DISCUSSION PAPER

Arrowsmith Water Service
Englishman River Water Intake Study

Phase 1 – Conceptual Planning

Discussion Paper 6-1: Watershed Hydrology Assessment

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1 Introduction

Kerr Wood Leidal (KWL) in partnership with Associated Engineering (AE) and Koers & Associates was retained by Arrowsmith Water Service (AWS) to develop an updated water management framework for the Englishman River, culminating in a water supply strategy and a conceptual design for water supply intake structure and treatment plant.

This paper is prepared under Task 6-1: Watershed Hydrology Assessment. It provides a general review of stream flows in the Englishman River, whether the flows would meet both the fish habitat and water supply requirements, and the storage deficits in the Arrowsmith Lake.

2 Englishman River Basin and its Current Operation Conditions

The Englishman River Watershed is located on the east coast of Vancouver Island near the City of Parksville. The river drains a watershed area of approximately 324 km^2 from the east-facing slopes of Mount Arrowsmith (1820 m) and Mount Moriarty Ridge. Figure 1 is a location plan of the Englishman River watershed.

The Englishman River is an important salmon-producing stream on the east coast of Vancouver Island that supports all species of salmon, including steelhead. The river is designated as a sensitive stream by the BC government under the Fish Protection Act.

The discharges in the Englishman River are dominantly a rainfall-driven. Heavy fall and winter rains generate high flows in the river from November through April. In spring, snowmelt contributes to runoff but not to the same extent as fall and winter rainfall. During the summer months from June to October, flows in the river decrease to minimum flows during the typically long dry period.

Arrowsmith Water Service and Arrowsmith Dam

In 1996, The Regional District of Nanaimo (RDN), the City of Parksville (CoP) and the Town of Qualicum Beach (ToQB) entered into a joint venture agreement to construct, operate and maintain the Arrowsmith Dam and associated water facilities. They formed the Arrowsmith Water Service (AWS) and were granted a water license (Conditional Water Licence No. 110050) from the provincial government to store water at Arrowsmith Lake and extract water from the Englishman River including:

- annual diversion of up to 1,540,000,000 gal/yr (approximately 7,001 ML/yr);
- maximum daily diversion of 10,550,000 gal/day (approximately 48 ML/day); and
- Storage of 7,300 acre-feet per year (approximately 9,004 ML/yr) at Arrowsmith Lake Reservoir.

The bulk water supply system operated by AWS services currently CoP, and RDN water service areas in Nanoose Bay and French Creek with possible future servicing to ToQB. The surface water in the Englishman River provided by the AWS is intended to supplement existing groundwater supply to the AWS service areas to address uncertainty regarding the sustainability of groundwater supplies for present and future needs. Prior assessments estimated that the Englishman River would be able to provide a long-term supplementary water supply for the AWS service areas. The current water licence held by AWS was based on providing sufficient supply to support water needs until 2021.

The Arrowsmith Dam is a gravity concrete structure with a free overflow spillway, a 900 mm dia. high-level outlet and a 600 mm low-level siphon. Flows through the low-level outlet and siphon are controlled using hydraulically operated butterfly valves. Construction of the dam was completed in October 1998. The dam controls the release of water from the Arrowsmith Lake reservoir to Arrowsmith Creek and the Englishman River downstream. The Arrowsmith Dam has a total live storage volume of 9.0 million m^3 from just above low level siphon at elevation 802 m to spillway crest elevation at 828.5 m. The reservoir fills over the winter and spring and when full, flows pass over the spillway to Arrowsmith Creek. During the summer and fall, the reservoir is drained using low-level outlet and siphon under the dam to support river flows for domestic water extraction and fishery resources.

Provisional Operation Rule and Conservation Flows

The requirements for release of water are governed by the Provisional Operation Rule (POR) for the licence. This rule provides guidance in target flows to be maintained at the Englishman River near Parkville Water Survey of Canada (WSC) gauge (08HB002) located at the Highway 19A Bridge (the "Orange Bridge"). The rules are based on a "rule band" which indicates required target flows based on available storage at the Arrowsmith Lake reservoir. In general, the POR requires that when storage is above normal a flow of 1.6 m^3/s is to be maintained at the gauge, when storage is about normal a flow of 1.4 m3/s is to be maintained and when storage is below normal a flow of 1.2 m3/s is to be maintained. A copy of the POR is included in Appendix A.

