UNBC UNIVERSITY OF NORTHERN BRITISH COLUMBIA

# Executive Summary: Land use change and hydrologic modeling in the Kiskatinaw Watershed. Summary of work completed by UNBC in fulfillment of research contract RC10-2156

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# Summary report on 'Groundwater – Surface Water Interactions in the Kiskatinaw River Watershed'

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The Kiskatinaw River Watershed (KRW) is a very important region for northern British Columbia (BC)'s social, environmental, and economic development. The river water has been the major water source within this watershed. The City of Dawson Creek provides drinking water to all inhabitants and other industrial users by collecting and treating water from the river since there are few reasonable alternative sources in the region. However, the river flow can show significant seasonal variations which may pose serious challenges to water demand by the community and many other water users, and thus result in stressing of water resources management. The quantification of groundwater-surface water interaction is then of great importance for understanding water availability and river flow variations within the watershed.

In order to examine groundwater-surface water interaction in the KRW, a groundwater monitoring network was established by installing 26 piezometers equipped with Odyssey data loggers in the KRW. Piezometers were inserted into the ground using hand auger and slide hammer such that the bottom of the piezometer remained minimum 40 cm below the groundwater level for capturing all season data. Each Odyssey data logger was calibrated using 3-point calibration method as outlined by Odyssey before inserting in the piezometer. Data loggers were set to 20 minutes for data collection of ground water level.

The regional groundwater flow direction in the KRW was determined using gridded surface subsurface hydrologic analysis (GSSHA) model (Downer, 2002) based on observed groundwater level data collected from the groundwater monitoring network of 26 piezometers. Before using these collected groundwater table data, barometric pressure correction was applied on those data because groundwater table fluctuates by atmospheric pressure with altitude change. Based on regional groundwater flow field in the KRW, it is found that the groundwater flow pattern in the KRW is mainly a through-flow system (i.e., groundwater passing through the stream network). The results also indicate that more shallow and deep monitoring wells data are needed for further characterization.

Groundwater (base flow) contribution to stream flow in the KRW was quantified for the period of January 2007 to December 2011 using PART base flow separation program of USGS. It estimates daily base flow by considering base flow to be equal to stream flow on days that fit a requirement of antecedent recession, and then linearly interpolates base flow for other days in the record (Rutledge, 1998). The results indicate that groundwater contributes significantly to stream flow, and this contribution varies time to time. By comparing annual mean stream flow, it is found that the annual base flow index (i.e. annual groundwater contribution to river flow) increases when the annual mean stream flow decreases, and vice versa. It is also found that the highest annual base flow index (75.13%) observed in the dry year (2008), and lowest annual base flow index (57.5%) observed in the wet year (2011). The mean annual groundwater contribution to river (base flow index) of the KRW of 2007-2011 was 69.5%.

In this study a groundwater - surface water interaction model in Mainstem (213.82 km$^2$) of the KRW was developed as a case study due to limited data through a Gridded Surface Subsurface Hydrologic Analysis (GSSHA) model using the field data (i.e. elevation, channel geometry, surficial geology, soils, land use and land cover, groundwater level, etc.) collected from the watershed for studying the impacts of climate change on groundwater contribution to stream flow. The model was calibrated and validated using observed stream flow data and climate data (i.e. precipitation and temperature) in the KRW by changing soil parameters (i.e. hydraulic conductivity, and porosity), overland surface roughness, channel roughness, overland retention depth, initial soil moisture and soil moisture depth. In addition to stream flow, the developed model was also calibrated and validated using observed groundwater level data (collected from piezometers) and the calculated monthly mean groundwater (base) flow index using PART base flow separation program of the USGS. After validation, the model was used to generate the future (i.e. 2012-2016) scenarios for investigating the climate change impacts on groundwater - surface water interaction in the in Main stem in the KRW under different greenhouse gas (GHG) emission scenarios (i.e. A2: heterogeneous world and high scenario, and B1: homogeneous world and low scenario).

Based on the simulation results we found that the lowest and highest mean monthly groundwater contributions to stream flow of 2012-2016 in A2 scenario were found in June (i.e. 45%), and January and December (i.e. 96%), respectively. On the other hand, the lowest and highest mean monthly groundwater contributions to stream flow of 2012-2016 in B1 scenario were found in May (i.e. 46%) and December (i.e. 99%), respectively. On average, stream flow is mostly dependent on groundwater during December in both scenarios. Stream flow is least dependent on groundwater during May and June in B1 and A2 scenarios, respectively. From the comparison of mean annual groundwater contribution to stream flow from 2012-2016 under climate change of A2 and B1 greenhouse gas emission scenarios with respect to current climate (i.e. 2011) condition, we found that the highest and lowest mean annual groundwater contributions to stream flow during 2012-2016 in A2 scenario were found in 2013 (i.e. 78.1%), and 2012 (i.e. 75.2%), respectively due to lowest (i.e. 509 mm) and highest (i.e. 530 mm) precipitation on those year. On the other hand, the highest and lowest mean annual groundwater contributions to stream flow during 2012-2016 in B1 scenario were found in 2012 (i.e. 80.2%), and 2013 (i.e. 77%), respectively due to lowest (i.e. 494 mm) and highest (i.e. 524 mm) precipitation on those year. On average, mean annual GW contribution to stream of 2012-2016 under A2 and B1 scenarios were 76.7% and 78.2%, respectively. The mean annual groundwater contributions to stream flow during 2012-2016 was correlated to yearly precipitation in both scenarios. From the non-linear relationship, we found that when annual precipitation increases, mean groundwater contribution to stream flow decreases in both scenarios, and vice versa.

