SECTION 7.0 – HYDROLOGY
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7.0 HYDROLOGY

7.1 Introduction

This section describes the hydrological characteristics in the aquatic local study area (ALSA) and the aquatic regional study area (ARSA) of the Pike 1 Project (the Project), assesses the potential impacts of the Project on surface water hydrology and describes planned mitigation measures. Surface water hydrology is a key component to the assessment of other aquatic resource indicators, including fisheries and water quality, and is linked to the groundwater resource within the study area.

7.2 Study Area

The boundaries of the ALSA and the ARSA for the Project are shown on Figure 7.2-1; catchment and subcatchment boundaries within the ALSA are shown on Figure 7.2-2. The ALSA was determined based on watercourses and waterbodies that may be directly or indirectly affected by the Project. The ALSA comprises the Kirby Lake/Hay Lake, Monday Creek and Sandy River catchments. The ALSA includes drainage from Sandy River, Monday Creek, a small amount of direct drainage to Winefred Lake, and the drainage from Kirby and Hay lakes.

The ARSA was delineated to determine the potential of the Project to contribute to the cumulative impact on fisheries and aquatic resources, in combination with other existing, approved and planned projects. The ARSA includes Winefred Lake, the Sandy River catchment, the Hay Lake and Kirby Lake catchments, the Sunday Creek catchment and Christina Lake and the southern portion of its catchment. Delineation of the ALSA and ARSA is also discussed in Volume 2, Section 3.2.

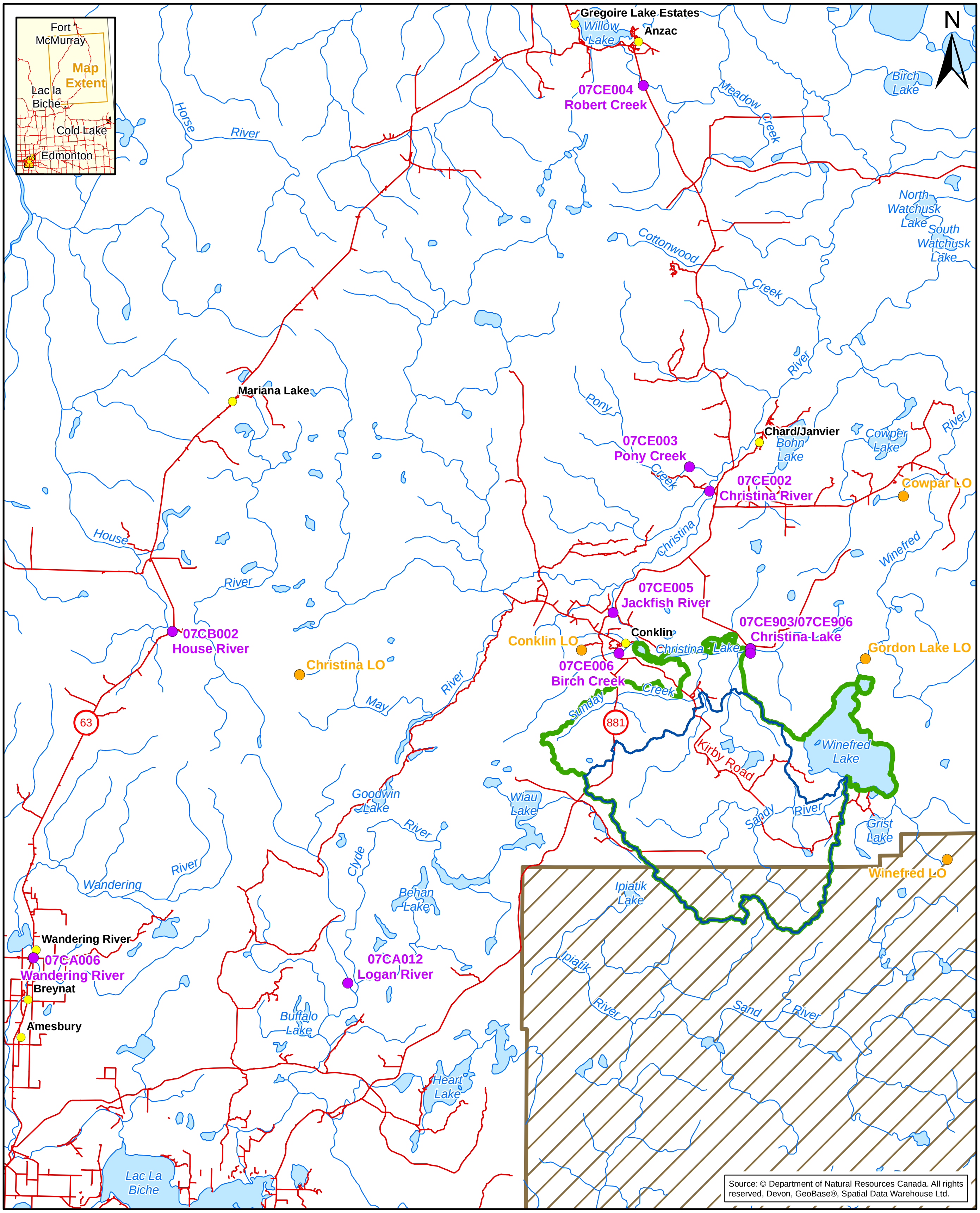
The existing hydrologic characteristics, including all projects present in the ALSA catchments, define the baseline conditions for the Project. A list of the Projects included in the baseline assessment is available in Volume 2, Section 3.0, Table 3.6-3. The Application Case and Planned Development Case assessments are based on potential impacts for the entire duration of the Project.

7.3 Assessment Approach

7.3.1 Identified Issues

Potential hydrological issues associated with the Project include changes in flow patterns and quantities. The timing and magnitude of flood peaks, the timing and magnitude of low flows and mean annual flow all have the potential to be impacted by Project activities.

The steam assisted gravity drainage (SAGD) bitumen extraction process associated with the Project may result in the potential for ground heave to occur. As part of the Devon Jackfish project (formerly the Devon Jackfish 1, 2 and 3 projects), Devon commissioned a study that indicated a maximum localized uplift of 60 mm (Altamira 2011) may occur as a result of the Project. As it is not expected that a heave of this magnitude would have any measurable effect on drainage patterns or identified issues, this effect is not discussed further in this assessment.



Legend

- Aquatics RSA
- Aquatics LSA
- Cold Lake Air Weapons Range
- Open Water
- Watercourse
- Road

Monitoring Station Type

- Meteorological Service of Canada Regional Climate Station
- Water Survey of Canada Station

10 5 0 10 20
Kilometres
1:800000

Pike 1 Project

Aquatics
Local and Regional Study Areas
and Regional Monitoring Stations

May 31, 2012 | Fig07.02-01 Reg Streamflow and Climate Mntr.mxd

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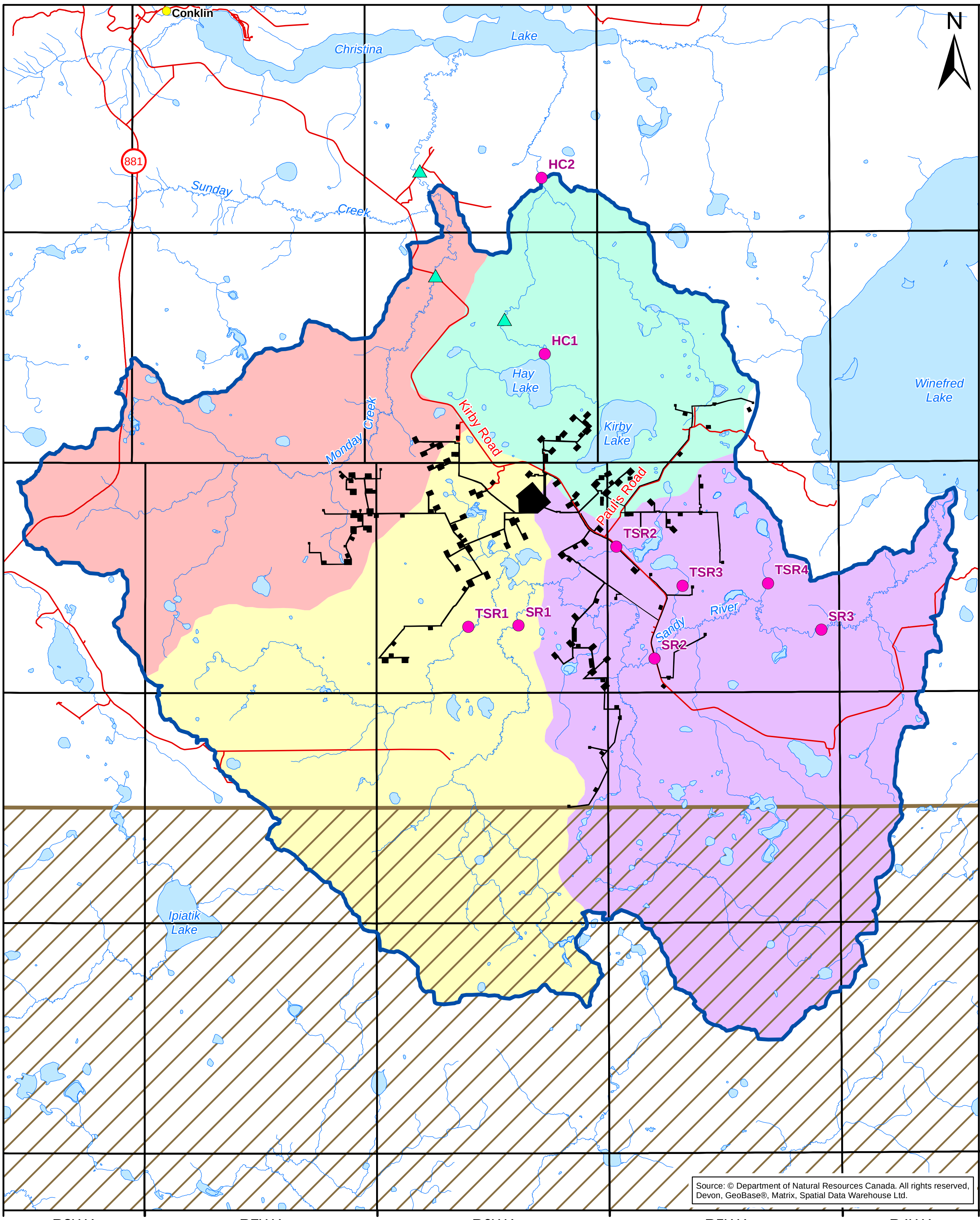
Figure 7.2-1

Map Path: S:\Gis\Projects\CE\Devon\04050_Pike\ArcGIS Projects\Volume 02 - Section 07 Surface Water Quantity\Fig07.02-01 Reg Streamflow and Climate Mntr.mxd Analyst - Trevor Robertson



Legend

- Aquatics LSA
- Pike Project Footprint
- Cold Lake Air Weapons Range
- Open Water
- Watercourse
- Road

Catchment

- Kirby Lake and Hay Lake
- Monday Creek

Subcatchment

- Sandy River Downstream
- Sandy River Upstream

- Manual Discharge Measurement Location
- Devon Wetland Monitoring Location

2 1 0 2 4
Kilometres
1:225000

Pike 1 Project

Subcatchments and Local Monitoring Stations

May 22, 2012
Fig07.02-02 ALSA and Catchments.mxd

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Figure 7.2-2

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Analyst - Trevor Robertson

7.3.2 Effects Characterization

The Project has the potential to affect flow patterns and quantities. To the extent possible, these changes were quantitatively estimated as changes in flows or as a percentage change relative to baseline and/or historical data. Project-induced changes to the baseline hydrologic regime were evaluated in terms of changes in flow patterns, mean annual flow, flood peaks (timing and magnitude) and low flows (timing and magnitude).Biological impacts potentially resulting from changes in hydrology are discussed in Volume 2, Section 9.0 of this environmental impact assessment (EIA).

7.4 Methods

7.4.1 Data Sources and Fieldwork

Long-term historical climate and streamflow data are unavailable within the ALSA. Historical regional hydrometeorological data were obtained to provide the basis for characterizing the climate and hydrological characteristics in the ALSA. Historical data were supplemented with onsite hydrometric monitoring (Matrix 2007, 2008 and 2009).

7.4.1.1 Climate

Daily precipitation and temperature records and available 30-year climate normal data were obtained from the Meteorological Service of Canada (MSC 2012) for the stations listed in Table 7.4-1. The locations of these stations in relation to the Project are shown on Figure 7.2-1.

Table 7.4-1: Regional Climate Stations

Station Number	Station Name	Period of Record	Seasonal/Year Round Data	Elevation (m)
3061580	Christina Lookout	1966 to 2001	Seasonal	823
3061800	Conklin Lookout	1954 to present	Seasonal	671
3061930	Cowpar Lookout	1957 to present	Seasonal	563
3062889	Gordon Lake Lookout	1964 to present	Seasonal	488
3067590	Winefred Lookout	1957 to 2008	Seasonal	744
3063685 & 3033686	Lac La Biche[1]	1958 to present	Year-round	567
3062693 & 3062700	Fort McMurray[1]	1944 to present	Year-round	369
3081680	Cold Lake[1]	1953 to present	Year-round	541

Notes:
[1] These stations are not shown on Figure 7.2-1 as they are located beyond the map extent.

7.4.1.2 Streamflow

Regional lake level and streamflow data were obtained from the Water Survey of Canada (WSC 2012) and Alberta Environment and Water for the stations listed in Table 7.4-2.

Table 7.4-2: Regional WSC Streamflow and Lake Level Monitoring Stations

Name	Station Number	Period of Record	Drainage Area (km^2)	Comments
Christina River near Chard	07CE002	1982 to present	4 860	Seasonal
Pony Creek near Chard	07CE003	1982 to present	278	Seasonal
Robert Creek near Anzac	07CE004	1982 to 1995	54.1	Seasonal
Jackfish River below Christina Lake	07CE005	1982 to 1995	1 270	Seasonal station, considerable lake influence
Birch Creek near Conklin	07CE006	1984 to 1995	232	Seasonal
Wandering River near Wandering River	07CA006	1971 to present	1 110	Continuous station
Logan River near the Mouth	07CA012	1984 to present	425	Seasonal
House River at Highway No. 63	07CB002	1982 to present	764	Seasonal
Christina Lake near Conklin	07CE903	1985 to 2001	1 270	Lake level
Christina Lake near Winefred Lake	07CE906	2001 to present	1 270	Lake level

As part of the adjacent Devon Jackfish District's *Environmental Protection and Enhancement Act* approval requirements, Matrix Solutions Inc. (Matrix) on behalf of Devon, has conducted an ongoing wetland monitoring program on Monday Creek, Sunday Creek and the Hay Lake outlet. The locations of the monitoring sites are shown on Figure 7.2-2.