The conservation flows of 1.2 m^3/s, 1.4 m^3/s and 1.6 m^3/s at the WSC gauge are based on minimum and preferred conservation flows in the lower reaches of the Englishman River to support juvenile fish rearing habitat. Originally, the water licence application report prepared by Ministry of Environment in 1996 recommended a minimum target of 1.13 m^3/s be required at the Englishman River Gauge with a longer-term target of 2.12 m3/s. The federal department of Fisheries and Oceans (DFO) also recommended a minimum target of 1.13 m^3/s and an absolute minimum of 0.71 m^3/s under all conditions.

The POR updated the minimum targets using current Ministry of Environment policy and input from both provincial and local biologists experienced with low-flow conditions on the Englishman River. Current Vancouver Island Provincial Water Stewardship Branch policy requires a minimum conservation flow of 10% mean annual discharge (MAD) of 1.44 m^3/s to be maintained. This is derived from a version of the Montana Method (Tennant, 1976) modified for local conditions in British Columbia.

We understand that no formal detailed field assessment of habitat availability at low-flows has been completed. This includes procedures such as the weighted useable area method outlined in the “Assessment Methods for Aquatic Habitat and Instream Flow Characteristics in Support of Applications to Dam, Divert, or Extract Water from Streams in British Columbia” prepared for the Ministry of Environment in 2004.

3 Methodology

The methodology that was carried out for this watershed hydrology assessment includes:

1. Collecting and reviewing historical data for flows in the Englishman River, water levels in the Arrowsmith Lake Reservoir and outlet flows released at the Arrowsmith Dam;
2. Identifying the limitation of the existing flows in meeting the fish habitat and water supply requirements;
3. Setting up a watershed water balance model to back calculate historical inflows to the Arrowsmith Lake;
4. Assessing storage deficits of the reservoir to achieve the required minimum and ideal conservation flows (1.2 m^3/s and 1.4 m^3/s, respectively) in the river and to meet the water supply demands during the selected historical periods, and assessing the shortfalls for the existing dam to release the desired flows within those periods;
5. Using the recorded flows at the Water Survey Canada (WSC) hydrometric gauge, performing a low flow frequency analysis to determine 10-year and 100-year return period drought condition watershed flows;
6. Assessing storage deficits and flow release shortfalls of the reservoir in meeting the minimum and ideal conservation flows and water supply demands under the 10-year and 100-year drought conditions;
7. Determining potential climate change impacts on flows in the watershed;
8. Assessing storage deficits and flow release shortfalls of the reservoir considering climate change impacts;
9. Estimating peak flood discharges (in the lower reaches of the river); and
10. Preparing this hydrology assessment report to summarize methodology and findings.

4 Hydrology Assessment

WSC Gauge Data

Recorded flows for the Englishman River WSC near Parksville gauge (08HB002) are available from 1913 to 1915 with consecutive flow records available for the gauge from April 1979 to present. The flow records indicate before the Arrowsmith Dam was constructed in 1998, minimum daily flows varied between 0.1 m^3/s and 0.7 m^3/s and mostly at around 0.3 m^3/s. Starting from 1999, with the controlled release of the reservoir water, minimum day flows were increased and varied between 0.7 m^3/s and 1.6 m^3/s and mostly at around 1.0 m^3/s. From the record it appears that construction of the Arrowsmith Dam and release of water during the summer has dramatically increased the minimum flows. Table 1 includes a summary of flows recorded at the WSC Englishman River gauge after 1999.

Table 1 also summarizes the number of days in a year when flows at the WSC gauge were less than the required 1.6 m^3/s flow and the days when flows were less than the 1.2 m^3/s minimum conservation flow. It is noted from the results that although the Provisional Operation Rule (POR) requires that the reservoir be discharged to provide a minimum flow of 1.6 m^3/s at the WSC gauge location, the actual flows from the reservoir have been released at rates less than the required values and on many occasions, flows at the WSC gauges were even less than the minimum required conservation flow of 1.2 m^3/s.