When land use/land cover (LULC) changes (i.e. increasing forest clear cut area, and decreasing forest and agricultural areas annually) were incorporated with climate change scenarios, the lowest and highest mean monthly groundwater contributions to stream flow of 2012-2016 in A2 scenario with LULC changes were found in June (i.e. 39%), and January (i.e. 95%), respectively. On the other hand, the lowest and highest mean monthly groundwater contributions to stream flow of 2012-2016 in B1 scenario with LULC changes were found in May (i.e. 40%) and December (i.e. 97%), respectively. On average, stream flow is mostly dependent on groundwater during January in both scenarios with LULC changes. Stream flow is least dependent on groundwater during May and June in B1 and A2 scenarios with LULC changes, respectively. From the comparison of mean annual groundwater contribution to stream flow from 2012-2016 under A2 and B1 greenhouse gas emission scenarios of LULC changes with respect to current climate and land use (i.e. 2011) conditions, we found that both scenarios show an opposite pattern of groundwater contribution to stream flow from 2012 to 2014, and similar pattern of GW contribution to stream flow from 2014 to 2016. The highest and lowest mean annual groundwater contributions to stream flow during 2012-2016 in A2 scenario with LULC changes were found in 2013 (i.e. 76.5%), and 2016 (i.e. 72%), respectively. The highest groundwater contribution was found in 2013 due to lowest (i.e. 509 mm) precipitation on this year, while the lowest groundwater contribution was found in 2016 due to more LULC change (i.e. more forest clear cut) occurred in 2016 compared to other years and the precipitation (i.2. 526 mm) in 2016 was close to the highest precipitation of 2012 (i.e. 530 mm). These LULC changes result more surface runoff due to increasing forest clear cut of low hydraulic conductivity soil annually. On the other hand, the highest and lowest mean annual groundwater contributions to stream flow during 2012-2016 in B1 scenario with LULC changes were found in 2012 (i.e. 79.3%), and 2016 (i.e. 72.9%), respectively. This is occurred due to similar reasons of A2 scenario. On average, mean annual GW contribution to stream of 2012-2016 under A2 and B1 scenarios with LULC changes were 73.6% and 75.7%, respectively. Compared to climate change effects only, these contributions were less than by 3.1% and 2.5% in A2 and B1 scenarios of LULC changes, respectively. Therefore, land use change has significant impact on groundwater contribution to stream flow. The mean annual groundwater contributions to stream flow during 2012-2016 was correlated to yearly precipitation in both scenarios with LULC changes. The relationships are non-linear similar to climate change scenarios, but the shape of relationship curves are different. From these non-linear relationships, we found that when annual precipitation increases, mean groundwater contribution to stream flow does not always decrease in both scenarios due to land use changes.

# Summary report on ‘Land Use-Land Cover Change Analysis in Kiskatinaw River Watershed’

Written by
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Watersheds in north-eastern British Columbia (BC) have been undergoing a wide range of land use and land cover changes (LULC) over the past few years due to the convergence of various industrial interests, for example, logging, mining, oil and gas development, large scale hydro development etc. (Lee & Hanneman, 2012). Among the north-eastern BC’s watersheds, Kiskatinaw River watershed (KRW) which is the study area of this research features considerable portion of the industrial development activities and their associated LULC changes.

Since the Kiskatinaw watershed serves as the primary drinking water source to the City of Dawson Creek and the neighboring village of Pouce Coupe as well as has number of other water use values, e.g. agricultural, farming, forestry, wild life etc., there is a significant concern emerged to understand the land use and land cover change dynamics within the watershed. In this context, the present study has endeavored to investigate the land use and land cover alteration within KRW over the past 26 years from 1984 to 2010. Remote sensing and GIS tools have been utilized in this study to capture LULC changes.

Landsat images for the years 1984, 1999 and 2010 have been analyzed using object oriented image classification technique for 11 LULC classes, namely cropland, coniferous forest, deciduous forest, mixed forest, re-growth/planted forest, forest fire, cut block, pasture, water, wetland and built-up Area. Then, various GIS editing have been performed on the classified output to incorporate different government data layers, like: road network, natural gas development infrastructure etc. to produce comprehensive LULC maps of the study area. This way, three separate LULC maps have been generated for KRW for the years 1984, 1999 and 2010 which have been taken for spatial change analysis in later part.

The study area which is a forested watershed maintained its large mature forest cover (around 80%) within the study period from 1984 to 2010. Subtle changes have been observed for the mature coniferous, deciduous and mixed forest types. The noticeable change of the planted or re-growth forest type and cut blocks indicates the dynamic forestry industry in this area, although cut blocks in recent images may be attributed to the gas development industry as well. In many cases, cropland and pasture were hard to differentiate during the digital image classification process of Landsat data since these land use types are more or less similar in spectral signature. But combined, cropland and pasture shows a considerable change in between 1984 to 2010 which highlights the amplified agricultural and farming activities within the watershed. This analysis identified a striking change in the extent of wetlands, while most of the wetlands depleted in between 1984 to 1999 which is estimated as 233.22 km$^2$. This significant change in wetland area needs further investigation to understand the depletion dynamics. An increase of 29 km$^2$ of built-up area indicates to the recent industrial booming in this area, particularly shale gas development activity. The forest fire affected 33.39 km$^2$ area represents the hour glass fire event in 2006 in and around the study area.

The comprehensive LULC information and inventory produced from this research should be updated regularly and taken further for an efficient monitoring of the land use and land cover change within the watersheds.

# Summary Report: Kiskatinaw River Surface monitoring network: methodology and rating curve development

Written by:
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## Executive Summary:

To determine surface water levels and discharge, staff gauges along with Odyssey capacitance data loggers were calibrated and installed at each study site. Cross sections were then completed in accordance with the BC Hydrometric Standards using Sontek's Acoustic Doppler Flow Tracker. Winter cross sections were completed on reaches that had not frozen all the way to the river bed. Discharge from cross sections was then correlated to the automated water level data and rating curves were developed for each study site.

The water level gauges were installed with the goal of achieving grade A data (table 1) as outlined in the BC Hydrometric Standards. Channel condition was a limiting factor at some sites due to the flashy nature of the local hydrology. At two sites, Oetata and East Headwater, beaver dams caused a drastic shift in the rating curve and a new cross section location needs to be explored. In addition, no freshet discharge measurements were taken which reduced the overall accuracy of the rating curves. For correction of all water level and discharge data quality control and quality assurance guidelines were followed.

Table 1. Summary of current data grade achieved for surface monitoring network, in accordance with BC hydrometric standards.

| Data grade | Instrumentation | Surveyed benchmarks | No. verticals per cross sxn | Cross sxn per year | Accuracy of rating curve | Results compared with other stations | Channel condition |
|---|---|---|---|---|---|---|---|
| GRADE A | Automated water level gauge, 2 mm accuracy ✓ | 3 ✓ | 20 or more<br>< 5 % of Q ↕ | 5 ✓ | < 7 percent ↕ | Yes ✓ | Stable, straight reach, minimal weeds & boulders ↕ |
| GRADE B | Automated water level gauge, 5 mm accuracy | 3 | 20 or more<br>< 10 % of Q ↕ | 3 | < 15 percent | No | Minor instability, occasional weed & boulder |
| GRADE C | Manual gauge, 1 cm accuracy | 1 | 10 or more<br>< 20 % of Q | 2 | < 25 percent ↕ | No | Unstable, erosion, turbulent, weed growth, boulder bed ↕ |

Annual hydrographs were produced from the rating curves calculated for each site. Annual hydrographs for all research sites can only be interpreted within the range of measured values. Beyond the peak measured values rating curves must be extrapolated. There are a number of methods in which rating curves can be extrapolated, some based upon channel physics while others are based upon graphical relationships. The Kiskatinaw rating curves have been extrapolated testing Manning's equation and the velocity-area method. For all rating curves the

Manning's equation underestimated the measured discharge while the area-velocity method appeared to have a more realistic visual extrapolation. The area-velocity method was used for extrapolated discharge values; therefore discharge values above the peak measured value must always be considered as estimated values. In order to have a high level of confidence in rating curves discharge measurements must be taken for all levels of the hydrograph.

