPITATION DEPTH FOR 24-HOUR SUMMER STORMS FOR THE STUDY AREA

Return period (Years)	AEP	Precipitation Depth (mm)	
		Center of Salmon River Upper Lakes Area	Tweed Station
2	50%	42.6	42.7
5	20%	55.2	52
10	10%	63.7	58.1
20	5%	71.5	65.8
25	4%	74.6	NA
50	2%	82.8	71.5
100	1%	90.9	77.1
200	0.5%	99.8	83.6
500	0.2%	111.1	91.6

Table 3-2 shows that the precipitation depths obtained at the center of the study area with the IDF-CC are greater than (but generally close to) those obtained from the Tweed Station. Therefore, the IDF values estimated by the IDF-CC interpolation tool were used to develop the rainfall hyetographs for the design storms used in this study.

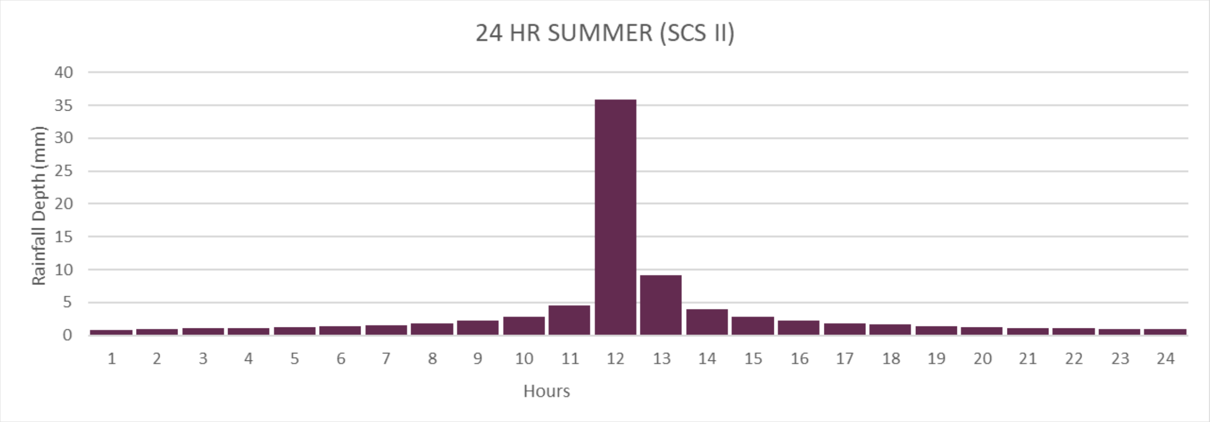
MNRF (2002) recommends applying aerial reduction factors (ARF) for the storms based on either the upstream drainage area or the equivalent circular area of the watershed. For this watershed, the upstream drainage area of 404 km^2 was used, which resulted in a 92% ARF. This value was applied to the precipitation depths before developing corresponding hyetographs.

Temporal distribution for the design storms was obtained using the synthetic SCS (U.S. Soil Conservation Service) Type II distribution. This storm distribution was originally developed for large watersheds greater than 25 km^2 and it is considered applicable to all inland regions of the United States and Canada. The resulting hyetographs for the summer events, ranging from 2 to 500 years return periods, are shown in Table 3-3. The hyetograph for the 100-year (1% AEP) summer storm is shown in Figure 3-2.

TABLE 3-3: 2-500 YEAR SUMMER RAIN DISTRIBUTIONS (24-HR SCS) FOR THE SALMON RIVER UPPER LAKES WATERSHED

Hour	Rainfall Depth (mm)							Extrapolated	
	2-Year	5-Year	10-Year	20-Year	25-Year	50-Year	100-Year	200-Year	500-Year
1	0.41	0.53	0.62	0.69	0.72	0.80	0.88	0.96	1.07
6	0.67	0.86	1.00	1.12	1.17	1.29	1.42	1.56	1.74
12	16.77	21.75	25.09	28.15	29.37	32.60	35.80	39.31	43.73
18	0.75	0.98	1.13	1.27	1.32	1.47	1.61	1.77	1.97
24	0.44	0.57	0.66	0.74	0.77	0.86	0.94	1.03	1.15
Total	39.18	50.81	58.62	65.78	68.62	76.17	83.65	91.84	102.17

FIGURE 3-2:STORM HYETOGRAPHS FOR 100-YEAR RECURRENT SUMMER STORM EVENT (IDF-CC)



3.1.3 SPRING STORMS

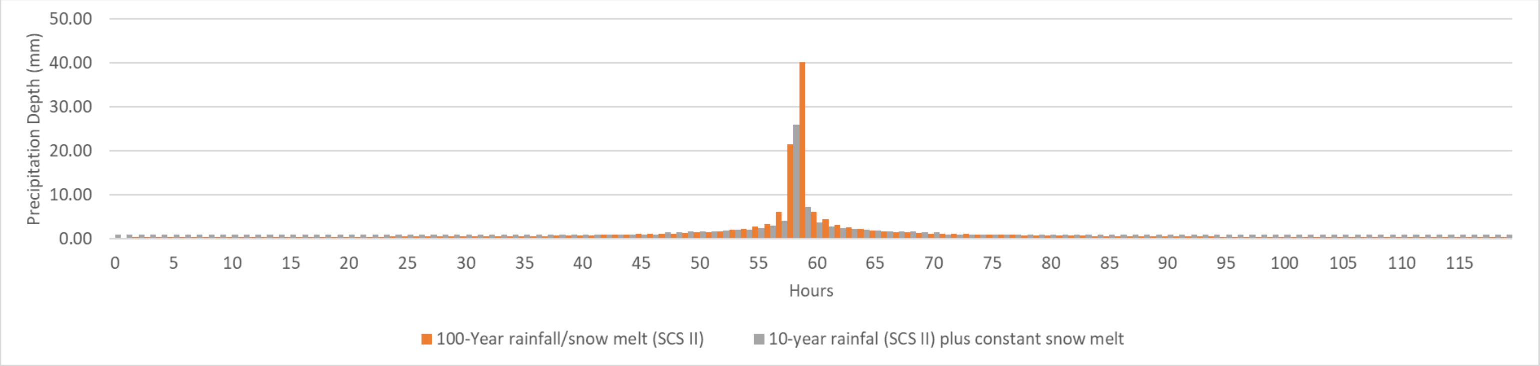
An assessment of historical events, using hydrometric data for the Salmon River, downstream of the study area, showed that spring flood events in the watershed are combinations of snowmelt and spring rainstorms.

In this study, instead of explicitly simulating snowmelt and adding it to a spring rainfall hyetograph, combined rain plus snowmelt IDFs were obtained directly from the ECCC database at the Tweed Station, for return periods ranging from 2 year to 100 years. A regression equation (with R^2 of 0.99) was used to extrapolate to the 200 and 500-year events from the available 2 to 100 year precipitation depths.

The snowmelt duration, historical daily rainfall, temperature, and snow on the ground from data at the Kaladar climate station was compared with the daily flow recorded at Water Survey of Canada (WSC) Hydrometric Station 02HM010 (Salmon River at Tamworth). The Kaladar climate station has records for both rain and snow on the ground and covers the same time frame as the flow records from WSC Station 02HM010. The comparison suggested that, on average, the duration of spring snowmelt takes five-days and that the peak runoff occurs within that time frame. Therefore, a 120-hr snowmelt event was adopted for simulation of the rain plus snowmelt (spring season) design storms.