Table 1
WSC Englishman River Gauge Flow Summary

Year	Mean Annual	Minimum	Maximum	Days of Flow less than 1.6 m^3/s	Days of Flow less than 1.2 m^3/s
	m^3/s	m^3/s	m^3/s	Days	Days
1999	19.35	0.89	194.00	28	16
2000	8.98	0.67	73.90	28	20
2001	9.41	1.12	174.00	40	3
2002	12.64	0.97	226.00	68	30
2003	15.86	1.02	256.00	74	38
2004	10.60	1.15	114.00	21	3
2005	12.54	1.22	275.00	27	0
2006	17.22	0.74	236.00	74	44
2007	14.86	1.56	259.00	5	0
2008	8.22	0.94	101.00	29	8
2009	11.91	0.76	303.00	103	23
Average	12.87	1.00	201.08	45	17

Arrowsmith Lake Levels

Historical lake levels are available from January 7, 2003 to present, except for two periods between November 27, 2003 and July 07, 2004, and between January 1 and March 16, where the data is missing. Figure 2 shows a plot of the recorded historical lake levels. The lake level plot show that the Arrowsmith Lake reaches its full volume or at its highest level at around July 1. The lake level usually drops to its lowest level in late October or early November. However, in the years of record, the lake has never dropped to the zero storage level at el. 802 m. The lowest recorded lake level on November 3, 2006 was at el. 805.6 m.

Arrowsmith Dam High Level Outlet and Siphon flows

Data for flows through the high-level outlet and the siphon at the Arrowsmith Dam are available for years 2002, 2003, 2004, 2005, 2007, 2008 and 2009. Figure 3 is a plot of the Arrowsmith Dam outlet flow data. The data indicate that flow is released from the dam starting around July 1 and ending around late October or early November. Based on discussion with CoP operations staff we understand that recent flows in the record may not be accurate due to faulty flow sensor on the siphon.

Based on the lake level and outlet flow patterns, we have designated a water year as starting from November 1 and end on October 31 in the subsequent year. Using a water year rather than calendar year allows the reservoir to operate through a full cycle of filling and emptying as part of the water balance analysis.

The existing configuration of the high-level outlet and low-level siphon restricts the amount of flow that can be released from the reservoir. The Arrowsmith Dam operation and maintenance manual indicates that a minimum flow of 1.13 m^3/s can be released through the high-level outlet and the siphon when reservoir levels are at or above el. 811.5 m, which is equivalent to 27% of the full storage. Below this elevation flows would only be supported by the siphon which has a maximum capacity of about 0.78 m^3/s below el. 811.5 m. This indicates that only about 6.6 million m^3 of the total 9.0 million m^3 is available for release at the minimum flow of 1.2 m^3/s.

An example of this restriction in outlet capacity is shown in the dam release data for 2009 (shown in Figure 3). Starting on September 11, 2009 flows released from the reservoir start decreasing even though the valves are fully open. This resulted in flows dropping below the desired minimum of 1.2 m^3/s at the WSC. If the outlet could be adjusted to maintain 1.2 m^3/s throughout the full storage range, the storage that is not currently accessible could support minimum flow release of 1.2 m^3/s for an additional 23 days. This assumes zero net-inflow to the reservoir such that inflows balance the evaporation losses during the period.

Downstream Watershed Flows

It was necessary to determine the downstream watershed flows in order to determine the additional flows required from the lake to meet the POR flow requirements at the WSC gauge location. The downstream watershed flows were calculated by subtracting total outflows of the Arrowsmith Lake from the flows recorded at the WSC gauge. The outflows of the lake include the flows from the dam outlets and overflows from the ogee spillway. The ogee spillway flows were estimated based on the lake levels and the ogee spillway rating curve.

Net Inflows to the Arrowsmith Lake

Net inflows to the lake are the sum of runoff from the watershed plus direct rainfall on the lake and minus evaporation and seepage losses. Net inflows were calculated based on the water balance for the Arrowsmith Lake, as follows:

Qin = Qout + dV

Where, Qin = Daily lake inflow
Qout = Daily lake outflow = Daily Dam Outlet Flow + Daily Ogee Spillway Flow
dV = Daily Change to Lake Storage (Lake storage were calculated using the lake levels and the storage-elevation curve for the reservoir)

The available data sources were used to compile flow and water level data required for the hydrology assessment for three water years (November to October) including 2004 to 2005, 2006 to 2007 and 2008 to 2009.