Currently the 7 tributary sites where discharge measurements were collected represent the majority, but not all of the tributary streams connected to the Kiskatinaw main stem (Table 2). As indicated in table 3, the surface water monitoring network only captures approximately 52 percent of the total volume that reaches the Farmington gauge. A total of 9 tributaries are not gauged (table 3) and may account for the additional volume. However inference can be made that groundwater may also contribute to the Kiskatinaw flow.

Table 2. Summary of mean daily and mean annual discharge for monitoring network and comparison to WSC gauge at Farmington. Note: Jackpine and West Confluence values from June 16 2011-Sept 6 2011 were interpolated using individual linear correlation relationships with Farmington. Jackpine $R^2$ is 0.73 and West Confluence $R^2$ is 0.87. For all sites data is missing from Jan 29, 2011 – April 1, 2011. No interpolation was completed for this period.

| **Station** | **Mean daily discharge (m3/s) for May 22, 2010 -Feb 13, 2012** | **Total discharge (m3) for May 22, 2010 – Feb 13, 2012 (630 days)** |
|---|---:|---:|
| Oetata | 0.53 | 26,101,229 |
| West Headwater | 1.16 | 55,691,277 |
| Jackpine | 1.00 | *interpolated values 47,306,574 |
| East Headwater | 1.17 | 36,994,168 |
| Sunderman | 0.28 | 12,205,628 |
| East Confluence | 3.99 | 216,644,262 |
| West Confluence | 4.03 | *interpolated values 218,818,828 |
| Farmington WSC 07FD001 | 16.19 | 847,801,259 |

Table 3. Summary of watershed volumes and licence withdrawals.

| | |
|---|---:|
| Total licence withdrawal per day | 39,438 $m^3$/day |
| Total licence with per year | 14,394,925 $m^3$/year |
| Total licence withdrawal from May 22, 2010 – Feb 13, 2012 (630 days) | 24,846,035 $m^3$ |
| Total discharge for Kiskatinaw tributaries: East Confluence + West Confluence + Oetata | 461,564,319 $m^3$ |
| Measured tributary volume minus licence withdrawal as percent of measured Farmington volume | 52 % |
| Kiskatinaw tributaries not gauged:<br>Brassey, Tremblay, Sunset, Fox, Borden, Ministik, Sunset, Coal, Mica | |
| Additional volume over 630 days not captured in above measurements:<br>Farmington – gauged tributaries – licence withdrawals | 361,390,905 $m^3$ |

# Summary Report on ‘Hydrological Modeling of the West Headwater sub-basin using HEC-HMS’

November 30, 2011

Written by: Clare Zemcov, Megan Harwood, Terry Tan, Tiffany Fong

## 1.0 Executive Summary

The Kiskatinaw River Watershed (KRW) is located in northeastern British Columbia and is the sole supply of drinking water to the City of Dawson Creek and Village of Pouce Coupe. Although the KRW is large, at approximately 3,750 km$^2$, little is known about its hydrology. Rapidly increasing oil and gas development in this region created a greater interest in developing a comprehensive water management plan.

The West Headwaters subwatershed located in the southwest corner of the KRW was modeled using the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS). The model was calibrated using field discharge data that was collected throughout 2010 for two precipitation events that occurred in September and November.
Future land use scenarios were created using projected increases in oil and gas, forestry, and road development in the WHW region for the years 2015 and 2020. In addition, 50-, 100-, and 200-year 24-hour storm events were determined based on available precipitation data. The hypothetical storm events were used to predict peak flows based on current and expected land use changes. The model predicted that increasing development caused increased flows over time.

It is recommended that continued flow monitoring of the entire KRW is completed as well as additional models for the remaining subbasins. This model will provide a tool for estimating the effects of the increased development on the hydrology on the KRW. Together with other studies it will aid the City of Dawson Creek in completing a watershed management plan.

## 2.0 Final Results

Once calibration was complete to a satisfactory level multiple different storm events were input into the model. A precipitation event from November 2010 was modeled and the resulting hydrograph compared to the true field data hydrograph to determine accuracy and flexibility of the model. The post-calibration results of the November 2010 event are shown in Figure 1.