To input the rain/snowmelt combinations representing the recurrent spring events into the hydrologic model, hyetographs were needed. Since there are no standard temporal distributions for rain/snowmelt combinations, various approaches were tested. They basically consisted of either distributing the entire water content of each event using the synthetic SCS Type II distribution (as in Section 3.1.2) or dividing the water content in two, with one part (i.e., rain) distributed over 24-hours using SCS Type II, and the rest (i.e., snowmelt) distributed evenly throughout the entire event (120 hours). Two hyetographs for the 100-year (1% AEP) rain plus snowmelt recurrent event are shown on Figure 3-3: one with the entire water content distributed using SCS Type II, and the other in which the rain amount would be similar to the 10-year-24-hour summer event and the rest of the water content is constant snowmelt. The first option would put more of the water content into rainfall, with a small contribution from snowmelt, while the second option would increase the snowmelt and reduce the rainfall component.

FIGURE 3-3: DIFFERENT TEMPORAL DISTRIBUTIONS OF 100-YEAR (1% AEP) RECURRENT RAINFALL PLUS SNOW MELT EVENT.



A sensitivity analysis was conducted by changing the input hyetograph to the hydrologic model. For this purpose, two hyetographs with different temporal distributions (described above) were generated. Results showed that the difference in flows at the outlet of the study area, obtained with these two hyetographs, was within 5%, so that the choice of temporal distribution was not found to be determinant on the results. The most conservative temporal distribution (using SCS Type II for the entire water content) was adopted. Table 3-4 shows the adopted hyetographs for the 2-year to the 500-year spring events.

TABLE 3-4: 2-500 YEAR SPRING RAIN PLUS SNOW DISTRIBUTIONS (120-HR SCS) FOR THE SALMON LAKES WATERSHED

Hour	Spring Rainfall Depth (mm)						Extrapolated	
	2-Year	5-Year	10-Year	25-Year	50-Year	100-Year	200-Year	500-Year
1	0.16	0.21	0.24	0.29	0.32	0.35	0.38	0.42
24	0.24	0.32	0.37	0.44	0.49	0.53	0.57	0.64
48	0.51	0.68	0.79	0.92	1.02	1.13	1.21	1.35
72	0.55	0.73	0.85	0.99	1.10	1.21	1.30	1.45
96	0.24	0.32	0.37	0.43	0.48	0.53	0.57	0.64
120	0.18	0.23	0.27	0.31	0.35	0.38	0.41	0.46
Total	79.32	104.56	121.28	142.40	158.06	173.62	186.56	208.44

3.2 Flow Data and Regional Flood Frequency Analysis (RFFA)

There are no hydrometric stations in the Salmon River Upper Watershed Area that provide flow data for conducting single station flood frequency analysis (FFA). As a result, a Regional Flood Frequency Analysis (RFFA) was conducted using the Index Flood Method, to estimate peak flows for the recurrent flood events. Nearby stations with a minimum of 20 years of historical flow records were selected for the RFFA. Table 3-5 provides a list of the stations utilized for this analysis.

TABLE 3-5: SUMMAY OF WSC STATIONS DATA USED FOR REGIONAL FLOOD FREQUENCY ANALYSIS

Station #	Station Name	Drainage Area (km^2)	Period of Record	Years of Record
02HM010	SALMON RIVER AT TAMWORTH	532	2002-2022	20
02HM002	DEPOT CREEK AT BELLROCK	181	1957-2022	55
02KF016	MISSISSIPPI RIVER BELOW MARBLE LAKE	359	1988-2022	35
02KF017	BUCKSHOT CREEK NEAR PLEVNA	152	1993-2022	29

A review of flow records, including annual maximum instantaneous flow values, at the selected stations indicates that the largest floods have occurred in the spring. Therefore, flood frequency analysis (FFA) was carried out on the annual maximum instantaneous data (spring events) for each station, using the HEC-SSP[2] software. For data at the selected stations, several tests including, independence of data series, homogeneity

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[2] developed by U.S. Army Corps of Engineers, Hydrologic Engineering Center.

of data, and detection of outliers were performed, with results provided in Appendix A. Multiple frequency distributions including Log Normal, Pearson III, Log Pearson III, Gumbel, Generalized Extreme, and Gamma were considered. The best fit of the data was determined by visual inspection (the frequency distribution that provided the best fit to all points was selected) and using the Kolomogrov-Smirnov test. Table 3-6 shows the peak flow values at each station obtained from the FFA. Figure 3-4 shows the fit of the adopted frequency distribution and the 95% confidence limits for the annual peak flow data at each station.

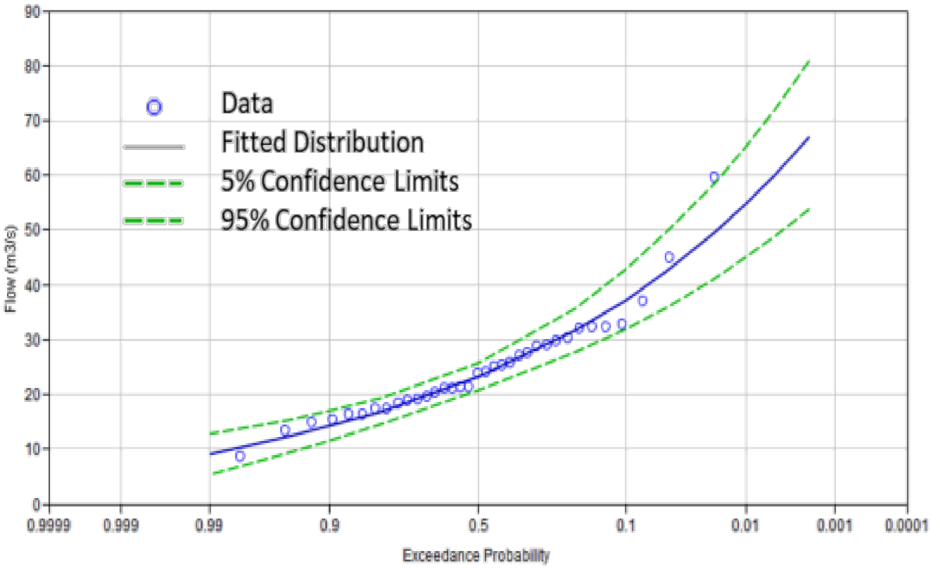
For the purpose of conducting Regional Flood Frequency Analysis, the annual maximum instantaneous flows were normalized using the mean annual flood, for which the peak flow corresponding to the 2.33 return period was used, as recommended in Dalrymple (1960). It should be noted that, for data at each station, the value for the 2.33-year return period flood was nearly identical for both Gumbel and Log Normal distributions.