Water Demand

An analysis of water demands for the AWS service areas was performed by Koers & Associates Engineering Ltd. (Koers). The results of Koers water demand analysis are summarized in the Discussion Pater 3-2 - Water Demands, dated October 8, 2009. Supplementary information regarding projected summer monthly demands was provided by Koers in the email from Koers to KWL dated April 29, 2010. The Koers' analysis results for monthly water demands are summarized in Tables 2 and 3 for 2015 and 2050, respectively.

Table 2
2015 Monthly Water Demand Summary

Maximum Day Demand	45,898 m^3/day or 0.531 m^3/s				
Max Day/Max Month Ratio	1.3				
Full Well Capacity	39000 m^3/day or 0.451 m^3/s				
Month	**% of Max Month**	**Demand**	**% of Full Well Capacity**	**Well withdraw**	**Required from the River**
		m^3/s		m^3/s	m^3/s
November	70%	0.29	80%	0.36	0.00
December	70%	0.29	80%	0.36	0.00
January	70%	0.29	80%	0.36	0.00
February	70%	0.29	80%	0.36	0.00
March	70%	0.29	80%	0.36	0.00
April	70%	0.29	80%	0.36	0.00
May	70%	0.29	80%	0.36	0.00
June	80%	0.33	80%	0.36	0.00
July	100%	0.41	100%	0.45	0.00
August	90%	0.37	80%	0.36	0.01
September	75%	0.31	80%	0.36	0.00
October	70%	0.29	80%	0.36	0.00

Table 3
2050 Monthly Water Demand Summary

Maximum Day Demand	87,329 m^3/day or 1.011 m^3/s				
Max Day/Max Month Ratio	1.3				
Full Well Capacity	39000 m^3/day or 0.451 m^3/s				
Month	**% of Max Month**	**Demand**	**% of Full Well Capacity**	**Well withdraw**	**Required from the River**
		m^3/s		m^3/s	m^3/s
November	70%	0.54	80%	0.36	0.18
December	70%	0.54	80%	0.36	0.18
January	70%	0.54	80%	0.36	0.18
February	70%	0.54	80%	0.36	0.18
March	70%	0.54	80%	0.36	0.18
April	70%	0.54	80%	0.36	0.18
May	70%	0.54	80%	0.36	0.18
June	80%	0.62	80%	0.36	0.26
July	100%	0.78	100%	0.45	0.33
August	90%	0.70	80%	0.36	0.34
September	75%	0.58	80%	0.36	0.22
October	70%	0.54	80%	0.36	0.18

The results indicate that under the 2015 water demand condition, water withdraw from wells would be marginally meet the total demand requirements. Only minor supplementary withdrawals would be required from the Englishman River and those would also only be required in August.

However, under the 2050 water demand condition, up to 0.34 m^3/s of supplementary demand withdrawals are required from the Englishman River. For this hydrology assessment, the 2050 water demand condition was used to assess storage and lake outlet discharge capacity deficits.

Low-flow Frequency Analysis

Low flow (drought year flow) frequency analysis was performed based on the WSC flow records for the water years. The results are summarized in Table 4.

Table 4
Mean Annual Runoff Frequency Analysis based on Water Years (1915-16 - 2008-09)

Return period	Annual Runoff	Mean Annual Discharge
(yrs)	(mm)	(m^3/s)
1	2344	24.08
2	1269	13.04
5	995.8	10.23
10	881.3	9.05
20	804	8.26
50	736.3	7.56
100	702.1	7.21
200	677.7	6.96
500	655.7	6.74

The annual runoff for three selected historical water years are 1182 mm, 1682 mm and 712 mm, for the 2004-2005, 2006-2007 and 2008-2009 water years. These years statistically correspond to 2.5-year, 1.5-year and 50-year return period drought conditions, respectively.

To assess the 10-year and 100-year return period drought conditions, lake inflows and downstream watershed flows were adjusted based on the ratios between the annual runoff of the recorded year and that for the design year.