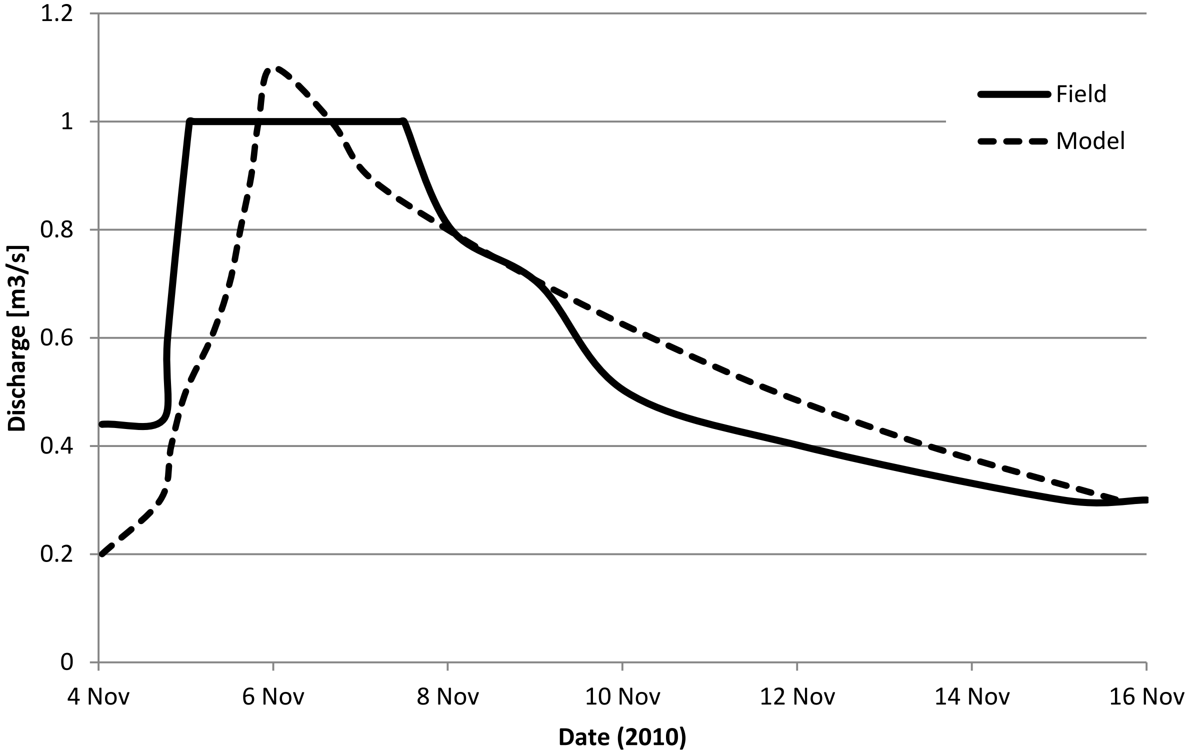

Figure 1. Model and field hydrographs for the November 2010 precipitation event (post-calibration).

A root mean square error (RMSE) of the September and November 2010 events was calculated according to the following equation

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}\left(x_{1,i} - x_{2,1}\right)^2}{N}} \qquad (1)$$

where:
$x_{1,i}$ = model discharge
$x_{1,i}$ = field discharge
N = number of days analyzed

Values for RMSE (Table ) were calculated based on discharge comparison on five different dates chosen to represent key components of the hydrographs: 1) start of the rising limb, 2) rising limb (influence by direct runoff), 3) peak flow, 4) falling limb, 5) inflection point (end of direct runoff influence, beginning of baseflow contribution). For both events, while poorly fitted model discharge occurs prior to peak discharge, the results show well fitted model and field discharges, where model flows fit within the error of field flows.

**Table 1.** Root mean square error (RMSE) comparison between calibrated model and field discharges.

| Precipitation Event | RMSE [$m^3/s$] | Model Discharge [$m^3/s$] | Field Discharge [$m^3/s$] | Quality |
|---|---|---|---|---|
| **September 2010** | ± 0.228 | | | |
| Start | | 0.2 | 0.6 | Poor |
| Rising limb | | 0.8 | 1.1 | Poor |
| Peak discharge | | 1.2 | 1.2 | Good |
| Falling limb | | 0.9 | 0.9 | Good |
| Inflection point | | 0.8 | 0.7 | Good |
| **November 2010** | ± 0.297 | | | |
| Start | | 0.2 | 0.6 | Poor |
| Rising limb | | 0.5 | 1.0 | Poor |
| Peak discharge | | 1.1 | 1.0 | Good |
| Falling limb | | 0.9 | 0.8 | Good |
| Inflection point | | 0.8 | 0.7 | Good |

Further comparison using relative percent difference (RPD) between model and field results for peak flows, flow volumes, lag times, and times to peak flow are included in table 2 below for the calibrated September 2010 and November 2010 precipitation events.

**Table 2.** Relative percent difference (RPD) between model and field hydrograph characteristics.

| Precipitation Event | Flow [$m^3/s$] | Total Flow Volume [$m^3$] | Lag time [min] | Time to Peak [min] |
|---|---|---|---|---|
| **September 2010** | | | | |
| Model | 1.2 | 728 | 3360 | 3060 |
| Field | 1.2 | 747 | 3900 | 3600 |
| RPD [%] | 0 | 1.3 | 7.4 | 8.1 |
| **November 2010** | | | | |
| Model | 1.1 | 684 | 2460 | 3180 |
| Field | 1.0 | 660 | 2880 | 1440 |
| RPD [%] | 4.8 | 1.8 | 7.9 | 38 |

## 3.0 Model Projections

Three future scenarios were investigated and modeled using the calibrated HEC-HMS model for the WHW. The first scenario involves modeling different storm events based on 50, 100, and 200 year return periods, while the second scenario involves modeling based on predicted land use changes in the next 5 and 10 years. The final scenario involved combining the hypothetical storm events with predicted land use changes in 5 and 10 years.

### *3.1 Hypothetical Storm*

In order to determine the future response of the watershed to different intensity storm events, a series of 24-hour storm events, 50, 100 and 200 years, were calculated using the Gumbel method.

Gumbel Distribution was used in determining 1 in 50, 100 and 200 years of 24 hour hypothetical storms which are developed based on annual maximum precipitation series of Tumbler Ridge data from 1989 to 2010 as shown in table 3.

**Table 3.** Annual maximum precipitation series at Tumbler Ridge (data period: 1989-2010).

| Year | 24hr maximum [mm] |
|---|---|
| 1989 | 27.9 |
| 1990 | 34.6 |
| 1991 | 14.1 |
| 1992 | 12.0 |
| 1993 | 30.6 |
| 1994 | 54.6 |
| 1995 | 20.3 |
| 1996 | 24.0 |
| 1997 | 44.3 |
| 1998 | 48.5 |
| 1999 | 51.7 |
| 2000 | 53.9 |
| 2001 | 122.6 |
| 2002 | 50.0 |
| 2003 | 22.3 |
| 2004 | 56.1 |
| 2005 | 37.6 |
| 2006 | 41.2 |
| 2007 | 40.6 |
| 2008 | 24.0 |
| 2009 | 94.0 |
| 2010 | 44.0 |

Using Gumbel Distribution equations,

$$X_T = \beta + \alpha Y_T \qquad (2)$$

$$Y_T = -\ln\left[\ln\left(\frac{T_R}{T_R - 1}\right)\right] \qquad (3)$$

Where:
$T_R$ is the return period in years, ,
$Y_T$ is the reduce variate which is dimensionless,
and $X_T$ is rainfallin millimeters.

Also, Gumbel parameters alpha, $\alpha$, and beta, $\beta$, related to standard deviation are also obtained as shown in equations in Appendix E (Millar, 2008 Civil 316 lecture notes). Standard deviation, $\sigma$ and mean, $\mu$ of annual maximum series were determined by general statistics formulas.

### *3.2 Hyetograph Determination*

For the 24 hour storm intensity from SCS rainfall distribution, it was assumed that Type II is most appropriate for British Columbia coastal regions (SCS, 1986). Using a Gumbel Distribution with return period, $T_R$ = 50 years, 100 years and 200 years, the respective peak 24 hour storms were calculated (table 4 & 5). Using Type II of SCS rainfall distribution over a 24 hour storm with a return period and a template provided by *Hydrocalc* online, the incremental rainfall depth over 24 hour storm hyetographs were constructed and input to the model. Figure 2 shows the 50 year hyetograph.