TABLE 3-6 : FLOOD FREQUENCY ANALYSES RESULTS FOR WSC STATIONS

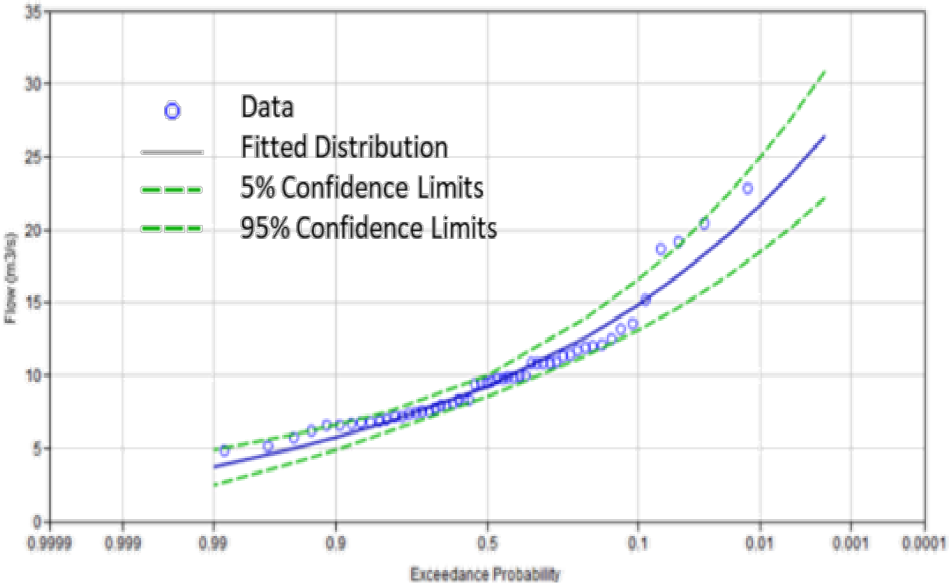
Return period	AEP	Flow (m^3/s) at			
		02HM010[1]	02HM002[2]	02KF016[3]	02KF017[4]
2	50%	31.4	9.3	23.2	13.1
2.33	43%	33.1	9.9	24.7	14.3
5	20%	40.2	12.6	31.5	19.3
10	10%	45.4	14.8	37.1	23.6
20	5%	50.0	16.9	42.3	27.9
50	2%	55.6	19.7	49.2	33.5
100	1%	59.5	21.7	54.3	38.0
200	0.5%	63.2	23.7	59.5	42.6
500	0.2%	67.9	26.4	66.5	48.8
Distribution		**Log-Normal**	**Gumbel**	**Gumbel**	**Log-Normal**

1. SALMON RIVER AT TAMWORTH
2. DEPOT CREEK AT BELLROCK
3. MISSISSIPPI RIVER BELOW MARBLE LAKE
4. BUCKSHOT CREEK NEAR PLEVNA

FIGURE 3-4 :PROBABILITY DISTRIBUTIONS FITTED TO ANNUAL PEAK FLOWS, WSC STATIONS (A) 02KF016 ,(B) 02HM002 ,AND (C)02HM010 (D) 02KF017



(a)



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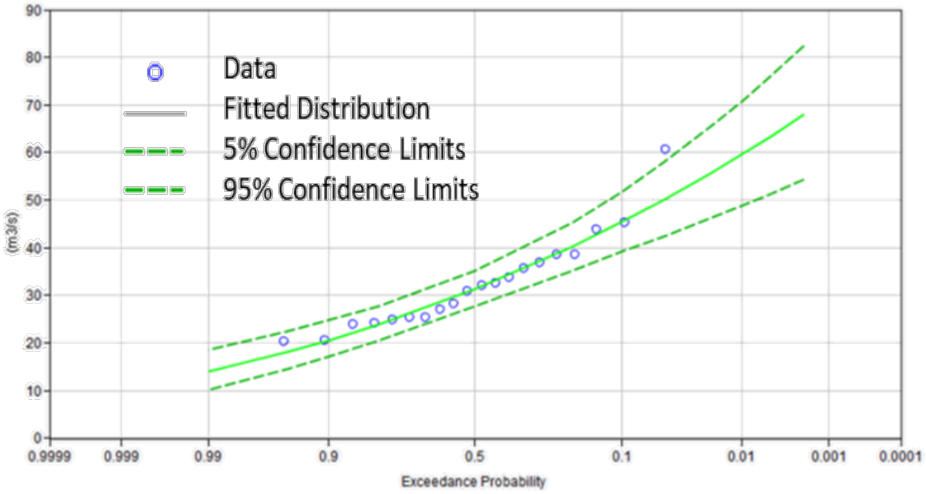
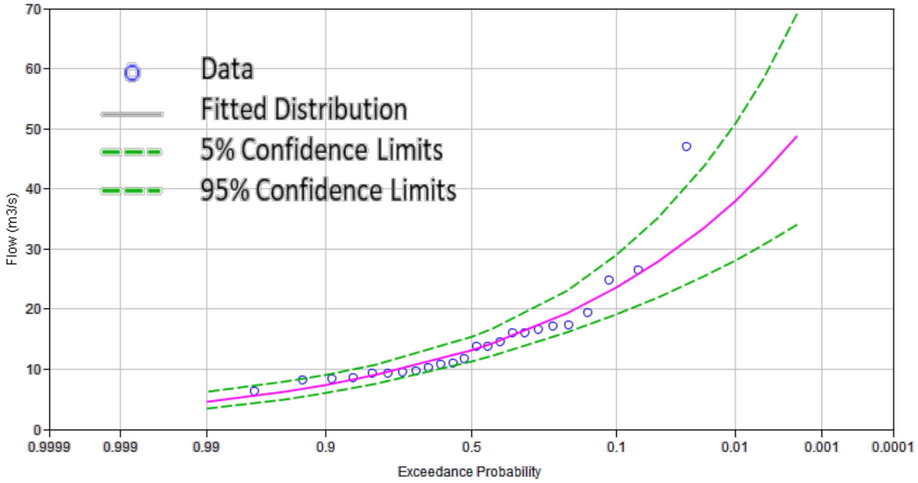


(c)



(d)

Regional Flood Frequency Analysis relies on the data to be homogeneous. To assess whether this condition was satisfied, the bell curve homogeneity test was employed. The outcome of this homogeneity test for Regional Flood Frequency Analysis, shown in Figure 3-5, indicates that the data from the selected stations are within the stipulated bounds, and therefore the stations satisfy this condition.

The normalized data from the four WSC stations were merged, and a Regional Flood Frequency Analysis (RFFA) was performed on the combined dataset. The result of the RFFA on the normalized data is provided in Table 3-7. The values in this table correspond to peak flow ratios, so that the recurrent peak flows at each location, can be obtained by multiplying these peak flow ratios by the peak flow corresponding to a 2.33-year return period.

FIGURE 3-5: RFFA HOMOGENITY TEST

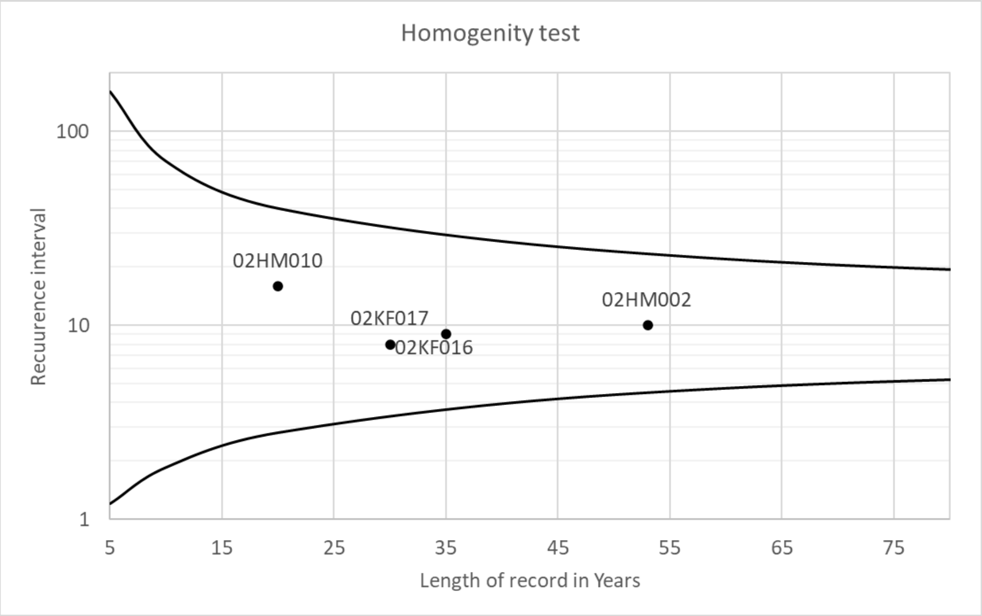
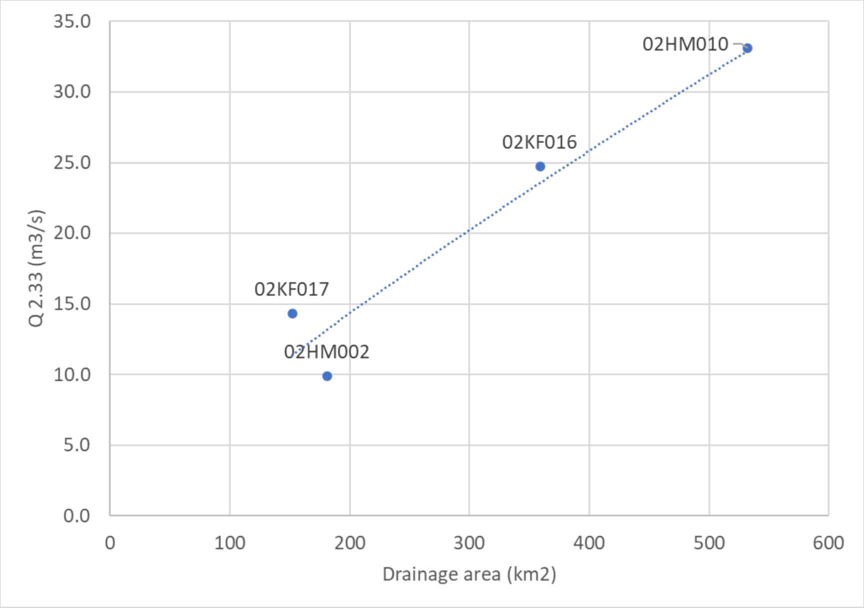