In addition to total annual volume, the distribution of flow throughout the year is also critical in assessing storage under drought conditions. The impacts of the flow distribution was tested using the recorded flow patterns for the 2004-2005, 2006-2007 and 2008-2009 water years. The recorded daily flow values for the selected water years were adjusted by the ratio of the average recorded flow and the estimated average drought flows for the 1:10-year and the 1:100-year droughts. The water balance was tested using the adjusted drought hydrographs to compare the impacts of flow distribution. Based on this assessment, it was determined that the 2008-2009 water year flow pattern was the most conservative and was selected for the analysis.

High-flow Frequency Analysis

A flood flow frequency analysis was carried out using available peak annual discharge data for the Englishman River. Both daily and instantaneous data was analyzed. Annual average daily peak flow data is available for the period from 1915 and 1916 as well as 1979 to 2008 (32 years). Annual instantaneous peak flow data is available for the period from 1986 to 2008 with 1992 flow missing (22-years). Based on the analysis of the data, the estimated peak daily and instantaneous discharges are shown in Table 5.

Climate Change Impacts

The climate change impacts were assessed based on the results of KWL's RHAM model. This model uses gridded precipitation and temperature downscaled using the ClimateBC model (Wang et. al. 2006) to calculate runoff for each 1 km^2 grid cell in the watershed. The Climate BC Model uses both spatial interpolation (weighted inverse-distance Interpolation) and elevation versus climate relationships (lapse rates) to downscale climate data available at larger grid sizes. The current period (1971-2000) is based on a gridded dataset developed from historical recorded data PRISM (Daly et al. 2002) while future 2050s period (2041 to 2060 Normal Period) climate data is derived on output from the Canadian Global Circulation Model (CGCM2).

The runoff for each grid cell was calculated using a monthly water balance model based on the USGS Monthly Water Balance algorithm. The model accounts for evapotranspiration, snow accumulation and melt, soil moisture storage, and ground water storage. Figure 4 shows the model logic for the USGS Water Balance model. The parameters used in the model have been calibrated based on recorded monthly average discharges in the Englishman River.

Finally, the gridded monthly runoff data is routed through the watershed using GIS flow accumulation routines. This routine identifies all the grid points in the watershed that contribute to flow at points along the stream network using a hydrologically correct 1:50,000 digital elevation model (DEM). The results of the accumulation routine are then used to calculate monthly average discharge at each of the points along the stream network using the gridded runoff data.

Monthly watershed flows at the Arrowsmith Lake outlet location (representing the total inflow to the lake) and at the WSC gauge location were extracted from the RHAM model for the existing, 2050 with severe climate impact (A2 Scenario)[1] and 2050 with moderate climate impact conditions (B2 Scenario).

The output from the model indicates that in general fall and winter flows could increase while spring and summer flows could decrease (see Figure 5). The primary drivers of these forecast changes are:

1. More precipitation in fall and winter months leading to higher runoff;
2. Higher winter temperatures resulting in more precipitation falling as rain and will runoff immediately rather than being stored in the snowpack;
3. Reduced snowpack accumulation leading to reduced spring runoff with river flows falling earlier in the year; and
4. Reduced summer baseflows a result of increased temperatures and evaporation as well as reduced summer precipitation.

The forecast changes in river flow in the Englishman River are similar to other climate change impact assessments completed in the region.

The results of the RHAM model have been used to assess climate change impacts on storage requirements at Arrowsmith Lake. The mean monthly ratios of change from the current condition (1971 to 2000 Normal Period) to the 2050 climate impact conditions were used to adjust the daily existing lake inflows and the downstream watershed flows to create design flows with climate impacts. The same ratios were used to scale both the average conditions and drought conditions.

Storage Deficits and Discharge Shortfalls Determination

The following procedures were performed to determine storage deficits and discharge shortfalls:

- Determine the required daily lake outflows to supplement the downstream watershed flows in order to meet the desired conservation flows at the WSC gauge and if applicable also the additional water supply demands;
- Determine the required daily lake storage volumes to meet the desired flow releases using the lake water balance formula, assuming enough flows would be released;

[1] Scenarios refer to greenhouse gas emission scenarios developed by the International Panel on Climate Change (IPCC). They describe forecast increases in greenhouse gas emissions and concentrations based on assumptions regarding future geo-political conditions (global versus regional focus) and technological changes (fossil fuels versus alternative energy). Scenarios A2 and B2 generate moderate high emissions and moderately low emissions and are considered appropriate for climate change impact assessment.