Project-specific streamflow measurements were recorded seasonally at sites throughout the ALSA to provide a check for values calculated from the WSC data. The locations and dates of these measurements are provided in Table 7.4-3. Discharge measurement locations are also shown on Figure 7.2-2.

Table 7.4-3: Manual Discharge Measurement Locations

Site	UTM Easting (m)	UTM Northing (m)	May 2010	Aug 2010	Oct 2010	Mar 2011	May 2011	Aug 2011
HC1	511539	6150677	X	X	X	X	–	–
HC2	511402	6158100	X	X	X	X	–	–
SR1	510434	6139224	–	–	X	X	X	X
SR2	516163	6137840	X	X	X	X	–	–
SR3	523200	6139038	–	–	–	–	–	–
TSR1	508317	6139171	–	–	X	X	X	X
TSR2	514557	6142549	X	X	X	X	–	–
TSR3	517343	6140905	X	X	X	X	–	–
TSR4	520941	6141011	X	X	X	X	–	–

Additional data sources included:

- light detection and ranging (LiDAR) digital elevation data;
- National Topographic System (NTS) 1:250,000 and 1:50,000 scale maps;

- air photo mosaics for the ALSA;
- site assessments conducted in the ALSA in 2009 and 2010 for the Devon Jackfish 3 project; and
- data gathered at three temporary water level monitoring stations installed in the ARSA in May 2002 and operated from May 2002 to October 2002.

7.4.2 Computational Models

The Hydrologic Modeling System was used to simulate precipitation-runoff processes to establish Baseline and Application Case peak flows. The program is designed for application to a wide range of geographic areas to address a range of assessment needs. The Soil Conservation Service method was used for its ability to quantitatively assess potential impacts to in runoff do to land cover and soil type changes (NEH 1972).

7.5 Baseline Case

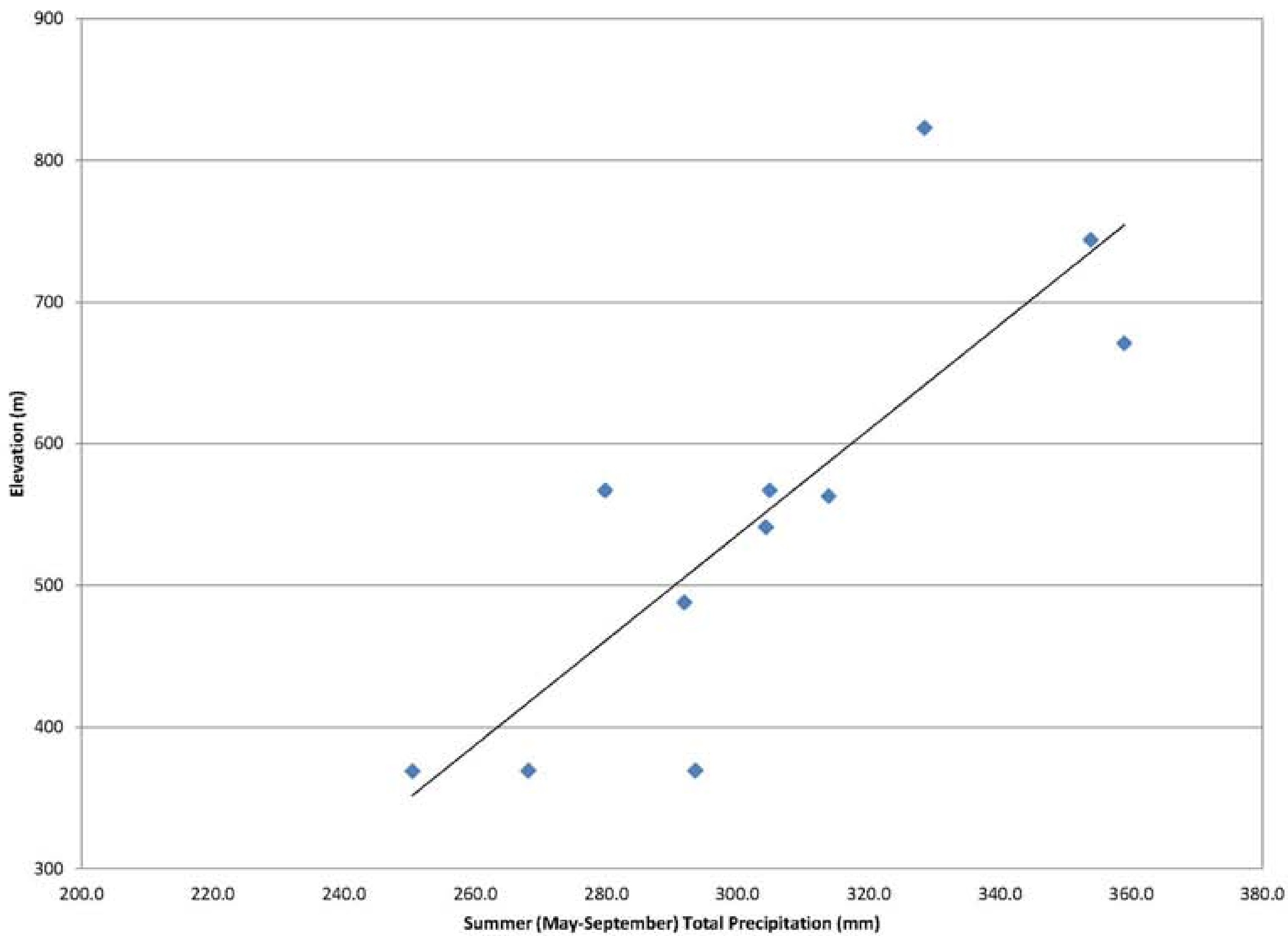
7.5.1 Climate

Baseline climatic conditions were defined from regional climate monitoring stations. There are five seasonal regional climate stations located within a 40 km radius of the ALSA based at fire lookout (LO) towers (Christina LO, Conklin LO, Cowpar LO, Gordon Lake LO and Winefred Lake LO).

The closest year-round climate monitoring stations are located at Lac La Biche (110 km southwest of the site), Cold Lake (125 km southeast of the site) and Fort McMurray (135 km north of the site). The Cold Lake station has the most complete climate record, is the second closest year-round station in elevation and distance and was, therefore, used as the basis for annual data in the ALSA. Fort McMurray and Cold Lake historical monthly evaporation and evapotranspiration rates (AEP 1993) and rainfall intensity-duration-frequency (IDF) data from MSC were used in the analysis. Fort McMurray and Cold Lake IDF data are dated 1995 and 2006, respectively.

7.5.1.1 Precipitation

Daily precipitation and temperature records and available 30-year climate normal data were obtained from the eight (five seasonal and three year-round) climate stations. Total seasonal (May to August) precipitation data from the regional climate stations were compared on the basis of elevation and found to correlate well. An elevation-based relationship was developed between total seasonal precipitation recorded at the regional stations, as shown on Figure 7.5-1. This relationship provided the basis for estimating the total summer precipitation at the Project site using a mean elevation of 663 m for the ALSA.



Map Path: S:\Gis\Projects\CE\Devon\04050_Pike\ArcGIS Projects\Volume 02 - Section 07 Surface Water Quantity\Fig07.05-01 Reg Seasonal Precip.mxd Analyst - Matt Millard

Source: Devon

Pike 1 Project

Regional Seasonal Precipitation

May 11, 2012 | Fig07.05-01 Reg Seasonal Precip.mxd

devon

PROVIDED BY: AMEC

FINAL MAPPING BY: AMEC

Figure 7.5-1

Annual precipitation was estimated using the proportion of seasonal to annual precipitation at Cold Lake; where 70% of annual total precipitation has been found to occur during the period from May to September. The monthly distribution of precipitation at the Cold Lake station was used to estimate the monthly proportions of precipitation at the Project site for the calendar year.

Based on year-round records from the Cold Lake station, approximately 71% of the annual total precipitation at the Project site is expected to occur as rain and the remaining 29% as snow. Annually, there is a 66% probability that snowfall will occur at least once during any given month from May to September. The results of the precipitation analysis are summarized in Table 7.5-1 and shown on Figure 7.5-2.

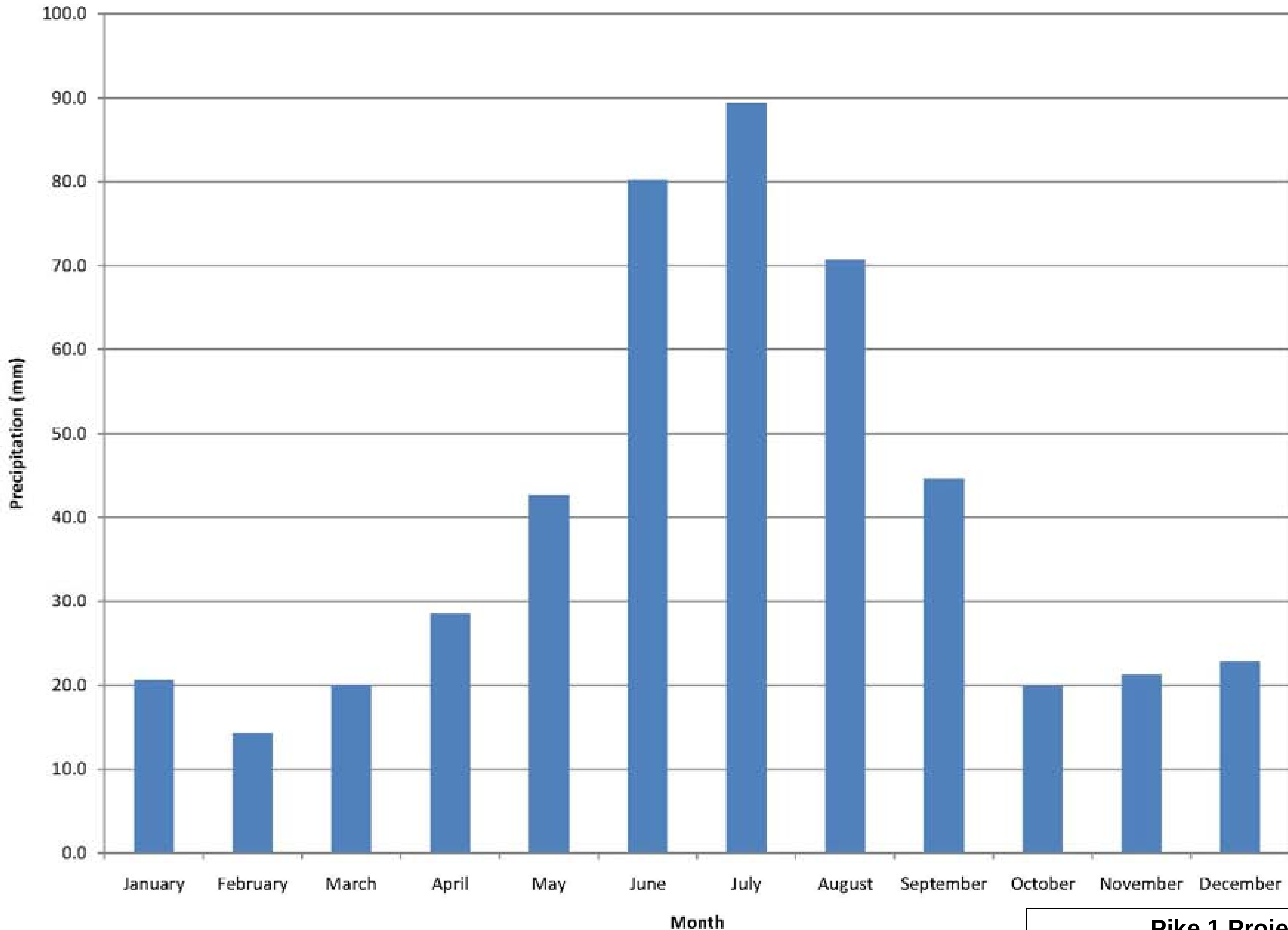
Table 7.5-1: Estimated Average Monthly Total Precipitation for the ALSA

Month	Total Precipitation (mm)	Rainfall (mm)	Snowfall (mm H_2O)
January	20.5	0.6	19.9
February	14.3	0.3	14.0
March	19.9	2.2	17.7
April	28.5	15.0	13.5
May	42.7	39.3	3.4
June	80.1	80.1	0.0
July	88.3	88.3	0.0
August	71.2	71.1	0.1
September	45.0	43.5	1.5
October	20.1	12.0	8.1
November	21.3	1.8	19.5
December	23.1	0.9	22.2
Annual Total	**475.0**	**355.0**	**120.0**

A frequency analysis was conducted on estimated annual total precipitation values for the ALSA. The results of the frequency analyses are provided in Table 7.5-2.

Table 7.5-2: Annual Precipitation Frequency Analysis for the ALSA

Return Period (years)	Annual Total Precipitation (mm)
2	467
5	547
10	590
20	626
50	669
100	697



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Source: Devon

Pike 1 Project

Mean Monthly Precipitation

April 12, 2012 | Fig07.05-02 Mean Monthly Precip.mxd

devon

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FINAL MAPPING BY: AMEC

Figure 7.5-2

7.5.1.2 Temperature

Long-term temperature data are unavailable for the ALSA. Data from the Cold Lake climate monitoring station show monthly mean temperatures vary from approximately -17ºC in January to +17ºC in July. Recorded extreme mean daily temperatures have varied from -48.3ºC in January to +36.3ºC in June. Based on a comparison of Cold Lake (elevation 541 m) monthly mean temperature data with summer (April to October) data recorded at the Winefred Lake LO climate station (elevation 744 m) and Gordon Lake LO climate station (elevation 488 m), average daily maximums at Cold Lake are slightly higher than those at Winefred and Gordon Lake LOs, average daily means are very similar at the two sites, and average daily minimums are very similar except in early spring and late fall when Winefred Lake LO and Gordon Lake LO have higher average mean and minimum temperatures, as shown on Figure 7.5-3.