TABLE 3-7: REGIONAL FREQUENCY ANALYSIS FLOOD INDICES

Return Period (Years)	Flood Index Peak Flow Ratios
2	0.91
2.33	1.00
5	1.25
10	1.50
20	1.77
25	1.86
50	2.15
100	2.46
200	2.80
500	3.29

To obtain the peak flow corresponding to a 2.33-year return period, for ungauged locations, a regression equation was developed relating this peak flow with the drainage areas of the available stations. The resulting relationship is shown in Figure 3-6.

FIGURE 3-6: REGRESSION ANALYSIS OF DRAINAGE AREA AND Q2.33



The corresponding equation is:

$$Q_{2.33} = 0.158 \times Drainage\ Area^{0.85}$$

This relationship was used to derive $Q_{2.33}$, for ungauged locations in the Salmon River Upper Lakes watershed, and upstream of Kennebec Lake and Big Clear Lake. The peak flows for different return periods were then calculated using the flood indices provided in Table 3-7, as formulated below:

$$Q_n = Q_{2.33} \times \frac{Flood\ Index_n}{Flood\ Index_{2.33}}$$

The results of the Regional Flood Frequency Analysis for a location at the downstream end of the study area is shown in Table 3-8. Values obtained with RFFA at various locations were subsequently used for verification of a hydrologic model, as explained in Section 3.3.2.

TABLE 3-8: REGIONAL FREQUENCY ANALYSIES RESULTS FOR THE SALMON RIVER UPPER LAKES WATERSHED

Return Period (Years)	AEP	Flow (m^3/s) Salmon River Upper Lakes Watershed
2	50%	24
5	20%	33
10	10%	39
25	4%	48
50	2%	56
100	1%	64
200	0.5%	73
500	0.2%	86
Drainage Area (km^2)		**404**

3.3 Hydrologic Modeling

A new hydrologic model of the Salmon River Upper Lakes watershed was developed as a part of this study to simulate the watershed response to recurrent storm events. The model was developed using HEC-HMS software version 4.11, developed by the US Army Corps of Engineers. Data for preparation of the model (including soil characteristics, land-use, and sub-catchment dimensions) were obtained from sources such as Land Information Ontario, Ontario Watershed Information Tool (OWIT) and the Ontario Agricultural Atlas. No previous hydrologic model or report, for the Salmon River Upper Lakes Watershed, was available at the time of preparing this study.

Several limitations were encountered while preparing a calibrated hydrologic model for this study. There are no hydrometric stations within the study watershed with measured flow data. Therefore, it was not possible to calibrate the model against observed flood events. To prepare a hydrologic model with reliable results to be used for floodplain mapping, the results obtained from RFFA were used to verify and refine the model parameters selected to represent the characteristics of the various sub-catchments within the watershed.

As indicated in Section 1.1, in the absence of well-defined level-discharge rating curves for most of the lakes within the study area, the decision was made to include lake routing in the hydraulic model rather than the hydrologic model. While fine-tuning the hydrologic model, a range of parameters was obtained that could potentially generate suitable inflows for the hydraulic model. The parameters presented in this report resulted in flow values within the same range as those obtained from the RFFA. It is important to note that the estimated parameters for the hydrologic model will be further refined based on the results obtained from the hydraulic model and after comparing them with the RFFA values.

3.3.1 HYDROLOGIC MODEL SETUP

The HEC-HMS hydrologic model was employed to simulate the response of the watershed to summer-rainstorm and spring-rain-plus-snowmelt events with the hyetographs developed in Sections 3.1.2 and 3.1.3.

The sub-catchment delineation for the watershed model was obtained using OWIT, and the corresponding HEC-HMS GIS built in tool, based on the topography of the watershed. The hydrologic model developed in this study contains 13 sub-catchments and four river reaches. A schematic representation of the model is shown in Figure 3-7.