- Determine whether the reservoir would have adequate capacity to support the desired released flow volume throughout the water year;
- Determine the corresponding daily lake levels at the required storage volumes using the reservoir storage-elevation curve;
- Determine the corresponding maximum dam outlet flows (with all valves fully open) at the lake levels and comparing these flows with the required flow releases to identify shortfall for the outlets to meet the required flows.

Three flow conditions in the Englishman River were assessed, including:

1. Minimum 1.2 m^3/s conservation flow plus current water supply demands
2. Minimum 1.2 m^3/s conservation flow plus additional withdrawal to meet the 2050 year water demand
3. Ideal 1.4 m^3/s conservation flow plus additional withdrawal to meet the 2050 year water demand

The inflow scenarios that were assessed for the three flow conditions include:

1. Recorded 2004 to 2005 water year flow condition
2. Recorded 2006 to 2007 water year flow condition
3. Recorded 2008 to 2009 water year flow condition
4. 10-year return period drought condition based on the 2008-2009 water year flow pattern
5. 100-year return period drought condition based on the 2008-2009 water year flow pattern
6. 10-year return period drought condition based on the 2008-2009 water year flow pattern, with the estimated severe impact of climate change to 2050
7. 10-year return period drought condition based on the 2008-2009 water year flow pattern, with the estimated moderate impact of climate change to 2050
8. 10-year return period drought condition based on the 2008-2009 water year flow pattern, with the estimated severe impact of climate change to 2050
9. 10-year return period drought condition based on the 2008-2009 water year flow pattern, with the estimated moderate impact of climate change to 2050

In order to run the analysis an initial water level and storage volume in the reservoir must be assumed. For the analysis using the recorded flows, the actual initial lake level at the beginning of the analysed water year was used. For the design drought conditions, we used a conservatoire assumption the storage would be fully depleted (lake level at zero storage) at the beginning the analysed water year.

5 Hydrology Assessment Results

Calculated storage deficits and number of days that the maximum flow releases from the Arrowsmith Dam outlet could not meet required releases for the above mentioned scenarios are summarized in Table 6.

Findings from the assessment can be summarized as follows:

To meet the 1.2 m^3/s minimum water conservation discharge requirement at the WSC gauge

This scenario represents the current condition where flow is released from dam to meet the discharge requirement at the WSC gauge with withdrawal of water occurring downstream of the intake and provides a review of current conditions. Under this scenario, the minimum conservation flow would only be maintained upstream of the intake while downstream of the intake the flow would be reduced by the water withdrawal. Therefore, this scenario can not be applied to any proposed intake locations upstream of the WSC gauge as flows at the gauge would be lower than the required minimum flows. The results indicate that:

1. The Arrowsmith Lake reservoir would have adequate storage for the three historical flow scenarios, the 10-year return period drought scenarios, the 100-year return period drought scenarios and the 10-year return period drought scenarios with severe and moderate climate impacts.

2. Under the above mentioned scenarios, the reservoir storage would have adequate storage to meet the desired release flows; however, the maximum flows that can be discharged from the lake (with the valves fully open) may not be great enough to meet the desired release rates at all times. Under three analyzed historical flow conditions and the 10-year return period without climate impact conditions, the dam outlet discharge would keep up with the required flows, but for the 10-year drought scenarios with the climate impacts and all the 100-year drought scenarios (both under existing climate and future climate), there would be days where flows would fall below desired minimum flow.

3. For 100-year return period drought scenarios with climate change impacts, both the lake storage and discharge capacity would not be adequate to meet the desired flow releases.

It is interesting to note that the model indicates that sufficient storage should have been available to support the 1.2 m^3/s conservation flow during the 2009-2009 even though in reality flows dropped below 1.2 m^3/s. It is likely that this is due to the fact that the model assumes that the reservoir is being operated perfectly and that flows are adjusted exactly to meet downstream flows with changing contributions from the downstream watershed. In reality, this is not possible as flows need to be adjusted in advance of increased inflows. Although flows are adjusted in advance using weather forecasts and past experience, accurately adjusting the flows to exactly meet the requirements would require more sophisticated forecasting and operation decision tools.