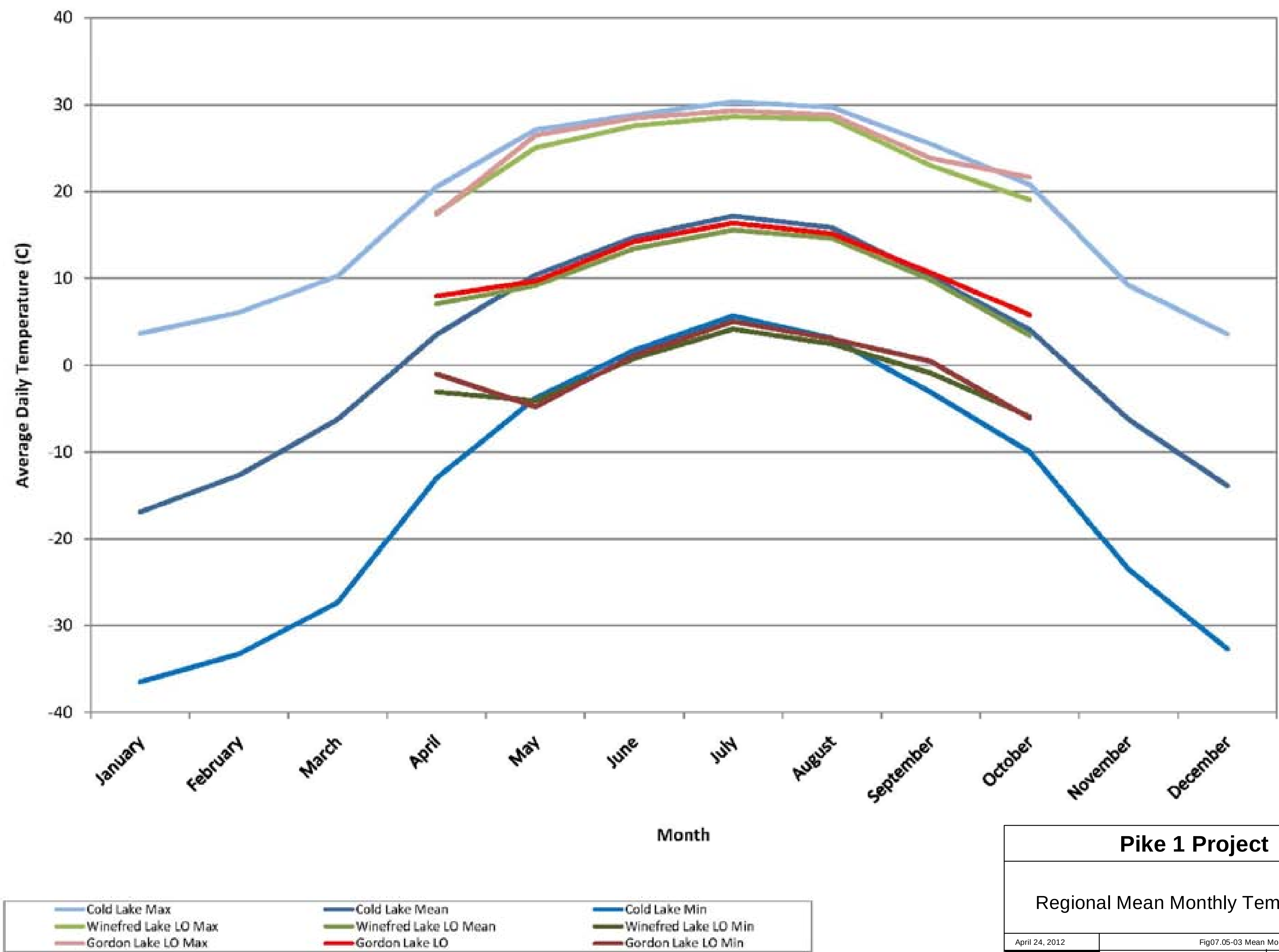
7.5.1.3 Evaporation and Evapotranspiration

Alberta Environmental Protection (AEP 1987, 1993) data for Cold Lake were used to evaluate mean monthly and annual evaporation and evapotranspiration rates at the Pike site. The Cold Lake station was used to estimate the evaporation and evapotranspiration values shown in Table 7.5-3 and on Figure 7.5-4.

Table 7.5-3: Evaporation and Evapotranspiration for the ALSA

Month	Evaporation (mm)		Evapotranspiration (mm)	
	Potential	Lake	Potential	Areal
January	-2	-2	-2	-2
February	1	1	1	1
March	26	21	23	15
April	102	67	102	23
May	154	107	152	49
June	167	129	164	82
July	167	135	162	95
August	136	106	132	68
September	76	48	72	18
October	26	20	25	12
November	0	0	1	0
December	-3	-3	-3	-3
Annual Total	**850**	**629**	**829**	**358**

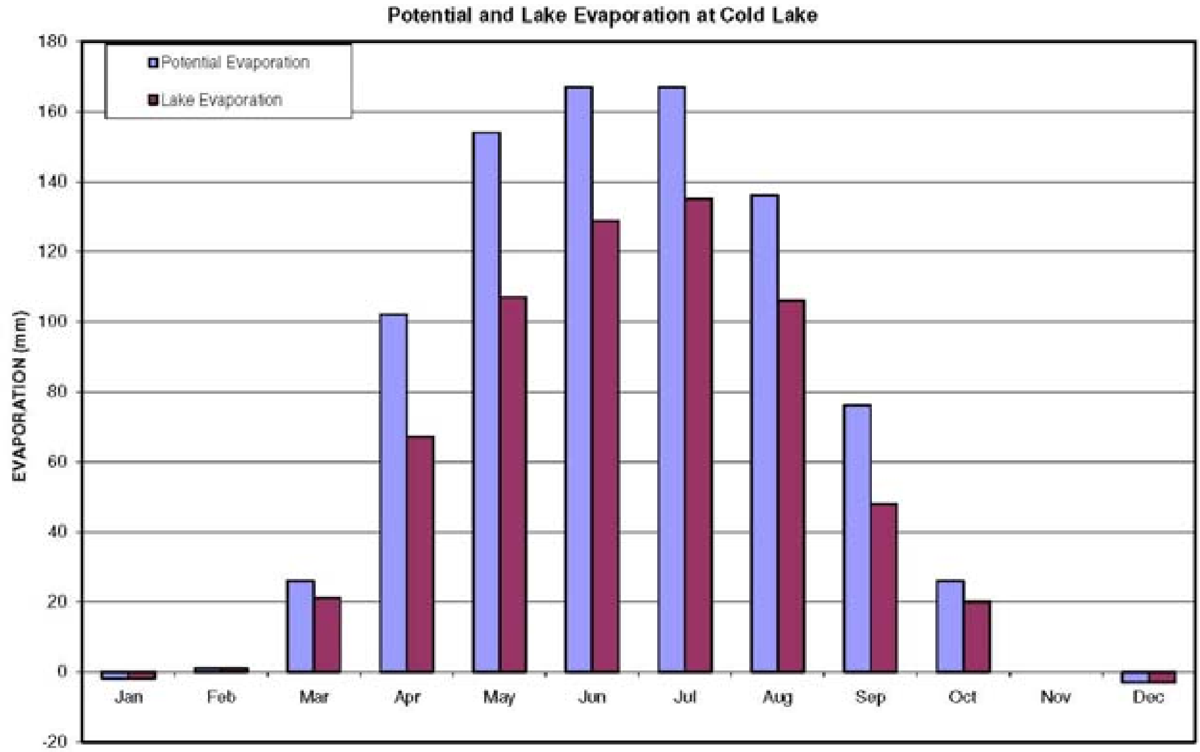
Potential evaporation—the evaporation that would occur from a very small area with an unlimited supply of water—averages approximately 850 mm/y. Actual evaporation from lake surfaces is approximately 26% lower (629 mm) due to the cooling effect that the water surface has on air passing over it, and the cooling that occurs due to evaporation from the water surface. Approximately 83% of the annual total evaporation loss occurs from May to September with a peak monthly lake evaporation of 135 mm in July.

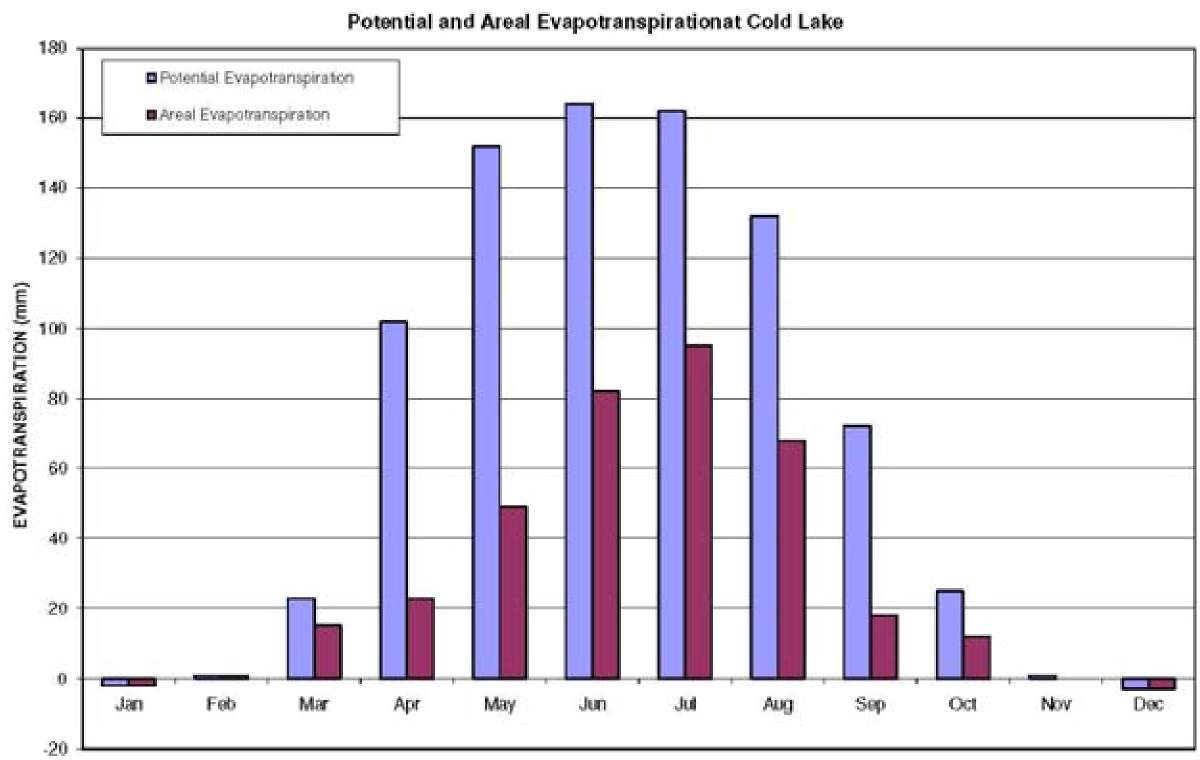


Source: AMEC, Devon

Map Path: S:\Gis\Projects\CE\Devon\04050_Pike\ArcGIS Projects\Volume 02 - Section 07 Surface Water Quantity\Fig07.05-03 Mean Monthly Temp.mxd Analyst - Matt Millard

Pike 1 Project		
Regional Mean Monthly Temperature		
April 24, 2012	Fig07.05-03 Mean Monthly Temp.mxd	
devon	PROVIDED BY: AMEC FINAL MAPPING BY: AMEC	**Figure 7.5-3**





Map Path: S:\Gis\Projects\CE\Devon\04050_Pike\ArcGIS Projects\Volume 02 - Section 07 Surface Water Quantity\Fig07.05-04 Evaporation and Evapotranspiration.mxd Analyst - Trevor Robertson

Source: Devon

Pike 1 Project

Cold Lake
Evaporation and Evapotranspiration

May 18, 2012 | Fig07.05-04 Evaporation and Evapotranspiration.mxd

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Figure 7.5-4

Potential evapotranspiration is almost as high as potential evaporation, averaging 829 mm/y. Areal evapotranspiration, which is limited by water availability and the cooling effects of evapotranspiration on the surrounding air, averages 358 mm/y. Approximately 87% of the annual total evapotranspiration occurs from May to August with a peak monthly areal evapotranspiration of approximately 95 mm in July.

7.5.2 Streamflow

7.5.2.1 Surface Water Drainage Patterns

The Project is located within the Monday Creek, Sandy River and Kirby and Hay Lake drainages. Christina Lake is the receiving waterbody for Monday Creek and the Kirby and Hay Lake drainage. Christina Lake drains into the Jackfish River from the northwest corner of the lake, and the Jackfish River flows into the Christina River, a tributary of the Clearwater River. Winefred Lake is the receiving waterbody for the Sandy River. The Winefred Lake outlet located at the north end of the lake drains into the Winefred River, a tributary of the Christina River.

The drainage areas of the catchments in the ARSA are presented in Table 7.5-4 and the catchment boundaries are shown on Figure 7.2-2.

Table 7.5-4: Catchment Areas for Drainages in the ARSA

Catchment Name/Number	Total Drainage Area (km^2)
Sandy River Upstream	250
Sandy River Downstream	290
Sandy River at Winefred Lake	540
Monday Creek	167
Kirby and Hay Lake Drainage	124
Christina Lake at the Outlet	1 270
Winefred Lake at the Outlet	1 181

LiDAR digital elevation modeling shows that ground elevations within the ALSA vary from a high point of 740 m at the southwest corner to approximately 572 m at the north side. The average ground surface gradient within the ALSA is less than 1%. There is sufficient topographical relief in the ALSA and ARSA to define the catchment boundaries. The ALSA and ARSA contain extensive muskeg areas that can cross sub-catchment boundaries.

7.5.2.2 Regional Hydrological Information

Baseline hydrologic conditions within the ARSA were defined based on recorded discharge data from the regional streamflow monitoring stations operated by the WSC. The streamflow monitoring stations are located within a radius of approximately 125 km of the Project and are shown on Figure 7.2-2.

7.5.2.3 Mean Monthly and Annual Discharges and Runoff Rates

Mean monthly discharge data were obtained for the regional WSC streamflow monitoring stations. The Wandering River has the only regional streamflow monitoring station with available year round discharge data. Seasonal (March to October) runoffs were reviewed for the other regional stations.

Minimum, average and maximum mean monthly discharges were determined for each station, as shown on Figure 7.5-5. Annually, flows increase in May due to snowmelt and typically remain near the same levels through July. After July, flows recede over the year to the minimum flow period, expected during the late winter months of February and March.