**Table 4.** Results for Gumbel Distribution.

| **Parameters** | **24hr Storm** |
|---|---|
| Standard Deviation, $\sigma$ | 25.33 |
| Mean, $\mu$ | 43.13 |
| A | 19.75 |
| B | 31.74 |

**Table 5.** 24-hour storms for 1 in 50, 100 and 200 year return periods.

| **Return Period, $T_R$ (years)** | **50** | **100** | **200** |
|---|---|---|---|
| Reduce Variate, $Y_T$ (dimensionless) | 3.9 | 4.6 | 5.3 |
| Rainfall amount, $X_T$ (mm) | 108.8 | 122.6 | 136.3 |

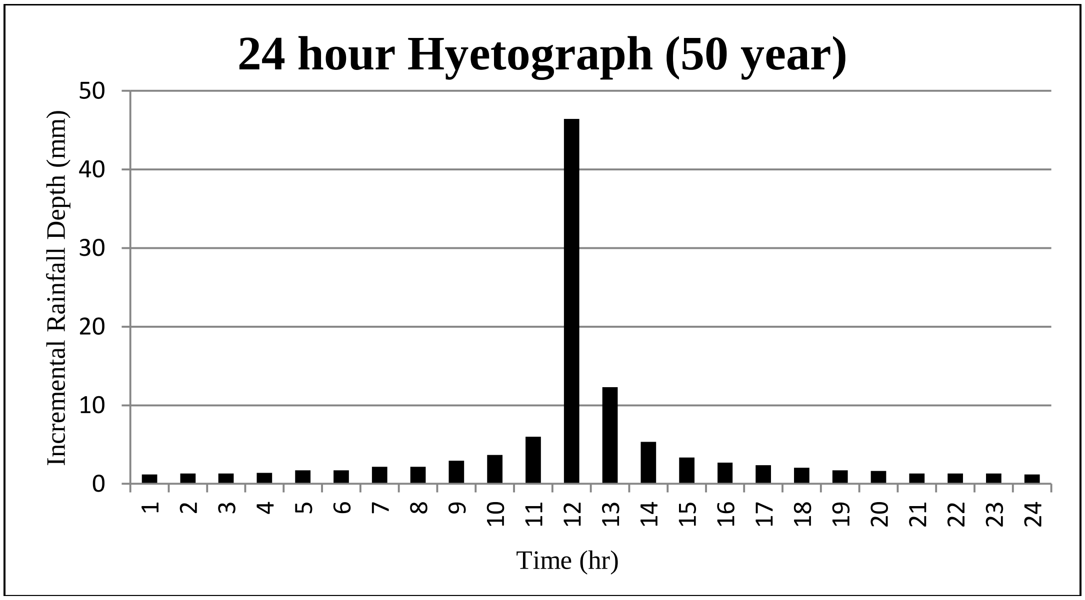

Figure 2. Hyetograph for 1 in 50 year period.

### *3.3 Land Use Scenarios*

Future land use scenarios were investigated and new CNs and initial abstraction values were developed based on land disturbance projections for the WHW developed by the Forest Practices Board (FPB) (2011). Land disturbance was determined according to equivalent clear-cut areas (ECA) expressed as a percentage of the total area of the KRW and developed according to historical land use trends and through discussion with industry professionals. According to the FPB, oil and gas activity around the WHW is expected to increase at a 3.3% rate, which is conservative compared to their high 5.8% rate. A 1.3% rate of increasing dirt road development was added to the oil and gas growth rate since the CN category was the same. Forest harvesting is expected to increase at a 6.3% rate. It is highly probable that these estimations will change as oil and gas activity in the KRW region shifts from the current exploration phase to full extraction development.

In addition, the September 2010, November 2010, and the 50, 100 and 200 year 24-hour storm events were modeled assuming increased land use for oil and gas and forestry within the WHW for the years 2015 and 2020.

The results for peak flow, time to peak, lag time, and total outflow volume in table 6 show a distinct trend in magnitude of outflow volume and peak flow. Peak flows indicate a consistently increasing trend over time with greater oil and gas and forestry activity in the WHW region. As expected, floods have a tremendous impact on increasing total discharge volume. Lag times decreased with time and with high volume floods. With more impervious surfaces predicted in future years, less time is required for the watershed to respond to precipitation events. Similarly, high volumes of water falling on the clayey watershed also reach rivers more rapidly.

**Table 6.** Model peak flow results for based on land use changes in 5 and 10 years from 2010.

| Event Description | | Peak Flow [$m^3/s$] | Time to peak [min] | Lag Time [min] | Total Outflow [1000 $m^3$] |
|---|---|---|---|---|---|
| **September** | 2010 | 1.2 | 3060 | 3360 | 727.5 |
| | 2015 | 1.5 | 3000 | 3240 | 883.2 |
| | 2020 | 1.7 | 3000 | 3300 | 990.8 |
| **November** | 2010 | 1.1 | 3180 | 2460 | 683.9 |
| | 2015 | 1.4 | 3120 | 2400 | 828.2 |
| | 2020 | 1.4 | 3060 | 2340 | 860.5 |
| **50-year** | 2010 | 38.1 | 2460 | 1740 | 21,944 |
| | 2015 | 41.7 | 2460 | 1740 | 24,003 |
| | 2020 | 42.1 | 2460 | 1740 | 24,129.9 |
| **100-year** | 2010 | 49.3 | 2460 | 1740 | 28,363.8 |
| | 2015 | 53.1 | 2460 | 1740 | 30,545.8 |
| | 2020 | 66.3 | 2400 | 1680 | 37,968.4 |
| **200-year** | 2010 | 61.1 | 2400 | 1680 | 35,117.8 |
| | 2015 | 65.2 | 2400 | 1680 | 37,441.7 |
| | 2020 | 66.3 | 2400 | 1680 | 37,968.4 |

# Summary Report on ‘Surface Water Hydrology in the East Confluence sub-basin, Kiskatinaw Watershed’

November 2012

Written by: Jaclyn Bowman, Paige Derry, Cindy Wang , Alan Zhao

## 1.0 Executive Summary

The Kiskatinaw River Watershed (KRW) located in Northern British Columbia has a total area of 3750km$^2$. Although the KRW is the primary water source for the City of Dawson Creek and the Village of Pouce Coupe, very little work has been done to understand the link between the hydrologic characteristics and water withdrawals within the watershed. Recently, aberrations in the relationship between precipitation and river discharge have appeared, leading to an in-depth investigation intended to develop a better water management plan for the KRW. As part of this investigation effort, various parts of the KRW must be mathematically modeled, and eventually compiled for a complete understanding of the watershed.