FIGURE 3-7: WATERSHED REPRESENTATION IN HEC-HMS MODEL

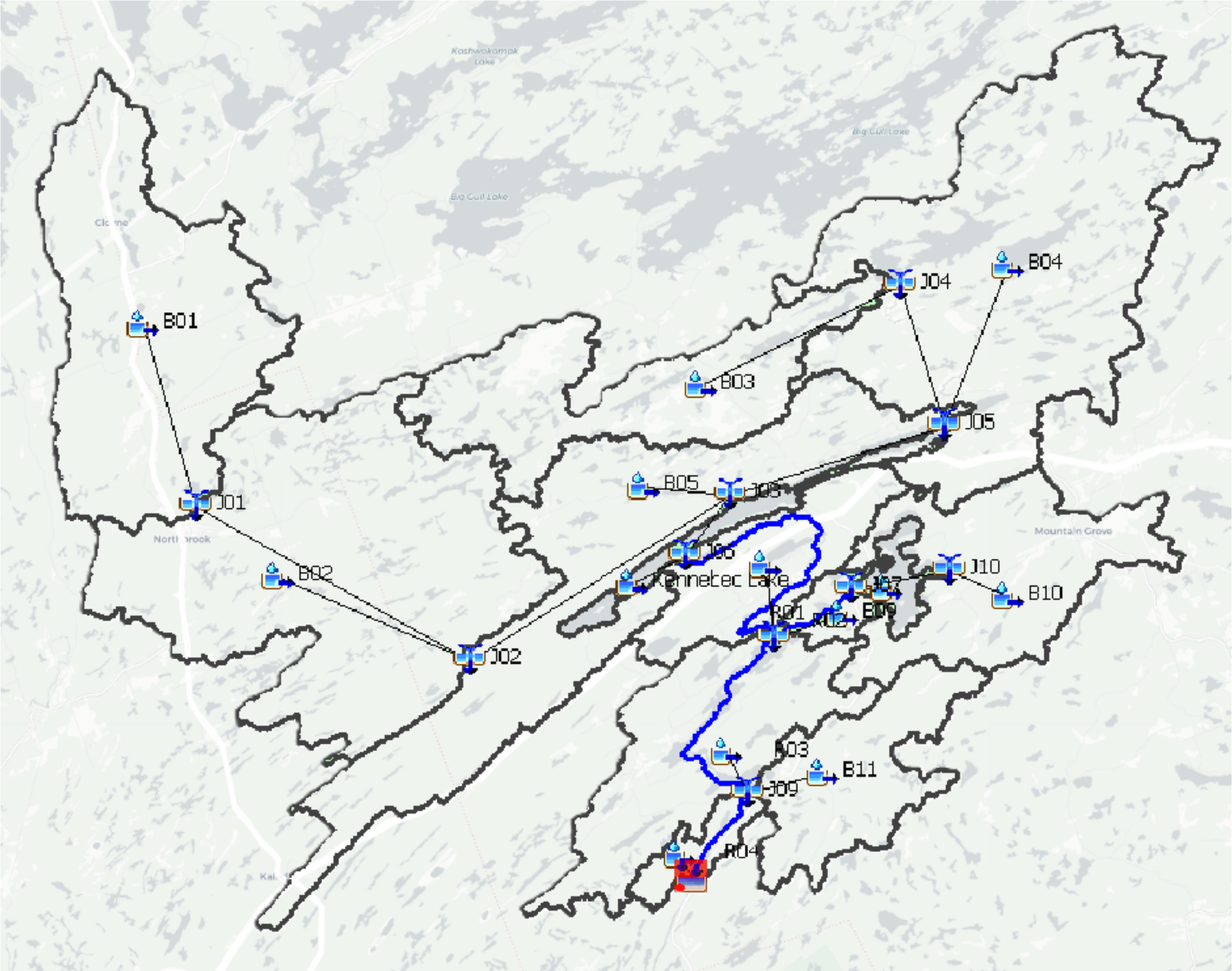
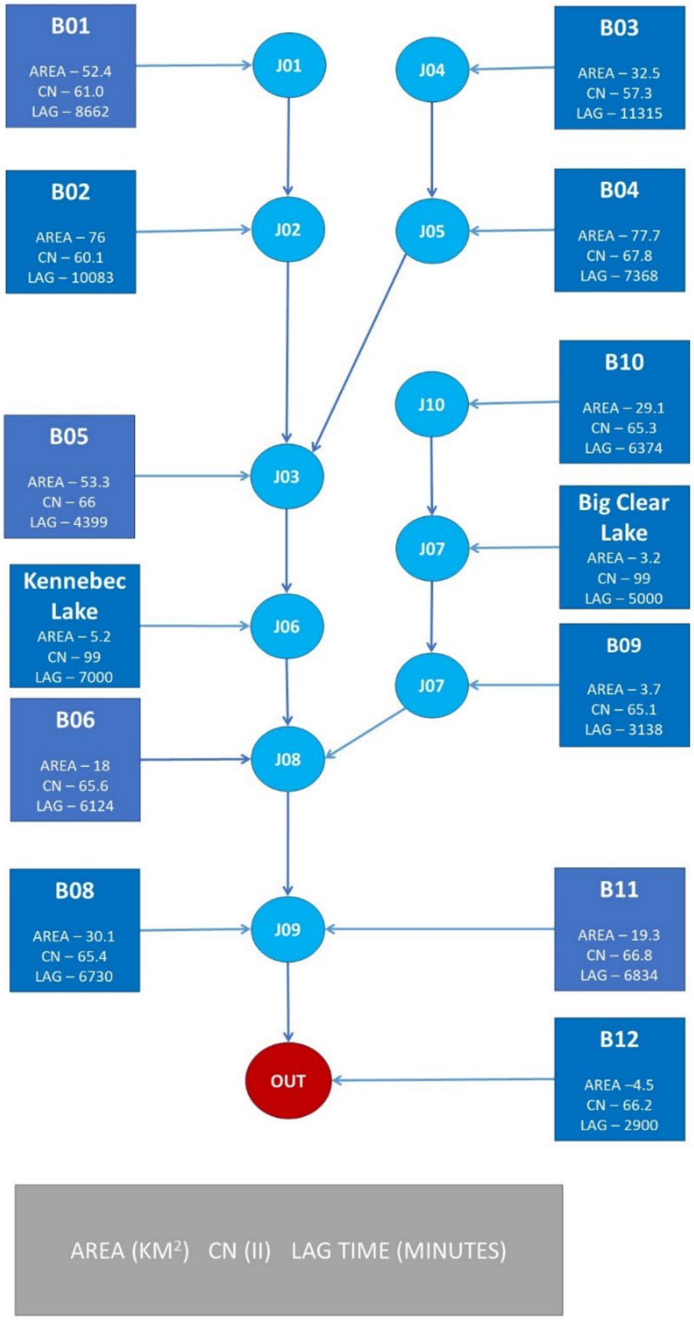


FIGURE 3-8: SCHEMATIC OF THE MODEL PREPARED FOR THE SALMON WATERSHED (KGS 2023)



The model computes runoff volumes for each sub-catchment using the US Soil Conservation Service (SCS) Curve Number (CN) method. In this method the hydrologic soil characteristics and Antecedent Moisture Condition (AMC) are represented by the selection of a CN value. The CN for each sub-catchment was obtained as part of this study, based on ground cover types and hydrologic soil types, obtained from the data available from Land Information Ontario (LIO), from sources such as OWIT and the Ontario Agricultural Atlas. For modeling purposes, soil average antecedent moisture conditions (AMC II) were used for summer events, and saturated soil (AMC III) were used for spring events. Initial abstraction (Ia) values were calculated based on the CN values using the formulas provided in the HEC-HMS Technical Reference Manual. The percentage of impervious area for each sub-catchment was calculated as the percentage of area that corresponds to open water and bedrock. Table 3-9 shows the hydrologic parameters, CN-II and CN-III, as well as the Initial abstractions adopted to describe land cover within the model. The watershed map with land use and hydrologic soil types are shown in the following.