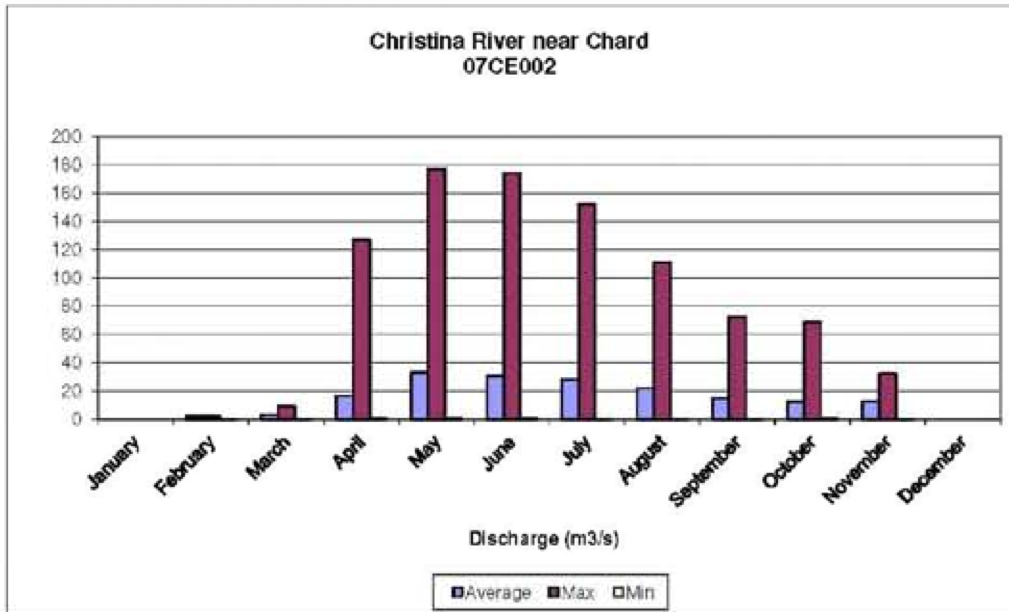
The periods of record for the regional stations are not concurrent. All stations have a common period of record from 1984 to 1995. Three of the stations (Robert Creek, Birch Creek and Jackfish River) were discontinued after 1995 so the extended data record from the remaining stations was examined to determine whether there had been any shift in average mean seasonal runoff since 1995. A test for homogeneity shows that the period of 1996 to 2009 was significantly wetter than the period of 1984 to 1995.

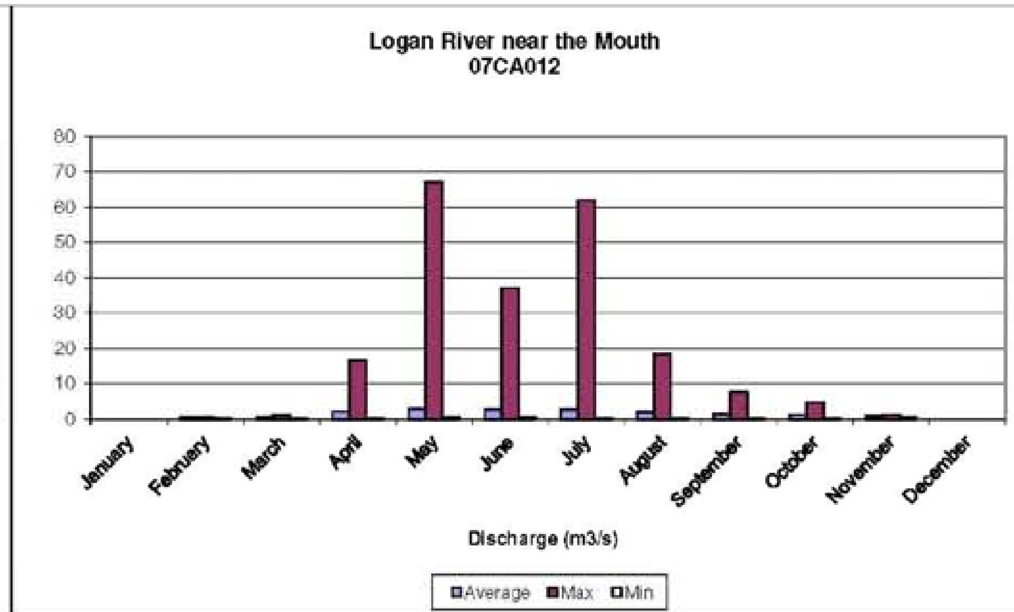
The period of record at the Wandering River station is the longest in the region, from 1971 to present. The mean seasonal runoff at the Wandering River site is 82 mm, or 22 mm greater than the average runoff over the 1984 to 1995 period. Seasonal runoffs at stations whose period of record only cover 1984 to 1995 were adjusted to derive the estimated mean seasonal runoff, total discharge and discharge summarized in Table 7.5-5. Mean seasonal total discharge for all stations is shown on Figure 7.5-6. Mean seasonal runoff varies from 71 to 119 mm.

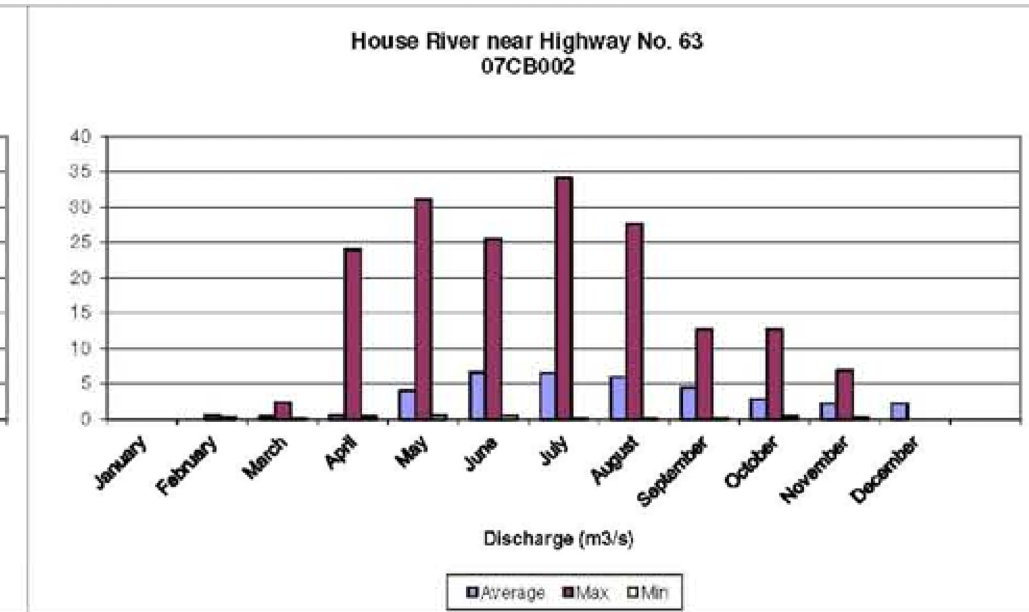
Table 7.5-5: Mean WSC Seasonal Discharges and Runoff for Regional Streamflow Monitoring Stations

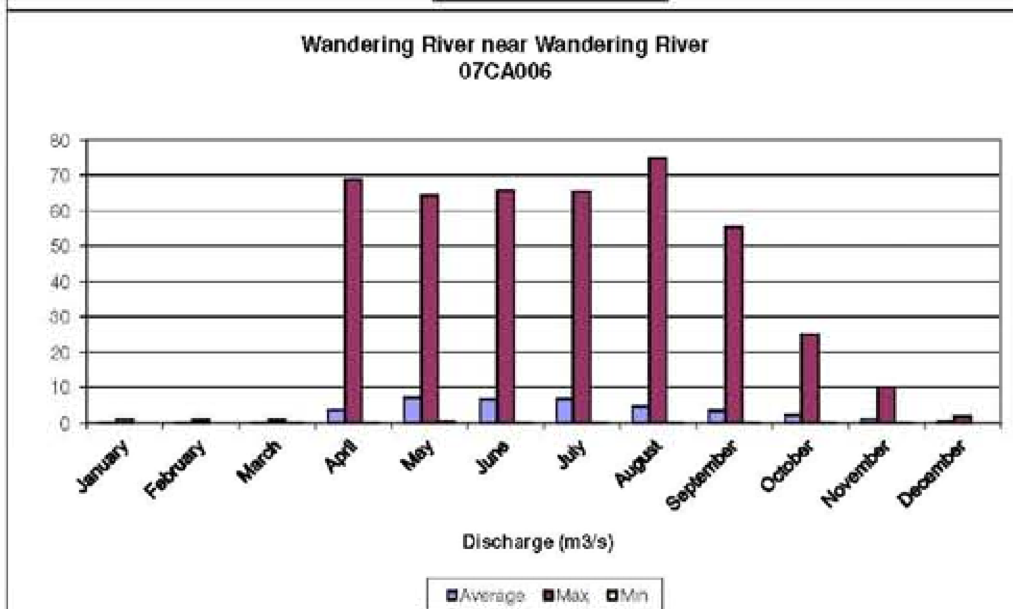
Station Name	Drainage Area (km^2)	Mean Seasonal Runoff (mm)			Mean Seasonal Discharge (m^3/s) [1]	Mean Seasonal Total Discharge (dam^3) [1]
		1984 to 1995	1984 to 2010	1971 to 2010[1]		
Robert Creek near Anzac	54.1	97	-	119	0.3	6 500
Birch Creek near Conklin	232	61	-	83	0.9	19 700
Pony Creek near Chard	279	69	84	85	1.1	23 825
Logan River near the Mouth	425	85	100	100	2.0	42 430
House River at Highway No. 63	781	98	113	111	4.1	86 942
Wandering River near Wandering River	1 120	59	72	82	4.3	91 720
Jackfish River below Christina Lake	1 290	49	-	71	4.3	94 200
Christina River near Chard	4 860	71	88	87	20.0	420 664

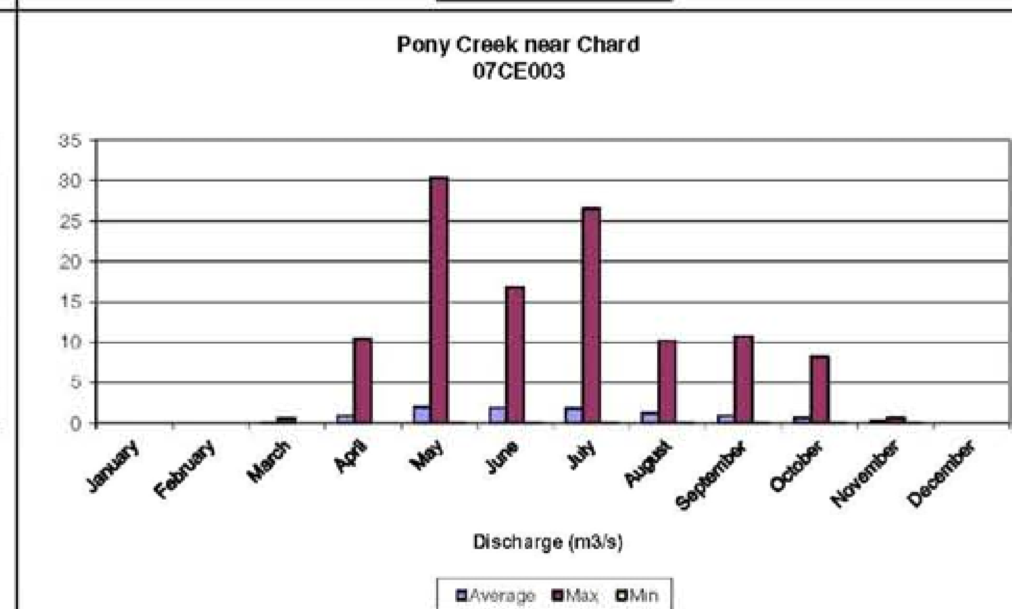
Notes:
[1] Mean seasonal runoff and discharge for Robert Creek, Birch Creek and Jackfish River adjusted for wetter period in long-term trend than for the period from 1984 to 1995.
[2] 1 $dam^3 = 1\ 000\ m^3$