To meet the 1.2 m^3/s minimum water conservation discharge requirement at the WSC gauge plus the additional 2050 water supply demand

This scenario represents future condition with the intake moved upstream of the WSC gauge. Under this scenario, flows upstream of the intake would be the minimum conservation flow plus the water supply withdrawal while downstream of the intake the flow would be at the minimum conservation flow. Under this scenario the minimum conservation flow would be maintained throughout the river. The results indicate that:

1. The Arrowsmith Lake reservoir would have adequate storage under the 2004-2005 and 2006-2007 water year scenarios, the three 10-year return period drought scenarios and the 100-year return period drought scenario with the 2006-2007 flow pattern. However, except for the 2004-2005 and 2006-2007 water year scenarios (the return periods for flows in those years are about 1.5 and 2.5 years), all other scenarios would have outlet discharge capacity shortfalls.

2. Both storage deficits and outlet discharge shortfalls would be expected for all other scenarios including the 2008-2009 water year scenario (approximately 50-year drought return period), the 100-year drought return period scenarios with the 2004-2005 and the 2008-2009 flow patterns and the 10-year and 100-year drought scenarios with climate impacts.

To meet the 1.4 m^3/s ideal water conservation discharge requirement at the WSC gauge plus the additional 2050 water supply demand

This scenario is similar to that described above except that the minimum conservation flows are increased to 1.4 m^3/s. The results of this assessment indicate that:

1. The Arrowsmith Lake reservoir would have adequate storage for the 2004-2005 and 2006-2007 water year scenarios and the 10-year return period drought scenario with the 2006-2007 flow pattern. However, except only the 2004-2005 water year flow scenario (with the return periods of about 1.5 year), all other scenarios would have dam outlet discharge capacity shortfalls.

2. Both storage deficits and outlet discharge shortfalls would be expected for all other scenarios tested in order to meet the 1.4 m^3/s discharge plus the additional 2050 water supply demand.

6 Conclusions

Our watershed hydrological assessment results in the following conclusions:

1. With proper flow release procedures, the existing Arrowsmith Lake reservoir and its outlet structure would be adequate to meet the minimum conservation discharge flow of 1.2 m^3/s at the WSC gauge including water supply demand under the 10-year return period drought conditions.

2. The lake storage would be adequate to meet the minimum 1.2 m^3/s conservation discharge flow including water supply demand, but the outlet structure at the dam would not be adequate to release the desired flows at all times, under 10-year return period drought conditions with climate change impacts and the 100-year return period drought conditions without climate change impacts,.

3. The lake storage would be adequate to meet the minimum 1.2 m^3/s conservation flow plus the 2050 demand under the 10-year return period drought conditions, but the outlet structure at the dam would not be able to discharge the desired flows at all times.

4. Under the 10-year drought conditions with climate change impacts and under all 100-year drought conditions, both lake storage and discharge capacity would not be sufficient to meet the minimum 1.2 m^3/s conservation flow plus the 2050 demand.

5. The existing Arrowsmith Lake reservoir and outlet structure would not be adequate to meet the ideal conservation flow of 1.4 m^3/s at the WSC gauge plus the additional 2050 water demand under both the 10-year and 100-year drought conditions.

6. Increasing the storage capacity of the Arrowsmith reservoir would not reduce the storage deficit as the inflows collected by the lake would not be sufficient to fill up the existing lake storage in extreme drought years.

7 Recommendations

Based on the results of the hydrological assessment outlined above, we recommend that:

1. A detailed field assessment of low flow impacts on fish habitat be completed (such as the weighted area method) to confirm required minimum conservation flows based actual field conditions and provincial guidelines;

2. Flow and level sensors at Arrowmsith Lake reservoir be checked and calibrated if required.

3. A detailed hydraulic assessment of the high-level outlet and low-level siphon at the Arrowsmith Lake Reservoir be completed to identify and review options to improve hydraulic capacity of the outlet such that flow released can be maintained at 1.2 m^3/s to the zero storage level.

4. A review of climate monitoring options be completed in the Arrowsmith Lake watershed to identify climate monitoring options to assist with operational decisions and forecasting.

5. A forecasting and operational model of the Arrowsmith Lake reservoir and Englishman River watershed should be developed to assist with operational decisions during the release period to optimize available storage.

6. A review of availability of alternative storage (ground water and surface water) options should be completed to assess storage requirements to support future 2050 demands and conservation flows under forecast future climate conditions.