FIGURE 3-9: LAND USE MAP OF THE WATERSHED

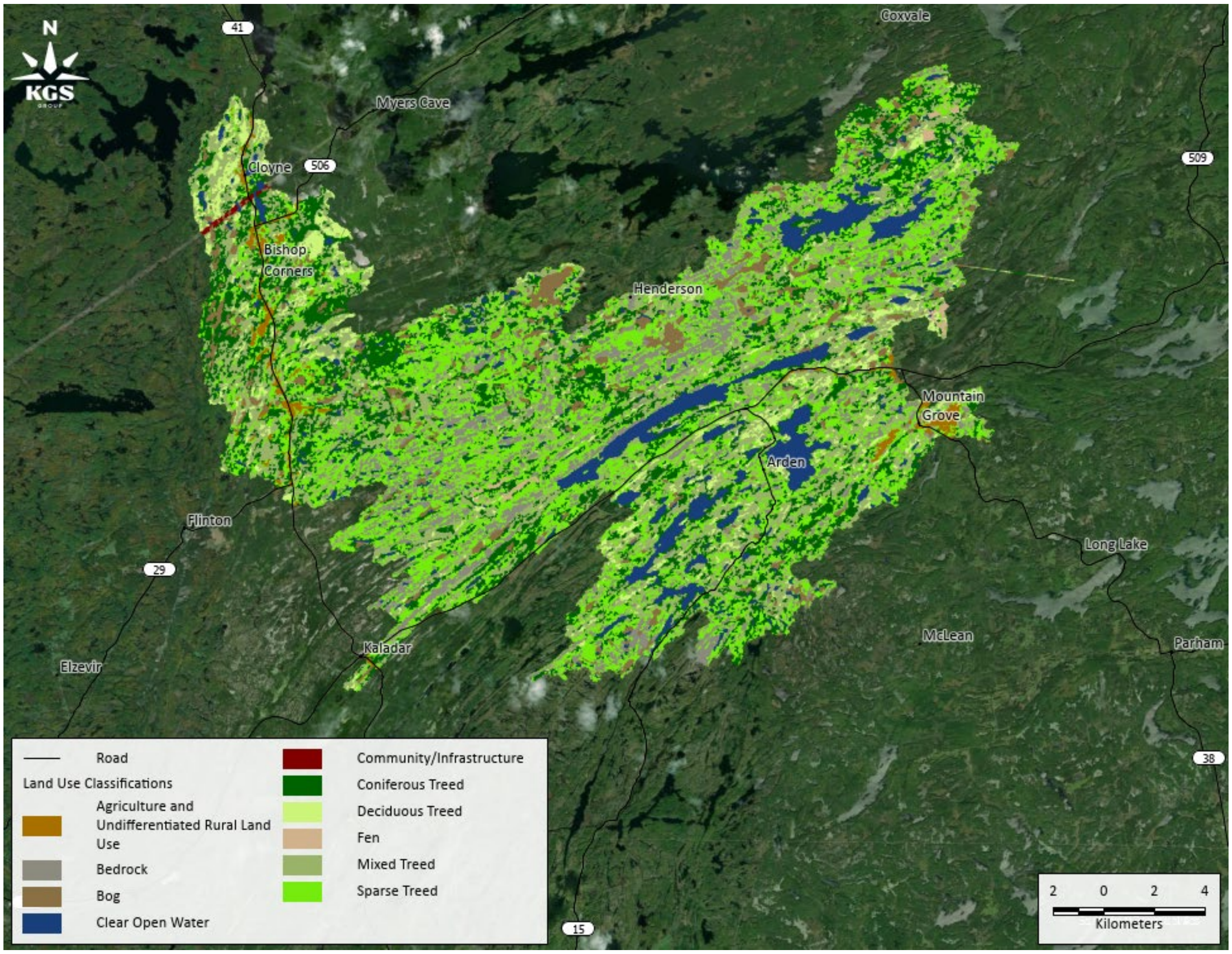
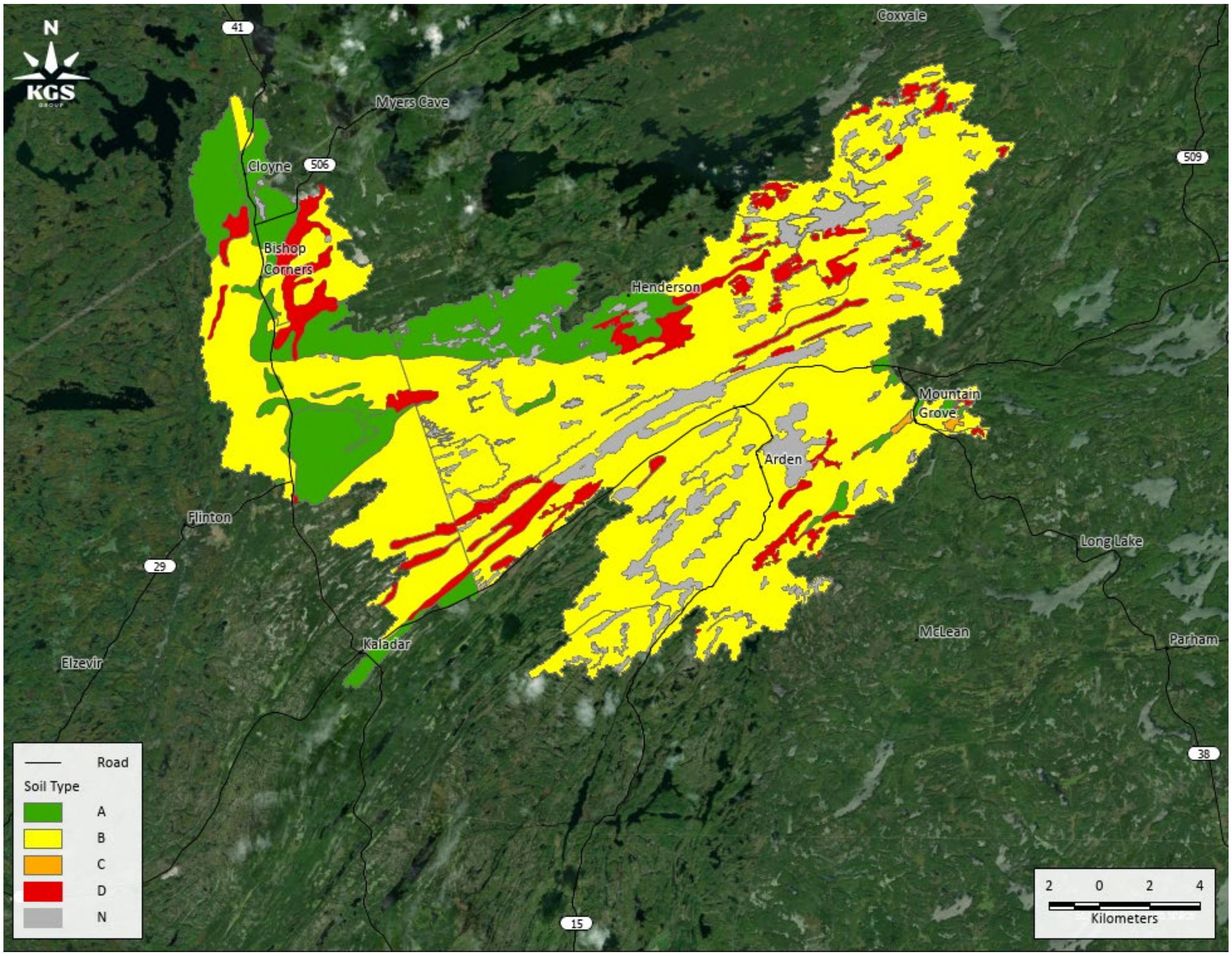


FIGURE 3-10: HYDROLOGIC SOIL TYPES IN THE WATERSHED



The model applies the SCS unit hydrograph method to estimate the direct runoff resulting from excess precipitation. The input parameters for this method are “lag time” and “peak rate factor”. Initial estimates of these model parameters were obtained using the SCS Watershed Lag formula and were further refined as part of refining the model parameters by comparing model results and FFA results (described in Section 3.3.2). Table 3-9 shows the values for the hydrologic parameters that gave similar results to the RFFA at two locations: Upstream of Kennebec Lake and upstream of Big Clear Lake (flow results are provided in Section 3.3.3).

TABLE 3-9: HYDROLOGIC MODEL PARAMETERS

Subcatchment	Area (Km^2)	CN (II)	CN (III)	Ia (mm) for CN II	Ia (mm) for CN III	Impervious (%)	Peak Rate Factor	Lag Time (min)
B01	52.4	61.0	78.2	32.5	14.1	2.9	484	8662
B02	76.0	60.1	77.6	33.7	14.6	19.8	484	10083
B03	32.5	57.3	75.5	37.9	16.5	21.8	484	11315
B04	77.7	67.8	82.9	24.2	10.5	22.0	484	7368
B05	53.3	66.0	81.7	26.2	11.4	26.8	484	4399
B06	18.0	65.6	81.4	26.7	11.6	26.6	484	6124
B08	30.1	65.4	81.3	26.8	11.7	27.7	484	6730
B09	3.7	65.1	81.1	27.2	11.8	23.5	484	3138
B10	29.1	65.3	81.3	26.9	11.7	13.2	484	6374
B11	19.3	66.8	82.3	25.2	11.0	17.9	484	6834
B12	4.5	66.2	81.9	25.9	11.3	58.0	484	2900
Kennebec Lake	5.2	99	99	0	0	99.9	484	7000
Big Clear Lake	3.2	99	99	0	0	99.9	484	5000

A base flow was included in the hydrologic model as a separate input based on the observed data at WSC Station 02HM010 which is located on the Salmon River, downstream of the study area. The model requires an input indicating the flood routing method to be applied along river reaches. In this case, the Muskingum method was used. It requires two input coefficients:

- a dimensionless weighting factor, X, that ranges from 0 to 0.5, and for which the initial value was 0.5 (reflecting no attenuation), and
- the travel time along channel reaches, K, for which the initial values were based on the channel lengths and flow velocities obtained with the Manning's equation.