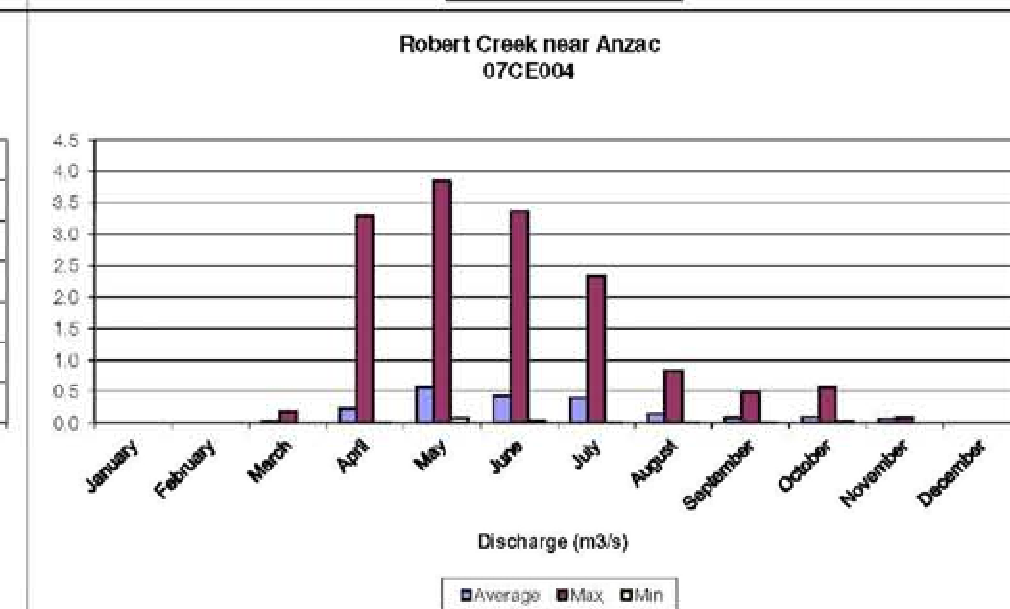


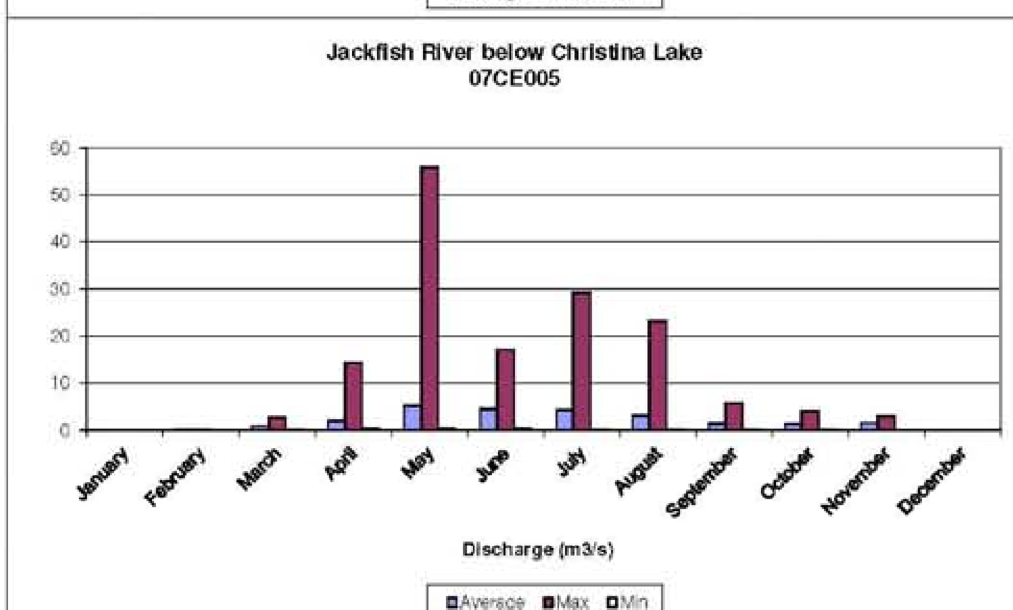


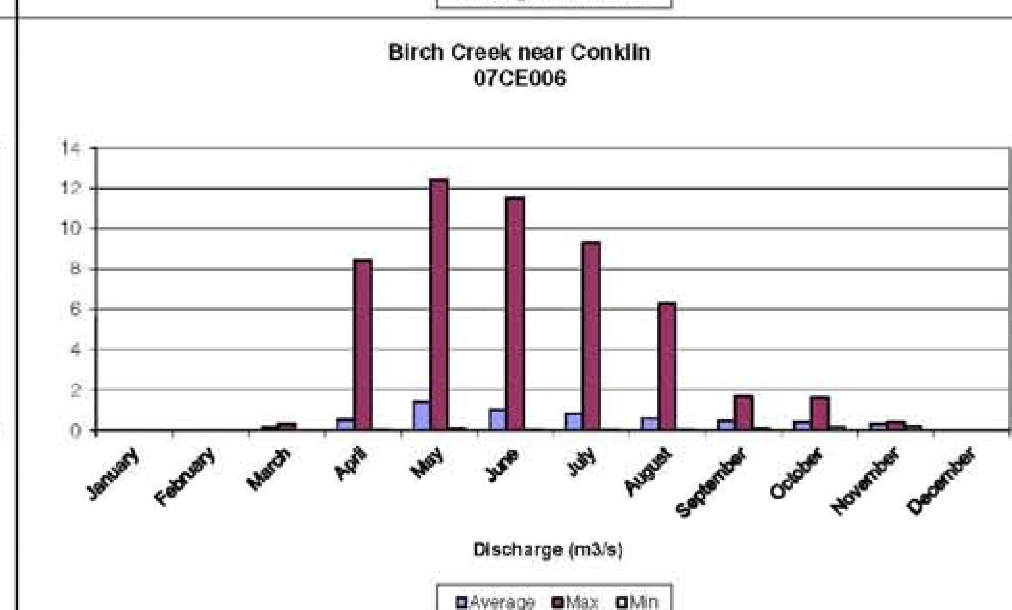












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Pike Project

Regional Historical Mean Monthly Discharges

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Figure 7.5-5

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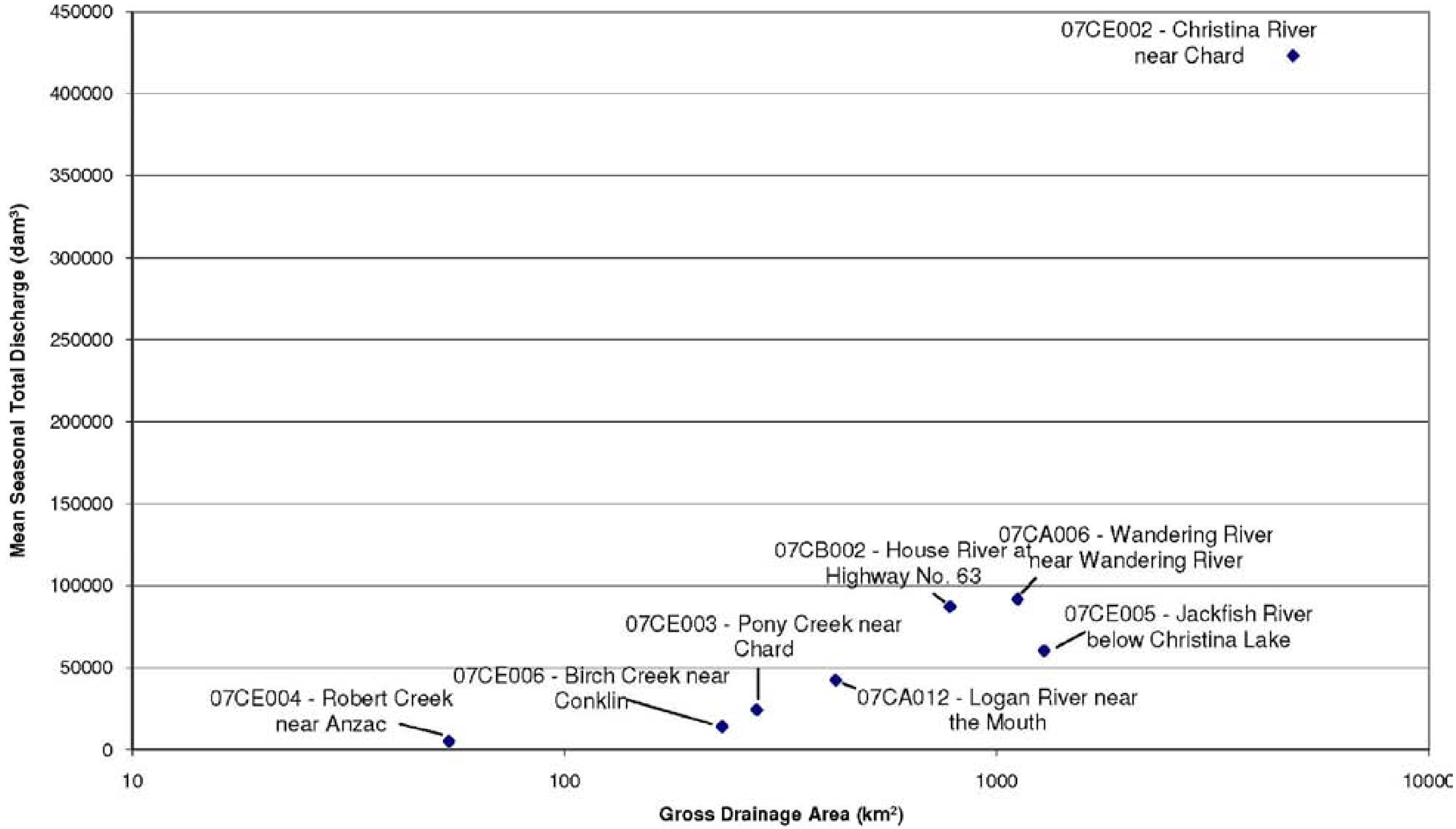

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Source: Devon

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Regional Mean Seasonal Total Dishcarge

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Figure 7.5-6

The variation in mean seasonal total discharge shown on Figure 7.5-6 is strongly correlated to drainage area. Mean seasonal runoff does not follow a similar trend due to regional factors such as local differences in precipitation, the proportion of lakes and storage in the catchment and the groundwater recharge received from regional aquifer systems.

Birch Creek is the closest regional streamflow station to the Project and the ALSA and, as shown in Table 7.5-6, has similar hydrological characteristics to catchments in the ALSA. The Birch Creek station was used as the primary source of information for characterizing the hydrologic characteristics of the ALSA, supplemented with information from the other regional stations.

Table 7.5-6: Comparison of Birch Creek and Project Catchments

Parameter	Wandering River near Wandering River (07CA006)	Birch Creek (07CE006)	Sandy River Upstream	Sandy River Downstream	Monday Creek	Kirby and Hay Lake Drainage
Drainage Area (km^2)	1 20	232	250	290	169	124
Maximum Elevation (m)	762	730	740	729	733	689
Minimum Elevation (m)	564	554	625	593	572	572
Mainstem Channel Length (km)	116.4	37.5	22.8	47.2	38.2	21.9
Mainstem Channel Gradient (%)	0.17%	0.48%	0.50%	0.29	0.42%	0.53%

The two main limitations of the Birch Creek data are the short period of record (1984 to 1995), and the lack of winter flow data due to seasonal gauge operation. The Wandering River station has seasonal data from 1971 to the present and has continuous data from 1972 to 1996. The Wandering River station was used to estimate Birch Creek winter discharges.

The Wandering River station data indicate that 95% of total mean annual discharge occurs during the March to October period and 5% of the total mean annual discharge occurs during the months of November to February. The proportion of the Wandering River total mean annual discharge occurring in November, December, January and February is 3.0%, 1.2%, 0.6% and 0.4%, respectively. The same monthly distribution was used to estimate Birch Creek winter discharge. The mean annual runoff for Birch Creek over the period of 1971 to 2010 was estimated to be 88 mm, 5 mm more than the average seasonal (March to October) runoff of 83 mm.

7.5.2.4 Peak Discharge and Runoff Rates

In the regional catchments, annual peak discharges typically occur in May due to snowmelt, with high discharges sustained through July due to basin storage and early summer rain. Peak flows can also occur in late summer (August and September) due to rainfall events. Annual peak discharges recorded at the regional streamflow monitoring stations are presented on Figure 7.5-7. Each of these stations recorded a high flood event in 1985. Other flood events occurred in at least half of the basins in 1996 and 1997.

Source: Devon

Pike Project

Regional Historical Annual Peak Discharge

April 12, 2012

Fig07.05-07 Reg Hist Peak Discharge.mxd

devon

PROVIDED BY: AMEC

FINAL MAPPING BY: AMEC

Figure 7.5-7

Analyst - Matt Millard

Map Path: S:\Gis\Projects\CE\Devon\04050_Pike\ArcGIS Projects\Volume 02 - Section 07 Surface Water Quantity\Fig07.05-07 Reg Hist Peak Discharge.mxd

Flood frequency analyses were conducted on annual maximum daily snowmelt and rainfall flows, and the results were correlated on the basis of drainage area as shown on Figure 7.5-8.

Equations of the form:

$$Q_{RP} = C\,A^{x}$$

were developed for both snowmelt and rainfall events, where Q_{RP} is the maximum daily flow for a given return period flood event, A is the drainage area of the catchment, and C and x are coefficients and exponents, respectively, resulting from the correlation. The coefficients for snowmelt and rainfall flood events are presented in Table 7.5-7.

Table 7.5-7: Regional Flood Discharge Relationships

Flood Return Period (years)	Regression Coefficient (C)	Regression Exponent (X)	Correlation Coefficient (R^2)
Snowmelt Flood Events			
2	0.022	0.839	0.85
10	0.150	0.765	0.97
50	0.259	0.763	0.92
100	0.293	0.767	0.89
Rainfall Flood Events			
2	0.049	0.809	0.92
10	0.127	0.799	0.90
50	0.181	0.805	0.86
100	0.198	0.808	0.84

A regional relationship was developed between maximum instantaneous (Q_i) and maximum daily (Q_{md}) flood discharges using recorded flood data from the regional streamflow monitoring stations. The maximum instantaneous discharge can be expressed as a function of maximum daily discharge as follows:

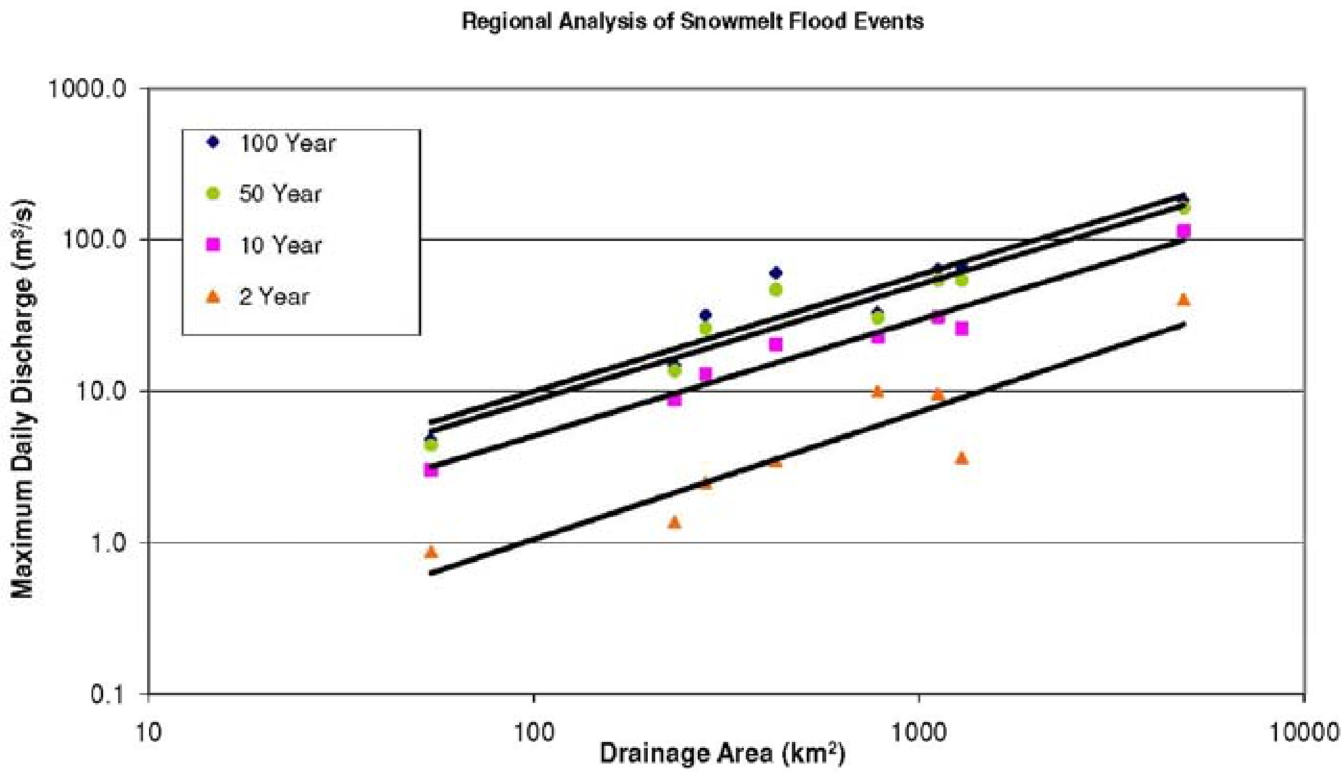
$$Q_i = 1.0065\,Q_{md} + 0.4585 \qquad (R^2 = 0.9995)$$