The East Kiskatinaw Watershed is a subwatershed located within the KRW. The precipitation-runoff processes in the subbasins were modeled using the Hydrologic Engineering Center Hydrologic Modeling System (HEC-HMS). Calibration of the model was completed based on the discharge data from the East Confluence gauging station, with a time span of May 2010 to February 2012.

The calibrated model was used to simulate storms of particular magnitudes of interest, as well as future scenarios. The storms of interest were the 1-in-50, 1-in-100, 1-in-200 years precipitation events. By modeling these storms under the current land use, a baseline is established for modeled future storms.

Future land use scenarios within the KRW were estimated for 2017 and 2022. This was achieved by reasonable deduction based on the existing trends in cumulative land disturbances due to past forest harvesting, oil and gas activities, construction of roads, and other land resources uses. In general, forest cover was reduced and cut blocks and built-up areas increased as a result of regional development.

The results indicate that expected hydrologic trends hold true in the East Kiskatinaw Watershed. With a decrease in forest cover and increase in cut blocks and built-up areas, there is an increase in modeled peak flows. Correspondingly, total outflow volumes for each precipitation event also follow the same increasing trend. Times to peak and lag times observed at the East Confluence gauging station decrease with increases in peak flow.

# 2.0 Final Results

## *2.1 Calculated return periods*

The calibrated model was used to predict flows for four additional storms of interest:

1. Record average of maximum 24-hr precipitation events recorded at NOEL i.e. "All-Years"
2. 1-in-50 year storm
3. 1-in-100 year storm
4. 1-in-200 year storm

The all-years storm is intended as a baseline reference for the other storms as it represents what is expected from the watershed during an average hydrologic year.

The return periods for 24-hr storms shown in table 1 below were calculated based on the Noel Climate Station precipitation data using a Gumbel distribution.

Table 1. Return Periods for the Noel Station 24-hr Maximum Precipitation Distribution

| **Gumbel Reduced Varitate "b"** | **Return Period (years)** | **24-hr Maximum Precipitation (mm)** |
|---|---|---|
| 3.902 | 50 | 113.0 |
| 4.600 | 100 | 127.0 |
| 5.296 | 200 | 141.0 |

The 1-in-50, 1-in-100 and 1-in-200 year storms calculated are estimations of high precipitation events that could be observed in the area around the Noel Climate Station. A comparison of the recorded precipitation events to the calculated return periods is shown below in

Figure. It can be seen that the 2001 storm event exceeded a 1-in-50 year event based on the calculated return periods. Using the return periods as inputs to the meteorological model for HEC-HMS, future storm streamflows were estimated at the East Confluence Gauging Station.

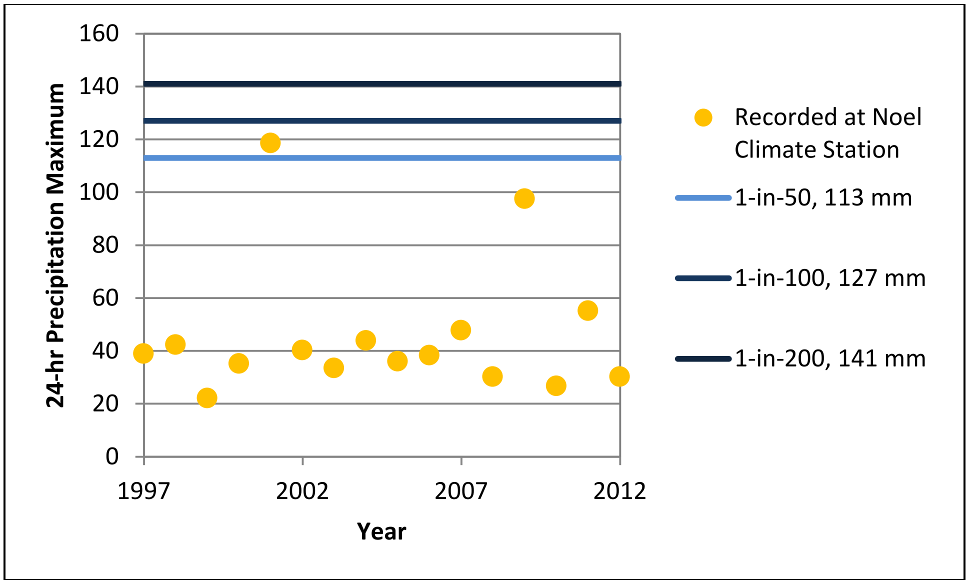

Figure1. Calculated return periods and measured storm events at the Noel Climate Station.

### *2.2 Current Land Use*

Figure below illustrates the resultant hydrographs for each storm event. The start date of June 1st was arbitrarily chosen as HEC-HMS required a specific input. The year is denoted as 2012 as the most recent 2012 climate data was also used in calculating the precipitation magnitudes and return periods.

The expected trend is clearly seen: an increase in the amount of precipitation falling on the watershed leads to an increase in flows. The magnitude of flows for the 1-in-50, 1-in-100, and 1-in-200 year storms display a significant increase over an average year's expected flows.

The storms of various return periods display an increase in magnitude more than ten times that of the all-years storm. Given the watershed's large size, the flows were deemed to not be excessively large.