These coefficients were subsequently adjusted using flow data at Station 02HM010.

It must be noted that the outflow of individual sub-catchments downstream of Kennebec Lake and Big Clear Lake, will be input to a 2D hydraulic model that will be used to perform unsteady state simulations of the floods. This approach will allow carrying out the routing of the various inflows as part of the hydraulic model simulation. It was chosen because the 2D model allows for a more accurate representation of flow conditions at the outlet of Kennebec Lake, where a well-defined outlet rating curve does not exist, as compared to the hydrologic model. A similar methodology (conducting flood routing through the lake within the hydraulic model and not in the hydrologic model) is also suggested for Big Clear Lake.

3.3.2 VERIFICATION OF HYDROLOGIC MODEL PARAMETERS

The hydrologic model was not calibrated because there is no adequate data for calibration. Instead, its input parameters were adjusted so that the model results approached the peak flow values obtained using RFFA. This exercise was carried out using the RFFA results at the upstream of the Kennebec Lake (a large portion of the watershed without significant lake effect drains to Kennebec Lake) and Big Clear Lake. The input parameters used were the peak rate factor and the lag time for the individual subbasins.

Table 3-10 shows the hydrologic model results at various locations. Peak flows upstream of Kennebec Lake and Big Clear Lake are in close agreement with the peak flows obtained from the RFFA. It should be noted that the outflow at the Crotch Lake Outlet (downstream end of the study area) is greater than the flow obtained from RFFA. This finding was expected as the hydrologic model does not account for routing through the lakes, which attenuates the peak flows. Additional adjustments may be required once the hydraulic model, which incorporates lake flood routing, is developed.

TABLE 3-10: COMPARISON OF RESULTS OBTAINED WITH RFFA AND HYDROLOGIC MODEL – SPRING PEAK FLOWS

Flow (m^3/s) at		Crotch Lake outlet		Upstream of Kennebec Lake		Upstream of Big Clear Lake	
Return period	**AEP**	**RFFA**	**Hydrologic model**	**RFFA**	**Hydrologic model**	**RFFA**	**Hydrologic model**
2	**50%**	24	26	18	17	2.5	2.3
5	**20%**	33	39	25	25	3.5	3.5
10	**10%**	39	47	30	31	4.2	4.3
25	**4%**	48	58	37	38	5.2	5.3
50	**2%**	56	67	42	43	6.0	6.1
100	**1%**	64	75	49	49	6.9	6.9
200	**0.5%**	73	82	55	54	7.8	7.6
500	**0.2%**	86	94	65	62	9.2	8.7

3.3.3 PRELIMINARY HYDROLOGIC MODEL RESULTS

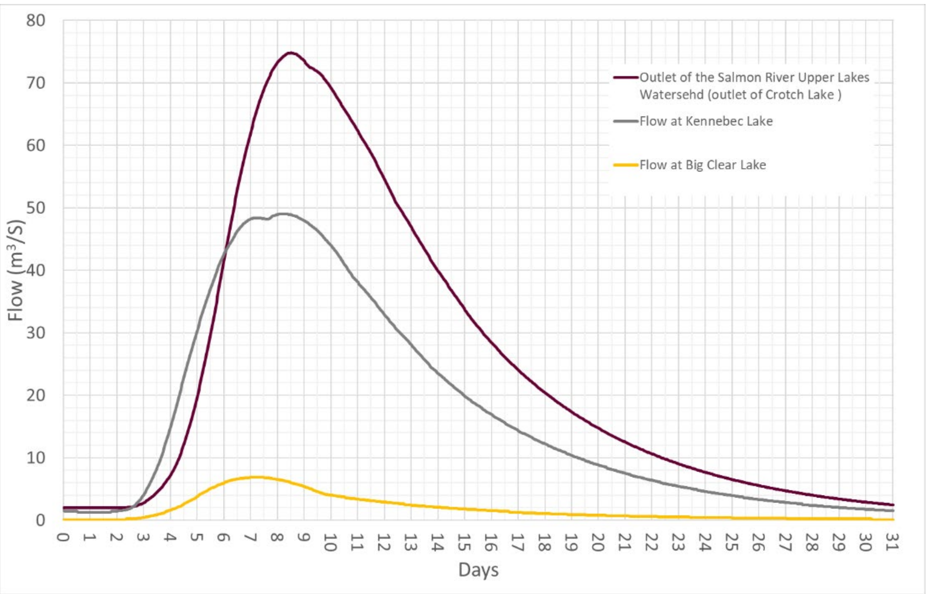
The hydrologic model was originally prepared for the simulation of the spring/winter events using AMC III. To simulate the summer storms, the same model was utilized with AMC II representing normal antecedent moisture condition. Table 3-11 shows the comparison between the peak flows generated with summer and spring recurrent events.

TABLE 3-11: HYDROLOGIC MODEL RESULTS-SUMMER AND SPRING FLOWS AT THE OUTLET AND UPSTREAM OF KENNEBEC LAKE

Return Period	AEP	Winter/Spring			Summer/Fall		
		Study Area Outlet	Kennebec Lake	Big Clear Lake	Study Area Outlet	Kennebec Lake	Big Clear Lake
2	**50%**	26	17	2.3	7	4	0.4
5	**20%**	39	25	3.5	10	6	0.6
10	**10%**	47	31	4.3	12	7	0.8
25	**4%**	58	38	5.3	15	9	1.1
50	**2%**	67	43	6.1	17	10	1.3
100	**1%**	75	49	6.9	20	12	1.5
200	**0.5%**	82	54	7.6	23	14	1.8
500	**0.2%**	94	62	8.7	27	17	2.2

The Regulatory Flood in the study area is the 100-year flood (1% AEP) as indicated in the "Technical Guide – River and Stream Systems: Flooding Hazard Limit" (MNRF, 2002). The results presented in Table 3-11 show that the peak flows generated in the spring (rain plus snowmelt) are greater than their summer counterparts. Therefore, the flood generated by the 100-year rain-plus-snowmelt event was selected as the regulatory flood event in the study area. The corresponding 100-year spring flood hydrographs at different locations within the study area are provided in Figure 3-8.

FIGURE 3-11: PRELIMINARY 100-YEAR (1% AEP) SPRING STORM EVENT HYDROGRAPHS AT DIFFERENT LOCATIONS OF THE STUDY AREA



3.4 Consideration of Climate Change Impacts

As indicated in Section 3.3, the results obtained for the 100-year (1% AEP) spring flood event will be used for the development of the floodplain maps as the regulatory flood.

While there is no scientific consensus on a methodology to consider the potential effect of climate change, the FHIMP guidelines indicate that a good approximation is to use the 200-year (0.5% AEP) event. As proposed for this project and agreed in the scope definition, that event (0.5% AEP) and the 500-year (0.2% AEP) will be used for a sensitivity analysis to consider the potential effect of climate change on the floodplain definition for the study area.