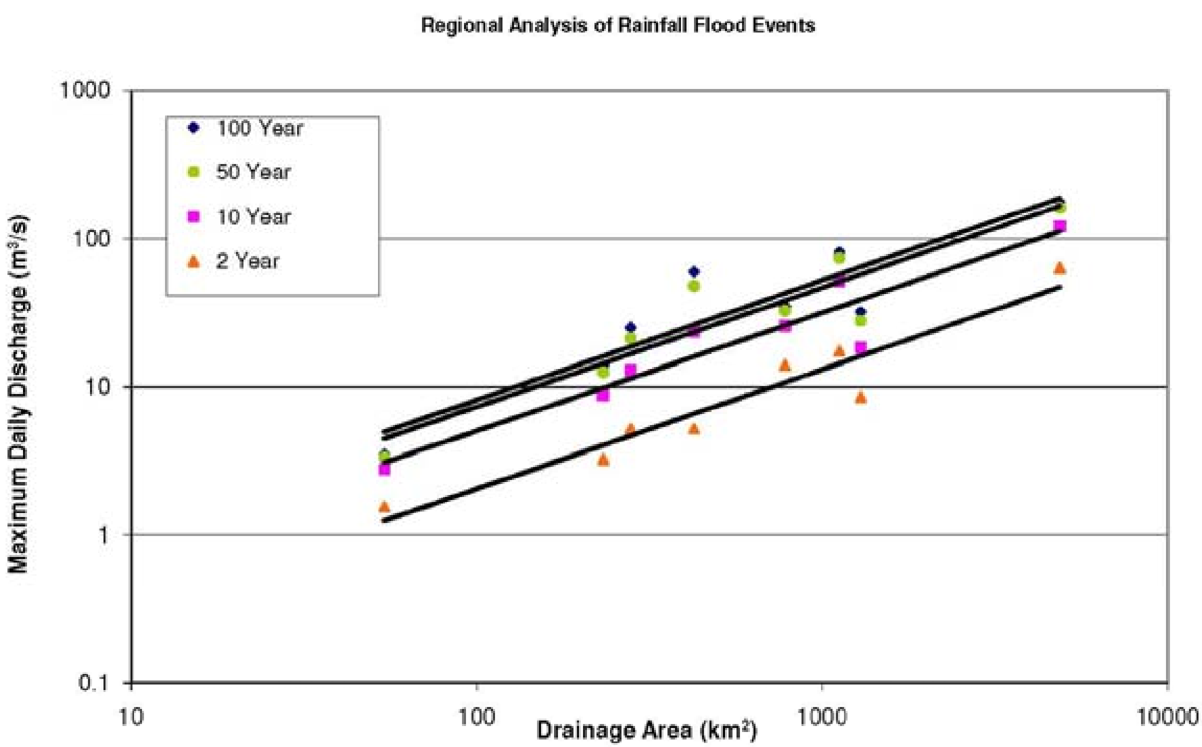
Using the developed relationships, maximum instantaneous snowmelt and rainfall flood discharges were computed for the principal drainages within the ARSA.

7.5.2.5 Low Discharges and Runoff Rates

Zero flows have been recorded and observed at both Birch Creek and Pony Creek during the late winter (February/March) period. The frequency of zero flow occurrences cannot be estimated on an annual basis since only seasonal flow records are available for most of the stations.

Recorded observations of zero flow in Birch and Pony creeks, as well as field observations, show that flows in the relatively small catchments of the ARSA are expected to frequently reach zero over the winter period (November to March). Small streams will also occasionally cease to flow over the summer months.





Pike 1 Project

Regional Analysis of Snowmelt and Rainfall Flood Events

May 24, 2012 | Fig07.05-08 Reg Snow and Rain Flood Events.mxd

devon

PROVIDED BY: AMEC

FINAL MAPPING BY: AMEC

Figure 7.5-8

Source: Devon

Map Path: S:\Gis\Projects\CE\Devon\04050_Pike\ArcGIS Projects\Volume 02 - Section 07 Surface Water Quantity\Fig07.05-08 Reg Snow and Rain Flood Events.mxd Analyst - Trevor Robertson

Flow duration curves were derived for each of the regional streamflow monitoring stations. The flow duration curves for Birch Creek are shown on Figure 7.5-9. Flows were correlated on the basis of drainage area for several probabilities of exceedence, for durations of 1, 7, 14 and 28 days.

7.5.2.6 Lake Levels

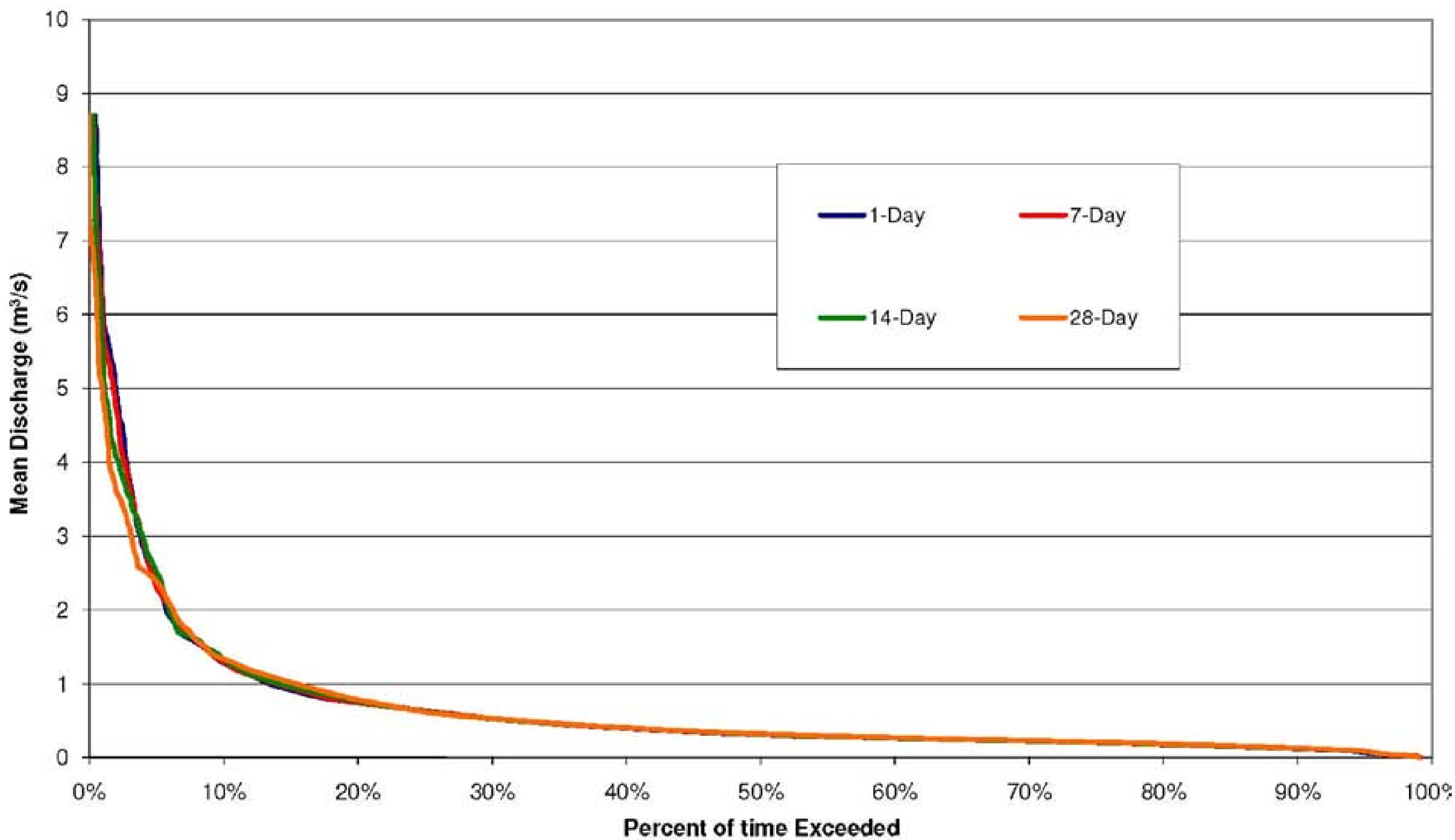
One of the largest surface waterbodies in the ARSA is Christina Lake, located 16 km north of the Project. Christina Lake has a surface area of approximately 21 km^2 and a volume of 369 000 dam^3 (Mitchell and Prepas 1990). The mean and maximum lake depths are 17.3 m and 32.9 m, respectively.

Lake levels in Christina Lake have been intermittently monitored by Alberta Environment and Water on a seasonal (May to October) basis since 1986. Historical recorded lake levels are presented on Figure 7.5-10. Average, minimum and maximum lake levels are summarized in Table 7.5-8.

Table 7.5-8: Historical Lake Levels for Christina Lake

Year	Recorded Lake Level (m)			
	Minimum	Average	Maximum	Range
1986	553.783	554.081	554.809	1.026
1987	553.673	553.924	554.116	0.443
1988	553.777	553.971	554.368	0.591
1989	553.865	554.107	554.331	0.466
1990	553.723	553.957	554.455	0.732
1991	553.654	553.994	554.347	0.693
1992	553.684	553.730	553.790	0.106
1993	553.730	553.898	554.092	0.362
1994	553.813	554.164	554.455	0.642
1995	553.740	554.057	554.617	0.877
1996	554.321	554.690	554.888	0.567
1997	554.351	554.583	555.118	0.767
1998	553.680	553.908	554.192	0.512
1999	Insufficient data available			
2000	553.738	553.926	554.164	0.426
2001	553.812	553.838	553.920	0.108
2002	553.787	554.105	554.583	0.796
2003	553.773	554.127	554.835	1.062
2004	553.824	554.133	554.761	0.937
2005	553.839	554.187	554.811	0.972
2006	553.807	554.078	554.577	0.770
2007	553.813	554.128	554.648	0.835
2008	553.812	554.086	554.620	0.808
2009	553.808	554.040	554.574	0.766
2010	553.807	554.159	554.749	0.942

Minimum water levels in Christina Lake have been trending higher since 1995, which supports the earlier observation of higher runoff since 1996 (Section 7.5.2.3).



Source: Devon

Pike 1 Project

Regional Flow
Duration Curves

April 13, 2012

Fig07.05-09 Reg Flow Dur Curves.mxd

devon

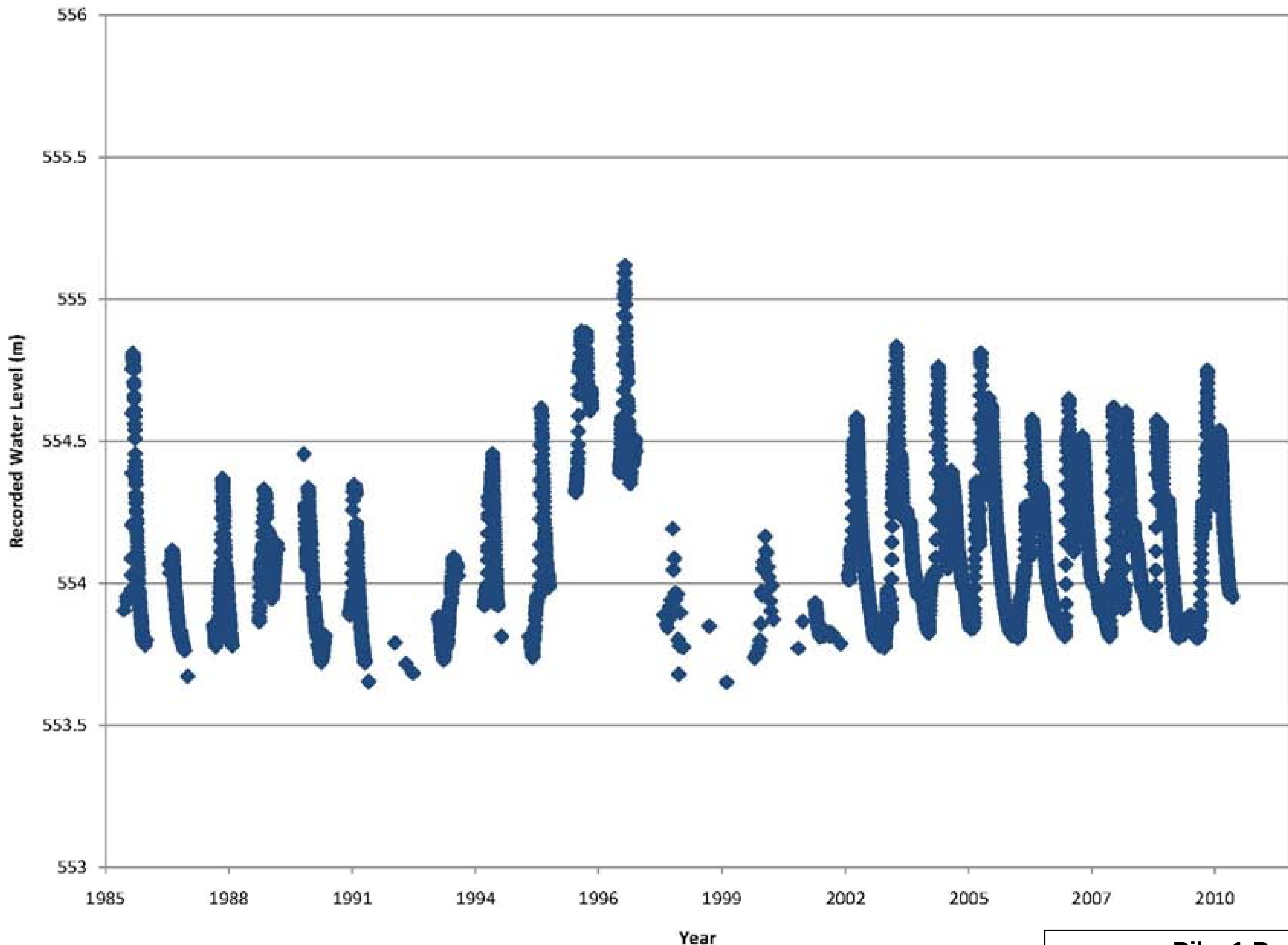
PROVIDED BY: AMEC

FINAL MAPPING BY: AMEC

Figure 7.5-9

Map Path: S:\Gis\Projects\CE\Devon\04050_Pike\ArcGIS Projects\Volume 02 - Section 07 Surface Water Quantity\Fig07.05-09 Reg Flow Dur Curves.mxd

Analyst - Trevor Robertson



Source: Devon

Pike 1 Project

Christina Lake
Historical Water Levels

April 13, 2012 | Fig07.05-10 Christina Lake Hist WL.mxd

PROVIDED BY: AMEC

FINAL MAPPING BY: AMEC

Figure 7.5-10

Map Path: S:\Gis\Projects\CE\Devon\04050_Pike\ArcGIS Projects\Volume 02 - Section 07 Surface Water Quantity\Fig07.05-10 Christina Lake Hist WL.mxd Analyst - Trevor Robertson

Winefred Lake has an average depth of 8 m and a maximum depth of 15 m (AENV 2000). No long-term water level records are available for Winefred Lake. NTS mapping shows the surface area of Winefred Lake is 122.8 km^2 with a maximum length of 15 km and a maximum width of 10 km. No information exists publicly on the depths or volumes of Winefred Lake.

Kirby Lake has a surface area of approximately 5.37 km^2 and a maximum depth of 11 m. Hay Lake has a surface area of about 2.97 km^2, a maximum depth of approximately 5 m and an average depth of 3.4 m. No long-term water level records are available for either Kirby Lake or Hay Lake.