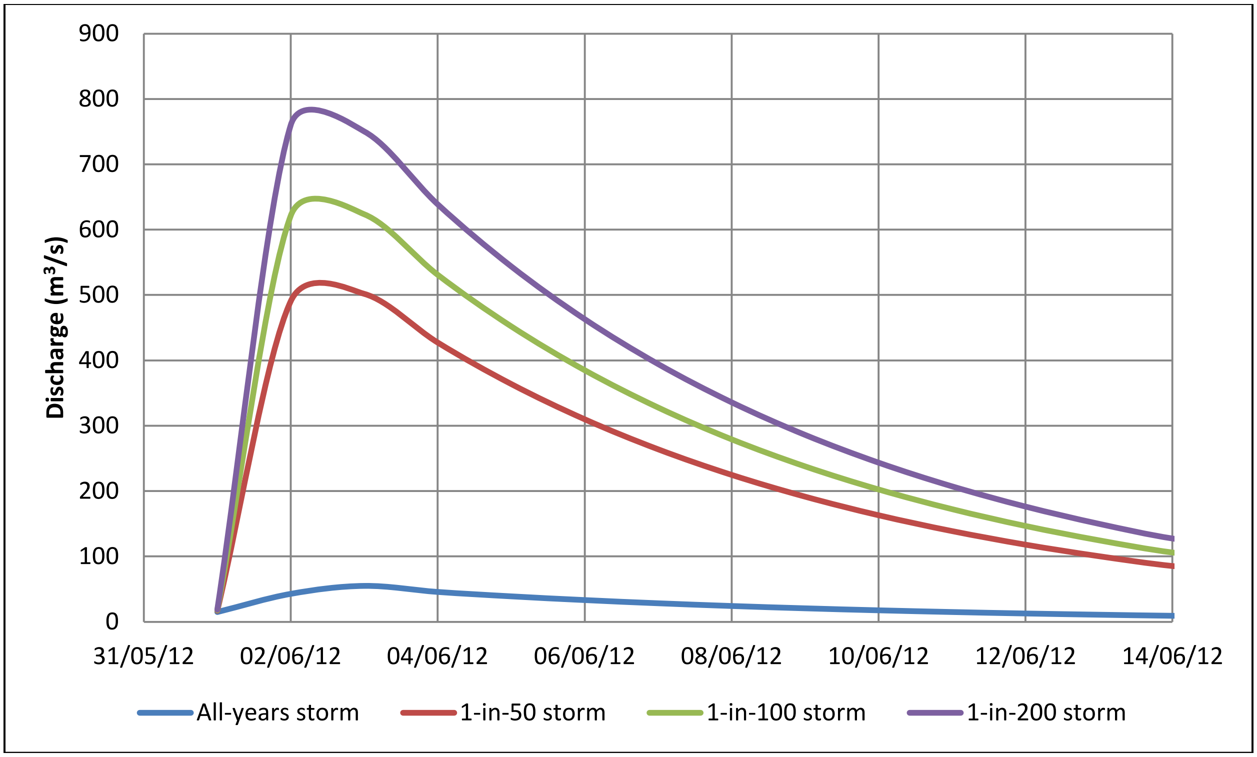

Figure 2. Resultant hydrographs for storms of interest.

### *2.3 Future Land Use Scenarios*

Once the reaction of the East Kiskatinaw Watershed to storms of various magnitudes was modeled under current conditions, future scenarios were run to gauge the response to changing land use within the watershed. Intervals of five years starting from 2012 up until 2022 were used. Many factors play into future development for the region, therefore, it was decided to not attempt to forecast beyond the following ten years.

In a 2011 report, the Forest Practices Board (FPB) performed a cumulative effects assessment on the Kiskatinaw River Watershed. The report summarized human activities in the Kiskatinaw region, and correlated them with potential hydrologic implications. As little development was projected in the East Kiskatinaw region, the project focused on disturbances that would result in forest soil loss. While changes in forest cover would translate to a change in curve numbers, forest soil loss can greatly affect the hydrologic conditions of a given area (Forest Practices Board, 2011). For this reason, projected forest soil loss as a percent of forested area was applied to predict future land cover in the East Kiskatinaw Watershed.

Using the values shown in table 2 below, a line of best fit was produced for each activity. Using the polynomial relationships, an estimate of each activity was calculated for the year 2022.

Table 2. Soil disturbance by source as a percent of forested land area in the Kiskatinaw Watershed (Forest Practices Board, 2011).

| **Disturbance** | **1985 (%)** | **1995 (%)** | **2007 (%)** | **2017 (%)** | **2022* (%)** |
|---|---|---|---|---|---|
| Forestry | 0.10 | 0.20 | 0.40 | 0.60 | 0.70 |
| Natural gas | 0.20 | 0.40 | 0.70 | 1.10 | 1.25 |
| Other | 0.00 | 0.10 | 0.30 | 0.40 | 0.39 |
| Roads | 0.50 | 0.90 | 1.10 | 1.10 | 1.05 |
| Total | 0.80 | 1.60 | 2.50 | 3.20 | 3.39 |

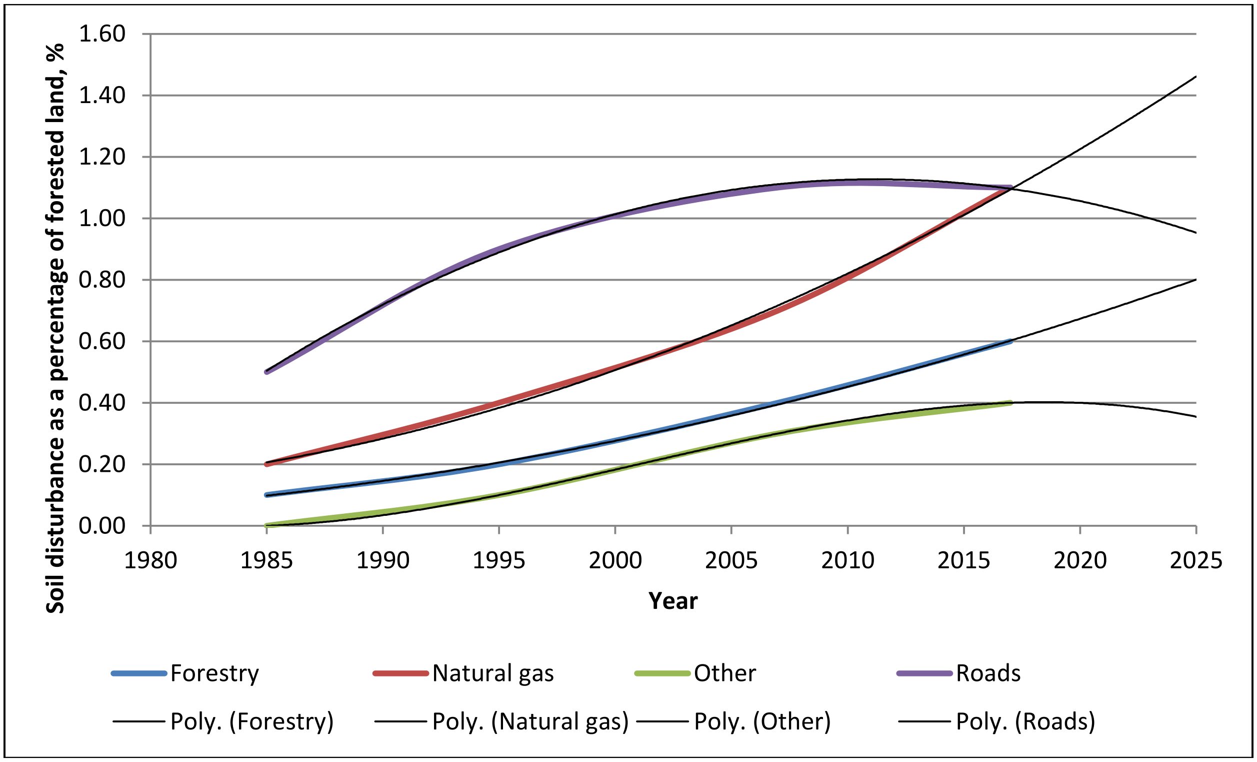

Figure 3. Projected soil disturbance as a percentage of current forested land.