3.5 Summary of Hydrologic Results

Based on the hydrologic model results, and the data available, the flood generated by the 100-year rain-plus-snowmelt event was selected as the Regulatory Flood for the study area. The hydrographs corresponding to the 100-year spring flood at different locations will be used as inputs to a 2D hydraulic model, which will be prepared for floodplain mapping. Due to the absence of clearly defined outlet rating curves for the lakes, the lake routing will be incorporated in the 2D hydraulic model (lake routing is not included in the hydrologic model). The parameters used in the hydrologic model are expected to provide adequate results, and if required, will be refined after verifying the results with the hydraulic model.

4.0 REFERENCES

1) Gaur et al (2020), Gridded extreme precipitation Intensity—Duration-Frequency estimates for the Canadian landmass. J. Hydrol. Eng. 2020, 25.

2) Dalrymple (1960), Manual of Hydrology: Part 3. Flood-Flow Techniques. Flood frequency analyses. US Geol. Survey Water Supply Paper, 1960.

3) Ontario Ministry of Natural Resources and Forestry, (MNRF 2002), River & Stream Systems: Flooding Hazard Limit Technical Guide.

4) Ontario Ministry of Natural Resources and Forestry, (MNRF 2011), Lakes and Rivers Improvement Act Administrative Guide and Associated Technical Bulletins.

APPENDIX A

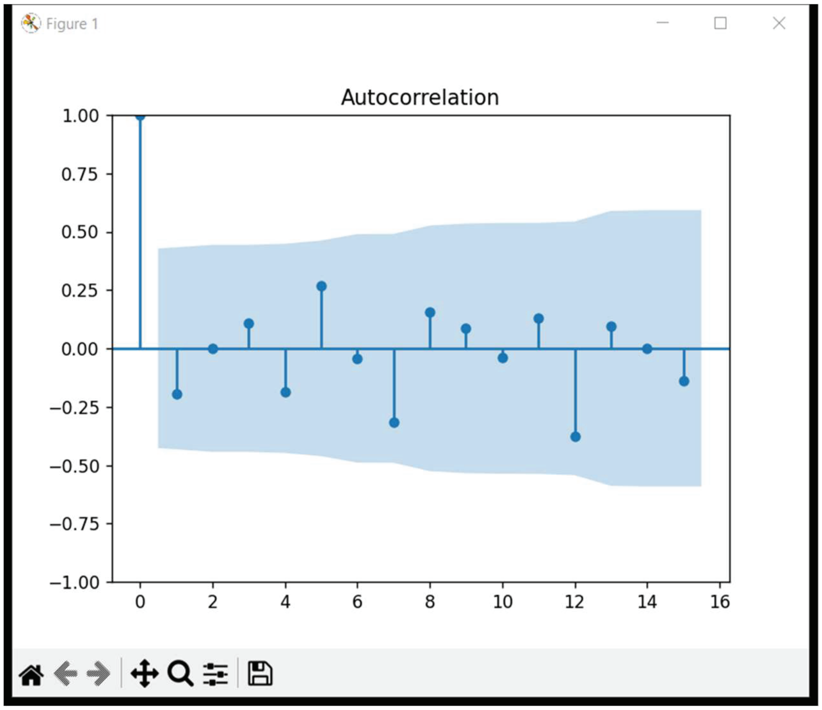
Flood Frequency Analysis Hypothesis Tests

The test for the outliers based on Bulletin 17C were performed for different stations and the potential outliers were eliminated from the data.

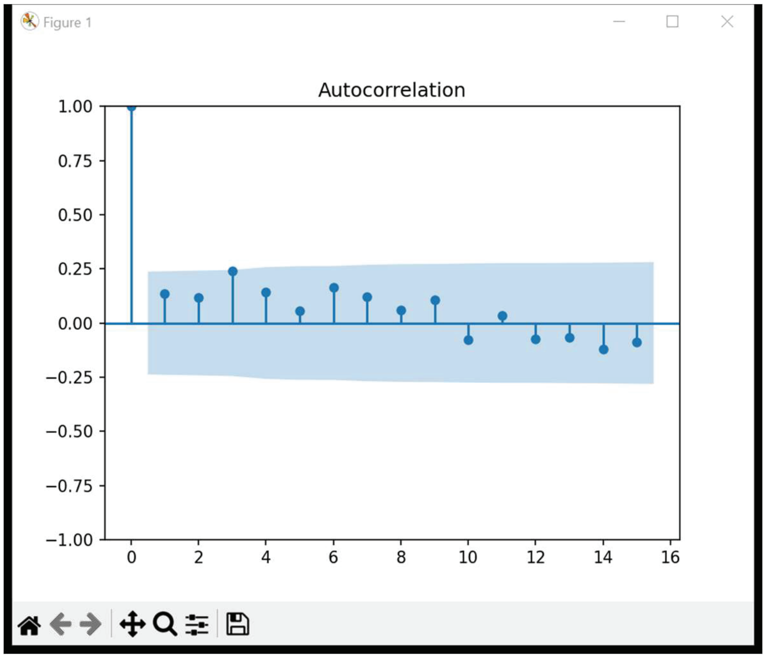
THE RESULT OF MANKENDALL TEST AND PETIT TEST FOR DIFFERENT STATIONS

Station	Auto correlation	Man-Kendall test		Pettit test		Number of detected outliers
02HM010	No	Trend	No	Homogeneity	Yes	1
		P-Value	0.48	P-Value	0.67	
		S	25			
02HM002	No	Trend	No	Homogeneity	Yes	0
		P-Value	0.3	P-Value	0.65	
		S	-136			
02KF016	Yes	Trend	No	Homogeneity	Yes	0
		P-Value	0.66	P-Value	0.81	
		S	31			
02KF017	No	Trend	No	Homogeneity	Yes	0
		P-Value	0.74	P-Value	0.81	
		S	-14			

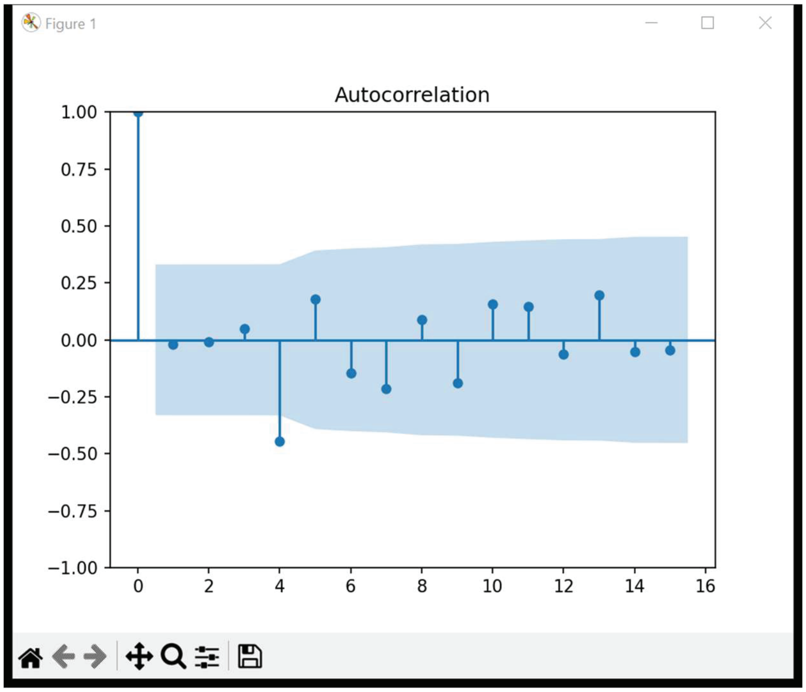
THE AUTOCORRELATION GRAPHS FOR DATA AT STATION 02HM010



THE AUTOCORRELATION GRAPHS FOR DATA AT STATION 02HM002



THE AUTOCORRELATION GRAPHS FOR DATA AT STATION 02KF016



THE AUTOCORRELATION GRAPHS FOR DATA AT STATION 02KF017