7.5.2.7 Baseline Hydrology Summary

The flow characteristics for the catchments in the ALSA are summarized in Table 7.5-9. Monthly runoff values for the waterways in the ALSA are presented in Table 7.5-10.

7.6 Application Case

7.6.1 Impacts on Hydrology

The construction, operation and/or reclamation phases of the Project may affect the following hydrological surface water parameters, for peak, low flow and average conditions:

- magnitude of overland flow and stream discharges;
- timing of overland flow and stream discharges;
- channel and lake water levels;
- drainage patterns;
- wetlands;
- sediment loading; and
- overall water balance.

The Project will not utilize surface water for steam generation, injection, extraction, or processing. Surface water temporary diversion licenses have been issued for Devon to use up to 90 200 m^3 of water per annum primarily for road maintenance. A list of all surface water licences within the ALSA is available in Volume 3, Appendix F.

Changes in water flow are examined through an analysis of potential Project impacts on peak flows, mean annual flows and on low flows in the Sandy River, Monday Creek and Hay and Kirby lakes catchment. The Sandy River was analyzed at two separate locations to ensure impacts to the upstream portion were examined independently of the downstream reach to assess localized effects.

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Table 7.5-9: Baseline Hydrological Characteristics of Catchments in the ALSA

Catchment/Subcatchment	Total Catchment Drainage Area (km^2)	Mean Seasonal (Mar-Oct) Discharge (m^3/s)	Mean Seasonal (Mar-Oct) Total Discharge (dam^3)[1]	Mean Seasonal (Mar-Oct) Runoff (mm)	Maximum Daily Flood Discharges for Snowmelt Events (m^3/s)				Maximum Daily Flood Discharges for Rainfall Events (m^3/s)			
					2 year	10 year	50 year	100 year	2 year	10 year	50 year	100 year
Sandy River Upstream[2]	249.9	1.0	20 700	83	2.3	10.2	17.5	20.2	4.3	10.5	15.4	17.1
Sandy River Downstream	540.0	2.1	44 800	83	4.4	18.5	31.6	36.5	8.0	19.4	28.5	31.9
Monday Creek[2]	167.0	0.7	13 900	83	1.6	7.5	12.9	14.8	3.1	7.6	11.1	12.4
Kirby and Hay Lake Drainage[2]	123.8	0.5	10 300	83	1.3	6.0	10.3	11.8	2.4	6.0	8.7	9.7

Notes:
[1] 1 dam^3 = 1 000 m^3.
[2] Flood discharges for rainfall events for Sandy River, Monday Creek, and Kirby and Hay Lake drainage catchment based on the regional flood relationships developed in Table 7.5-6 and shown on Figure 7.5-8.

devon

Table 7.5-10: ALSA Estimated Baseline Mean Monthly Runoff

Estimated Mean Monthly Runoff	Runoff (mm)	Sandy River Upstream		Sandy River Downstream		Monday Creek		Kirby Lake and Hay Lake Drainage	
Month		**Volume (dam^3)**	**Discharge (m^3/s)**	**Volume (dam^3)**	**Discharge (m^3/s)**	**Volume (dam^3)**	**Discharge (m^3/s)**	**Volume (dam^3)**	**Discharge (m^3/s)**
January	0.5	140	0.05	290	0.11	90	0.03	70	0.03
February	0.3	90	0.04	190	0.08	60	0.02	40	0.02
March	0.4	90	0.03	190	0.07	60	0.02	40	0.01
April	8.5	2 120	0.82	4 580	1.77	1 420	0.55	1 050	0.41
May	17.3	4 330	1.62	9 370	3.50	2 900	1.08	2 150	0.80
June	15.7	3 920	1.51	8 470	3.27	2 620	1.01	1 940	0.75
July	16.6	4 150	1.55	8 980	3.35	2 780	1.04	2 060	0.77
August	11.4	2 850	1.06	6 160	2.30	1 900	0.71	1 410	0.53
September	8.0	2 000	0.77	4 320	1.67	1 330	0.51	990	0.38
October	5.2	1 300	0.49	2 820	1.05	870	0.32	650	0.24
November	3.0	740	0.29	1 600	0.62	490	0.19	370	0.14
December	1.0	260	0.10	560	0.21	170	0.06	130	0.05
Seasonal Total (March-October)	**83.0**	**20 770**	**1.0**	**44 880**	**2.1**	**13 880**	**0.7**	**10 290**	**0.5**
Annual Total (January-December)	**88.0**	**21 990**	**0.7**	**47 520**	**1.5**	**14 690**	**0.5**	**10 900**	**0.3**

There will be 4.2 ha of disturbance to the direct drainage area of Winefred Lake as part of the Project. This disturbance represents 0.0035% of the drainage area of Winefred Lake at the outlet. Due to the difficulty in accurately modeling a lake the size of Winefred Lake, and the very small Project footprint within its direct drainage area, effects to the direct drainage to Winefred Lake have not been assessed. Any effects to Winefred Lake due to Project-related changes within its direct drainage will be lower in magnitude than those in the modeled catchments and well below detectable limits.

7.6.2 Changes in Surface Runoff Due to Surface Disturbances

Vegetation clearing and construction of infrastructure (roads, well pads, pipelines and central processing facility) may result in changes to water flows in streams. The estimated magnitude of these changes has been based on the areal extent and nature of the surface disturbances that are expected to occur.

7.6.2.1 Surface Disturbances

Expected disturbances within the Sandy River, Monday Creek, and Kirby and Hay Lake drainages are summarized in Table 7.6-1. Total area of the Project disturbance as a percentage of the total drainage basin areas are 1.5%, 1.2%,1.1% and 1.5% for the Upper Sandy River, Lower Sandy River, Monday Creek and Kirby and Hay Lake drainages, respectively.

Table 7.6-1: Summary of Disturbances

Disturbance Type	Sandy River Upstream	Sandy River Downstream	Monday Creek	Kirby and Hay Lake Drainages
Borrow Pit (ha)	57.4	54.9	35.6	42.1
Right-of-way[1] (ha)	130.7	179.2	67.2	72.2
Source/Disposal Well (ha)	1.2	12.5	4.5	1.5
CPF (ha)	68.7	28.1	0.0	0.0
Well Pad (ha)	103.6	81.4	69.2	75.2
Total Disturbance (ha)	**362**	**356**	**176**	**191**
Total Drainage Area (ha)	24 939	28 944	16 786	12 379
Pike Disturbance as a % of Entire Basin	**1.5%**	**1.2%**	**1.1%**	**1.5%**

Note:
[1] Includes roads, pipelines, power.

Project impacts were evaluated assuming that all the Project components would be in operation at the same time. This is a conservative assumption that overestimates the amount of disturbance and its associated hydrologic impact since some facilities (e.g., well pads) will be constructed and decommissioned in phases over the life of the Project.

7.6.2.2 Changes to Mean Annual Runoff

The mean annual precipitation for the ALSA is 475 mm and the mean annual runoff for the ALSA is 88 mm. During past work for the Devon Jackfish 2 EIA (Devon 2006), AMEC developed a relationship between annual total runoff and precipitation for various terrain types in the Fort McMurray region. Natural terrain types include lowland and upland. Disturbed terrain types include cleared upland and lowland, borrow pits and plant site. The designation of these terrain types for the Project is described below:

- *Natural Lowland* – lowland areas have less runoff per unit area than upland areas since they are generally at lower elevations, have flatter gradients, receive less precipitation and have substantial wetland areas with high evapotranspiration rates. For the Project, the lowland region is defined as all areas of the catchment containing wetlands and the entire catchment located below the mean elevation of the ALSA;
- *Natural Upland* – upland areas typically have higher gradients, better developed drainage networks and greater runoff per unit area than lowlands. For the Project, the upland region is defined as the non-wetland portion of the catchment located above the mean elevation of the ALSA;
- *Cleared Lowland* – these are lowland areas that have been cleared of natural vegetation but typically have a grass cover. Examples include pipeline and utility corridor rights-of-way (ROWs);
- *Cleared Upland* – these are upland areas that have been cleared of natural vegetation but typically have a grass cover. Examples include pipeline and utility corridor ROWs;
- *Graveled Surface* – these are hard surfaces, such as roads and well pads, which have relatively high runoff rates;
- *Plant Site* – this is a relatively impervious area with high runoff rates; and
- *Borrow Pit* – this is a cleared and excavated area with a relatively high runoff rate.

The mean annual runoff estimated from regional streamflow data is 88 mm for the ALSA. While the relationships developed for predicting runoff on the Devon Jackfish 2 Project are found to overestimate the total runoff from an area, they do provide an indication of the relative difference in runoff between the different land surfaces. Estimated mean annual runoff for baseline conditions, the correction factor and the Project Application Case mean annual runoff, are shown in Table 7.6-2.

Table 7.6-2: Mean Annual Runoff Estimate

	Sandy River Upstream	Sandy River Downstream	Monday Creek	Kirby and Hay Lake Drainage
Estimated Mean Annual Runoff (mm)	122.9	122.7	124.1	124.5
Correction Factor	0.72	0.72	0.71	0.71
Corrected Mean Annual Runoff (mm)	88.0	88.0	88.0	88.0
Pike Development Mean Annual Runoff (mm)	89.3	89.0	88.8	89.2

Table 7.6-3 shows the estimated increase in mean annual discharges due to the Project.

Table 7.6-3: Increase in Mean Annual Runoff Associated with the Project

	Sandy River Upstream		Sandy River Downstream		Monday Creek		Kirby and Hay Lake Drainages	
	Volume (dam^3)	Discharge (m^3/s)	Volume (dam^3)	Discharge (m^3/s)	Volume (dam^3)	Discharge (m^3/s)	Volume (dam^3)	Discharge (m^3/s)
Existing Mean Annual Runoff	21 987	0.70	47 521	1.51	14 692	0.47	10 896	0.35
Increase in Mean Annual Runoff	317	0.01	551	0.02	138	0.00	147	0.00
Percent Increase in Mean Annual Runoff (%)	1.4%		1.2%		0.9%		1.3%	

The stormwater ponds at the plant site and runoff collection areas at well pads will need to be drained as required in order to prevent overflow. This will not substantially increase evaporation or alter monthly runoff volumes. Due to their minimal footprint and drainage areas, these discharges will not appreciably alter the monthly and annual water balance estimates.

7.6.2.3 Changes to Peak Discharge

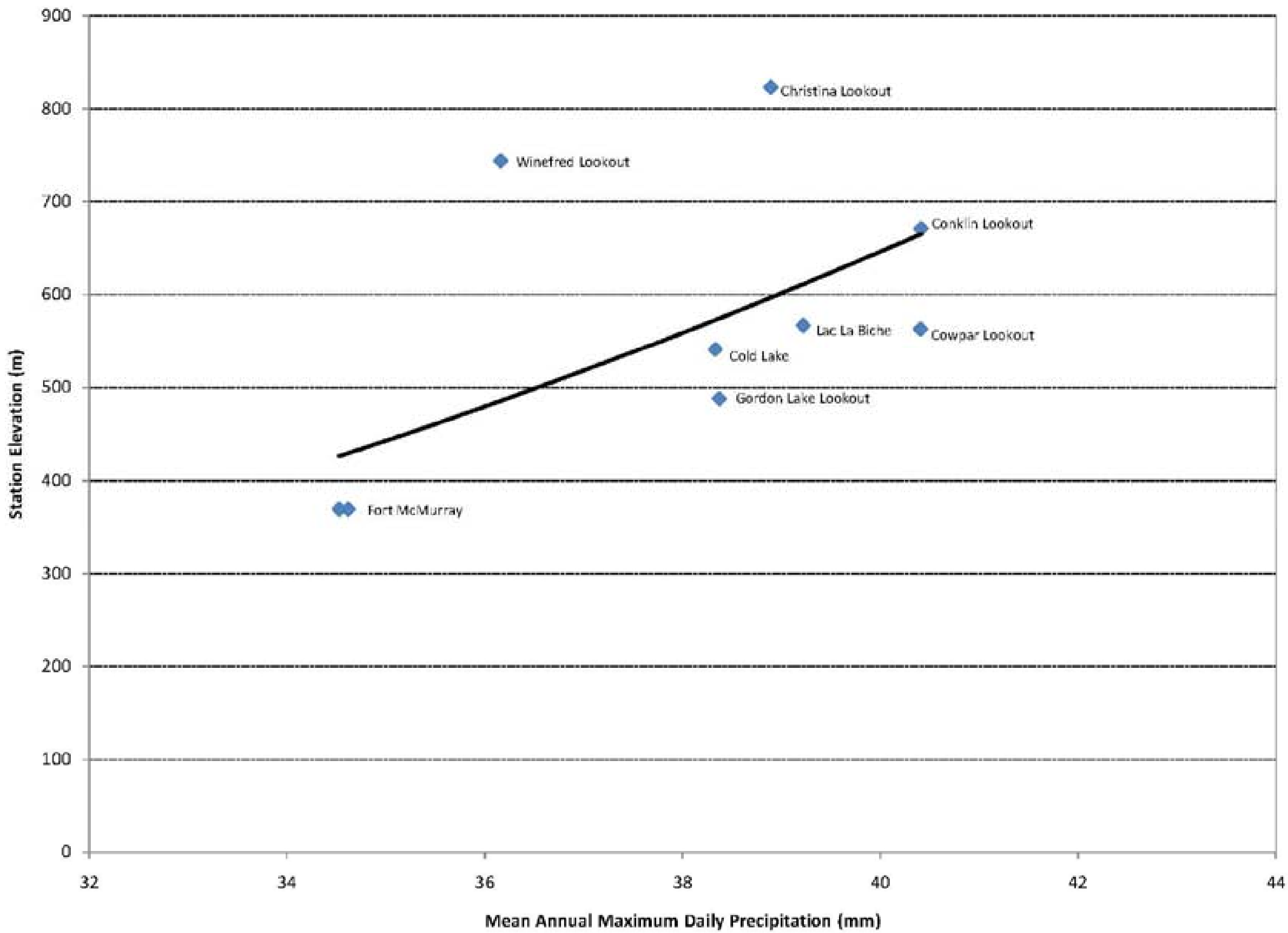
The Hydrologic Modeling System computer model was used to simulate floods in the affected catchments to determine changes in peak discharge due to land clearing and gravelled and paved surfaces associated with the development. The 1:10 year and 1:100 year floods were evaluated.

Design storm rainfall amounts were obtained from IDF curves developed by MSC (Environment Canada) for Cold Lake (elevation 541 m) and Fort McMurray (elevation 369 m) and a regional relationship between elevation and mean annual maximum daily precipitation (Figure 7.6-1). The 1:10 year and 1:100 year, 24-hour duration rainfall events for the ALSA were estimated to be 64.7 mm and 96.4 mm respectively.