All disturbed forested areas were subtracted from deciduous forests. The disturbed areas were allocated to cut blocks or built-up areas depending on the disturbance activity. Forestry, Others, and Roads were considered cut blocks, and Natural Gas was considered part of the built-up area in the sub-basins.

The soil disturbance percentages for 2017 and 2022 were applied to each subbasin with the exception of Bearhole (W540, W560, W580) where the headwaters for the East Kiskatinaw are located. This is due to the fact that the majority of the headwaters are under federal protection, and little development is permitted in the region (Hirshfield, East Kiskatinaw River, 2012). In these regions, the percentages of disturbed land were re-allocated to be distributed evenly amongst the remaining subbasins. Table 3 below summarizes the applicable curve numbers for 2017 and 2022.

Table 3. Projected curve numbers for 2017 and 2022.

| | **Present** | **2017** | **2022** |
|---|---|---|---|
| **Subbasin ID** | **Curve Number** | **Curve Number** | **Curve Number** |
| W560 | 74.42 | 74.42 | 74.42 |
| W580 | 74.43 | 74.43 | 74.43 |
| W530 | 74.44 | 74.50 | 74.57 |
| W520 | 74.64 | 74.64 | 74.64 |
| W540 | 74.64 | 74.64 | 74.64 |
| W320 | 74.90 | 74.96 | 75.03 |
| W370 | 75.44 | 75.52 | 75.60 |
| W350 | 75.98 | 76.07 | 76.16 |
| W380 | 75.98 | 76.07 | 76.16 |
| W400 | 76.83 | 76.93 | 77.03 |
| W390 | 76.83 | 76.93 | 77.03 |
| W340 | 77.23 | 77.33 | 77.43 |
| W470 | 77.32 | 77.35 | 77.38 |
| W500 | 77.32 | 77.35 | 77.38 |
| W460 | 77.65 | 77.76 | 77.86 |
| W410 | 77.79 | 77.82 | 77.85 |

The CNs remain largely unchanged as the percentages are in reality quite low, especially when applied to a large area such as the East Kiskatinaw Watershed. As a result of the updated CNs, the abstraction and lag time values were also updated.

### *2.4 Model Results*

Table 4 below summarizes the model results for all five storms of interest for years 2011/2012, 2017, and 2022. Lag time and time to peak decreased with increasing magnitudes of precipitation events. This is expected as streams with a fixed cross-sectional area will experience an increase in flow velocity with an increase in flow volume, as per the Manning’s equation which rules the stream network in the HEC-HMS model. It is safe to assume that the maximum cross-sectional flow area is reached during storm events due to the high flows.

Table 4. Summary of modeled future land use scenarios.

| Event | Year | Peak Flow (cms) | Time to Peak (min) | Lag Time (min) | Total Outflow (1000 m³) |
|---|---|---|---|---|---|
| 22-May | 2011 | 40.1 | 2400 | 1710 | 21,353 |
| | 2017 | 40.4 | 2385 | 1470 | 21,543 |
| | 2022 | 40.8 | 2400 | 1470 | 21,738 |
| 09-Jul | 2011 | 94.6 | 2190 | 1485 | 56,011 |
| | 2017 | 95.1 | 2175 | 1470 | 56,262 |
| | 2022 | 95.7 | 2175 | 1470 | 56,679 |
| All-years | 2012 | 54.9 | 2340 | 1635 | 32,550 |
| | 2017 | 55.4 | 2325 | 1620 | 32,824 |
| | 2022 | 55.8 | 2340 | 1635 | 33,107 |
| 1-in-50 | 2012 | 501.8 | 1815 | 1105 | 300,024 |
| | 2017 | 503.7 | 1815 | 1105 | 301,248 |
| | 2022 | 505.8 | 1815 | 1105 | 302,498 |
| 1-in-100 | 2012 | 623.5 | 1770 | 1059 | 373,486 |
| | 2017 | 625.8 | 1770 | 1059 | 374,899 |
| | 2022 | 628.1 | 1770 | 1059 | 376,336 |
| 1-in-200 | 2012 | 760.3 | 1755 | 1043 | 450,130 |
| | 2017 | 763.5 | 1740 | 1028 | 451,718 |
| | 2022 | 766.8 | 1740 | 1028 | 453,331 |

The differences in each output parameter are not significant when compared from one year to another. This is due to the minimal change expected in land cover over the next ten years in the East Kiskatinaw region. However, the increase in CNs due to decreases in forested areas has lead to the expected trend of increasing flows. This conforms to the convention that higher CNs denote higher runoff potential. The lag times and times to peak also decreased as greater rainfall events and greater runoff potential leads to faster movement of water over land and into the stream network.

### *2.5 Limitations of HEC-HMS*

The SCS UH loss method was chosen based on data availability. One of the limitations in using CNs as part of the SCS UH method is the inability of the model to vary precipitation spatially within the model. Infiltration can by varied if the subbasins are made small enough to represent one infiltration area. However, this is unrealistic, and a gridded method would be preferred in this case.

Only one meteorological station was available within the watershed. This may not have successfully captured the great spatial variability in precipitation events within the East Kiskatinaw Watershed. The key characteristics of a hydrograph, such as its shape, the timing, and peak flow, are known to be greatly affected by the precipitation distribution (Singh & Woolhiser, 2002). Again, a gridded precipitation method would give greater resolution into this meteorological input.

The CN is representative of surface and moisture conditions, soil group, and land use. Only one curve number can be applied to each subbasin. Limitations of CNs include: the infiltration rate approaching zero during long storms, values not following with classical unsaturated flow theory, and the intensity of rainfall not being considered (US Army Corps of Engineers, 2000). There is no CN available for permanent snow or ice conditions which could be problematic when using it to model winter and spring months. In these cases, the model can be calibrated to produce results that have good adherence to field data, but the exact value for various inputs may not be representative of actual environmental conditions.

## *2.6 Conclusions and Recommendations*

The calibration results of the model show that it can produce results that are representative of the watershed. When the model was applied to future land use scenarios and large storm events, the results were not unreasonable for the size of the watershed.

In order to improve the model, a longer dataset of both hydrology and meteorological be beneficial. This would allow for calibration using discharge data from multiple years. Also, a longer climate record would improve the accuracy of the storm return period calculation.