Basic catchment characteristics for the study area including drainage area, channel length and channel gradient were obtained from LiDAR generated topographic mapping.

The land use runoff curve number (CN) for baseline conditions was estimated based on the existing disturbances within the catchments. CN numbers listed below were used for the baseline conditions:

- Sandy River Upstream: CN = 62.79;
- Sandy River Downstream: CN = 62.74;
- Monday Creek at Confluence with Sunday Creek: CN = 63.08; and
- Kirby and Hay Lake: CN = 63.31.



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Source: Devon

Pike 1 Project		
Regional Mean Annual Maximum Daily Precipitation		
April 24, 2012	Fig07.06-01 Mean Ann Max Daily Precip.mxd	
devon	PROVIDED BY: AMEC FINAL MAPPING BY: AMEC	Figure 7.6-1

The CN numbers for the various development surfaces were based on published values, and were:

- plant site: CN = 100;
- well pad, road, disposal well, observing well: CN = 90; and
- utility pipeline and gas line: CN = 75.

The flood modeling results for peak daily discharge and volume are shown in Table 7.6-4. The plant site will have stormwater ponds that will be designed to contain a 1:100 year, 24-hour duration storm event. The plant site ponds will marginally attenuate flood peaks in the Sandy River for the 1:100 year (the design criteria for the ponds) and lesser return period floods.

Table 7.6-4: Increase in Peak Daily Discharge and Volume Associated with the Project

Rainfall Return Period	Condition	Upper Sandy River		Sandy River at Winefred Lake		Monday Creek		Kirby Lake and Hay Lake Drainage	
		Volume (dam^3)	Peak Discharge (m^3/s)	Volume (dam^3)	Peak Discharge (m^3/s)	Volume (dam^3)	Peak Discharge (m^3/s)	Volume (dam^3)	Peak Discharge (m^3/s)
1:10	Baseline Case	1 614	17.0	3 475	40.1	1 118	19.6	843	17.2
	Application Case	1 668	17.6	3 578	41.3	1 143	20	870	17.8
	Difference	55	0.6	102	1.2	25	0.4	27	0.6
	% Difference	3.4%	3.5%	2.9%	3.0%	2.3%	2.0%	3.2%	3.5%
1:100	Baseline Case	5 055	53.6	10 906	126.4	3 465	63	2 592	56.7
	Application Case	5 162	54.8	11 100	128.6	3 512	63.9	2 643	58.0
	Difference	107	1.2	194	2.2	47	0.9	51	1.3
	% Difference	2.1%	2.2%	1.8%	1.7%	1.4%	1.4%	2.0%	2.3%

Table 7.6-4 indicates that increases in peak flows are no greater than 3.5% in the affected catchments. These increases are not expected to impact other surface water users or increase erosion potential.

7.6.2.4 Changes to Low Flows

Low flows typically occur during the winter months and winter low flow is primarily supplied by the release of infiltrated water from the near-surface groundwater system and deep groundwater. The Project could affect low flows in two ways: by reducing infiltration and by reducing the amount of flow available to surface watercourses through groundwater withdrawals.

Hard surfaces, such as paved and gravelled areas, reduce infiltration. The amounts of paved and gravelled areas for the affected catchments are shown on Table 7.6-5. Assuming no infiltration occurs from the paved and gravelled areas; low flow changes to Sandy River, Monday Creek and Kirby and Hay Lake drainage areas can be estimated. This is a conservative assumption, as some infiltration over gravelled areas would be expected, and additional infiltration adjacent to paved and gravelled surfaces could occur from ponded runoff.

Table 7.6-5: Surface Disturbances Low Flow Effects for the Project

	Sandy River Upstream	Sandy River Downstream	Monday Creek	Kirby and Hay Lake Drainage
Total Catchment Area (ha)	24 939	53 883	16 786	12 379
Pike Paved/Graveled Areas (ha)	68.7	96.8	0.0	0.0
Percent of Catchment Area Paved/Gravel by Pike (%)	0.28%	0.18%	0%	0%

The change in groundwater interactions with surface water due to Project-related groundwater withdrawals were calculated as part of the hydrogeology assessment (Volume 2, Section 6.0). Included in the analysis of low flow effects of the Project are the maximum Application Case effects of groundwater withdrawals. The maximum Application Case effects used are considered conservative as they will only occur for a short period of the Project. The predicted effects of groundwater withdrawals on surface water flows are shown on Table 7.6-6.

Table 7.6-6: Groundwater Withdrawal Low Flow Effects for the Project

	Sandy River Upstream	Sandy River Downstream	Monday Creek	Kirby and Hay Lake Drainage
Maximum Effect of Application Case Groundwater Withdrawal (m^3/s)	1.26E-04	1.67E-04	3.71E-04	1.37E-04

As shown on Table 7.6-7, the decrease in winter low flow due to reduced infiltration and the effects of groundwater withdrawals is no greater than 0.48% in each potentially affected catchment and as such is not expected to impact other surface water users or instream flow needs. Furthermore, zero flows are expected to occur frequently in the catchments in the ALSA. The frequency of zero flow events is not expected to be measurably changed by the Project.

The Project, including potential subsurface impacts, is not expected to have a measurable effect on low flows within the ALSA.

7.6.2.5 Summary of Hydrologic Impacts

Table 7.6-8 summarizes the expected hydrologic impacts due to surface disturbances from the Project. Predicted increases in runoff for these basins are low, ranging from 0.24% to 3.53%. Changes in evapotranspiration and infiltration for these basins are also low.

Table 7.6-7: Winter Low Flow Changes Associated with the Project

Month	Sandy River Upstream		Sandy River at Winefred Lake		Monday Creek		Kirby and Hay Lake Drainage	
	Baseline (m^3/s)	Application (m^3/s)	Baseline (m^3/s)	Application (m^3/s)	Baseline (m^3/s)	Application (m^3/s)	Baseline (m^3/s)	Application (m^3/s)
November	0.28	0.28	0.61	0.61	0.19	0.19	0.14	0.14
December	0.09	0.09	0.21	0.20	0.06	0.06	0.05	0.05
January	0.05	0.05	0.11	0.11	0.03	0.03	0.03	0.03
February	0.04	0.04	0.07	0.07	0.02	0.02	0.02	0.02
Mean Winter Flow	0.12	0.11	0.25	0.25	0.08	0.08	0.06	0.06
% Decrease In Flow	0.38%		0.25%		0.48%		0.24%	

Table 7.6-8: Summary of Hydrologic Impacts

Parameter		Sandy River Upstream		Sandy River at Winefred Lake		Monday Creek		Kirby and Hay Lake Drainage	
		Baseline Case	**Application Case**	**Baseline Case**	**Application Case**	**Baseline Case**	**Application Case**	**Baseline Case**	**Application Case**
Area	Total (km^2)	249		539		168		124	
	Undisturbed (km^2)	237	234	514	508	157	155	105	103
	Disturbed (km^2)	12	16	26	32	11	13	19	21
Mean Annual	Volume (dam^3)	21 987	22 304	47 521	48 072	14 692	14 830	10 896	11 043
	Flow (m^3/s)	0.7	0.71	1.51	1.52	0.47	0.47	0.35	0.35
	Increase (%)	1.40%		1.20%		0.90%		1.30%	
1:10 Year Rainfall Event	Volume (dam^3)	1 614	1 668	3 475	3 578	1 118	1 143	843	870
	Flow (m^3/s)	17	17.6	40.1	41.3	19.6	20	17.2	17.8
	Increase (%)	3.53%		2.99%		2.25%		3.49%	
1:100 Year Rainfall Event	Volume (dam^3)	5 055	5 162	10 906	11 100	3 465	3 512	2 592	2 643
	Flow (m^3/s)	53.5	54.8	126.4	128.6	63	63.9	56.7	58
	Increase (%)	2.24%		1.78%		1.43%		2.29%	
Low Flows	Mean Winter Flow (m^3/s)	0.12	0.11	0.25	0.25	0.08	0.08	0.06	0.06
	Decrease (%)	0.38%		0.25%		0.48%		0.24%	

7.6.3 Mitigation

The Project has been designed using cumulative constraints mapping, which included hydrological considerations (Volume 2, Section 3.4). The placement of the central facility, pads, and corridors has been laid out using LiDAR generated topography and wet areas mapping so as to minimize or mitigate, wherever possible, potential hydrologic impacts. Further, potential hydrological impacts and associated mitigation methods are summarized in Table 7.6-9. These mitigation measures will be incorporated into surface water management practices for Pike 1 to minimize the impacts of the Project on the hydrologic regime of the ALSA. In all cases, every effort will be made to maintain natural drainage patterns and minimize disruptions to surface flows.

Table 7.6-9: Mitigation Measures for the Project

Development	Potential Impact	Mitigation Measure
Roads	• May block near-surface flows through muskeg and wetland areas. • Sedimentation during construction. • Fish habitat disruption at channel crossings. • Sedimentation during road maintenance/grading.	• Provide culverts at all defined surface channels, at low points along the alignment and at regular intervals through wetland areas to provide cross-drainage. • Use appropriate sediment control techniques to prevent sediments from entering watercourses during construction and ongoing maintenance. • Install bridges/culverts in accordance with current codes of practice.
Pipelines	• Sedimentation during construction. • Flow interruption during construction. • Instability of disturbed channel banks at crossings.	• Use appropriate sediment control techniques to prevent sediments from entering watercourses. • Install crossings in accordance with current codes of practice. • Select stable crossing locations and avoid steep crossing approaches where possible. • Use erosion control measures on approach slopes. • Restore and stabilize channel banks to prevent bank erosion.
Plant Site and Well Pads	• Increased runoff. • Sediment entrainment in, and potential contamination of, runoff. • Disturbance to existing surface channels and drainage patterns.	• Construct stormwater ponds or collection points to capture and detain stormwater runoff in order to attenuate peak flows. • Construct stormwater ponds or collection points to detain stormwater for sediment settlement and to allow for water quality testing prior to release in accordance with standard insitu oil sands EPEA approvals. For runoff that does not meet the facility EPEA approval requirements treat prior to release, recycle to the plant water treatment system or send to an approved disposal well.

7.6.4 Residual Project-Specific Effects

Analysis of residual Project-specific surface runoff effects is based on the assumption that the foundation materials (gravel and clay) from the roads, well pads and plant site will not be removed from the constructed infrastructure in the reclamation stage. This is a conservative assumption as reclamation will include removal of gravel from all areas, and removal of fill from pads in wetland areas and at former culvert locations in roads (Volume 1, Section 6.0). The hydrological response of the reclaimed gravel areas will differ slightly from the response of the natural muskeg areas. This assessment is based on the restoration of evapotranspiration to pre-development conditions and of surface runoff patterns (mean annual, peak, and low flows) to a near natural state. The residual change is expected to be in subsurface flow patterns resulting from compaction of material below development areas. The effect is judged to be local in extent, low in magnitude, negative in direction, and long-term in duration (Table 7.6-10). The understanding of the impact, mitigation opportunities, and the adequacy of the site-specific data and regional information are good, therefore, the confidence in this assessment is rated as good.

Table 7.6-10: Assessment of Residual Project Application Case Impacts

Impact Assessment Attribute	Impact Assessment
Direction of Impact	Negative
Geographic Extent of Impact	Local
Magnitude of Impact	Low
Duration of Impact	Long-term
Confidence	Good
Overall Hydrology Impact Assessment Rating	Low

7.7 Planned Development Case

7.7.1 Planned and Existing Disturbances

The existing and planned disturbances within the local and regional study areas include various insitu operations, including Devon's Jackfish project, Cenovus' Christina Lake project, CNRL's Kirby Expansion project and KNOC's BlackGold project. In addition, Al-Pac has forest harvesting operations, including both cutblocks and access roads, within the ALSA and ARSA.

The Christina Lake project is downstream of the Pike development, located approximately 1 km south of the confluence of Sunday and Monday creeks; the KNOC BlackGold project will be approximately 5 km northwest of the Pike development, located immediately adjacent to Christina Lake; and the Devon Jackfish project is located immediately north of the Project. The EIA studies for the Christina Lake thermal project (PanCanadian Petroleum Limited 1998), the BlackGold project (KNOC 2008) and for the Jackfish 1, Jackfish 2 and Jackfish 3 project applications (Devon 2003, 2006, 2010) were reviewed. The following information is drawn from the surface water quantity impact assessments:

- Christina Lake, Kirby, BlackGold and Jackfish are SAGD projects that use groundwater; and
- groundwater use is expected to have little to no impact on surface water. There is assumed to be no real potential to change the water regime either in the ALSA or in the vicinity of Christina Lake and Winefred Lake.

Overall, these existing and planned disturbances will result in an increase in surface water runoff due to the increase in non-vegetated low permeability surfaces. However, the effect of the increased runoff from developed areas during rainfall and snowmelt events is expected to be minimal.

7.7.2 Cumulative Effects

The cumulative effects of the Pike, Jackfish, BlackGold and Christina Lake projects in Monday Creek, Sandy River and the Hay and Kirby Lake catchment are summarized in Table 7.7-1.

Table 7.7-1: Cumulative Impact Assessment for the Project

Attribute	Final Impact Rating
Geographic Extent	Local
Magnitude	Low
Direction	Neutral
Duration	Long
Confidence	Good

7.8 Monitoring

Existing continuous monitoring stations installed as part of the Devon Jackfish project monitoring programs will be maintained on Sunday and Monday creeks. As part of the baseline for monitoring programs for the Project, Devon has undertaken the following:

- streamflow monitoring at representative sites within the ALSA;
- continuous water level and temperature monitoring on Hay and Kirby lakes;
- annual ice thickness surveys; and
- continuous air temperature measurements near Kirby Lake.

Devon is currently developing a monitoring program for the Jackfish projects to assess potential changes to fish and fish habitat associated with SAGD-related thermal heave. This program will include hydrology and water quality components. Once finalized, it will be the basis for developing a similar program for the Project if required.

Devon is also an active member of Regional Aquatics Monitoring Program (RAMP) and has been working with RAMP to extend the monitoring network into the southern region. In 2012, RAMP monitoring stations are planned for installation on Sunday Creek, Jackfish River and Christina Lake.

7.9 Summary

Construction and operation of the Project will include clearing of timber and grading for construction and operation of access roads, utility ROWs, well pads, and a plant site. Releases from the stormwater retention ponds at the plant and from stormwater collection areas on the well pads will be managed to align with the natural flow patterns within the development area.

Residual surface water impacts due to the Project are rated to be low. These impacts are judged to be local in extent, low in magnitude and long-term in duration. The understanding of the impact, mitigation opportunities, and the adequacy of the site-specific data are good; therefore the confidence in this assessment is rated as good.

7.10 References

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