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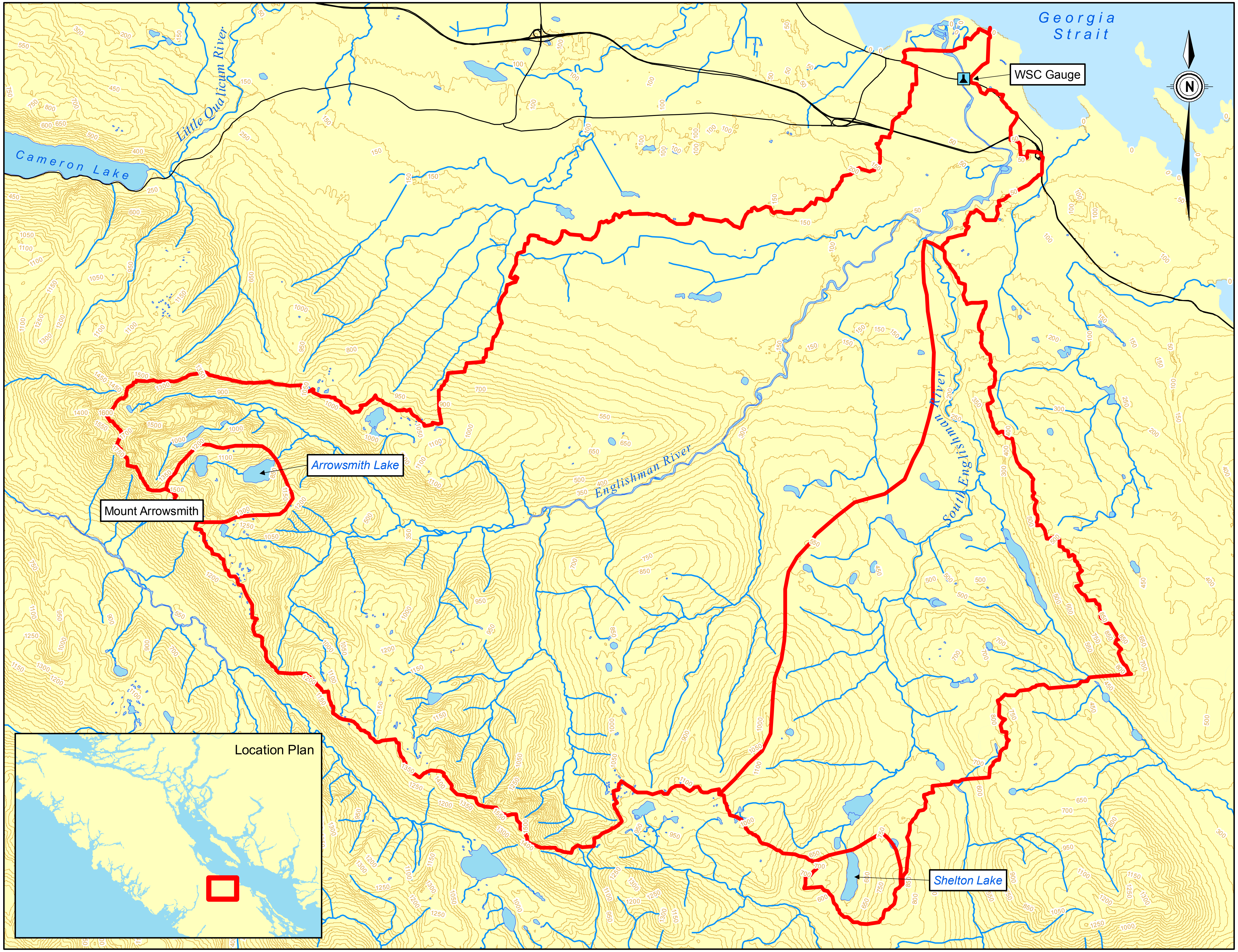
Englishman River Intake



Legend

- WSC Gauge (Active)
- Englishman River Basin
- Major Road
- Water Body (WSA)
- Stream Line (WSA)
- 50m Contour

KERR WOOD LEIDAL associates limited CONSULTING ENGINEERS

2.5 1.25 0 2.5
Km
Scale 1:100,000

Project No.	Date
2248-005	June 2010

Watershed Map

Figure 1

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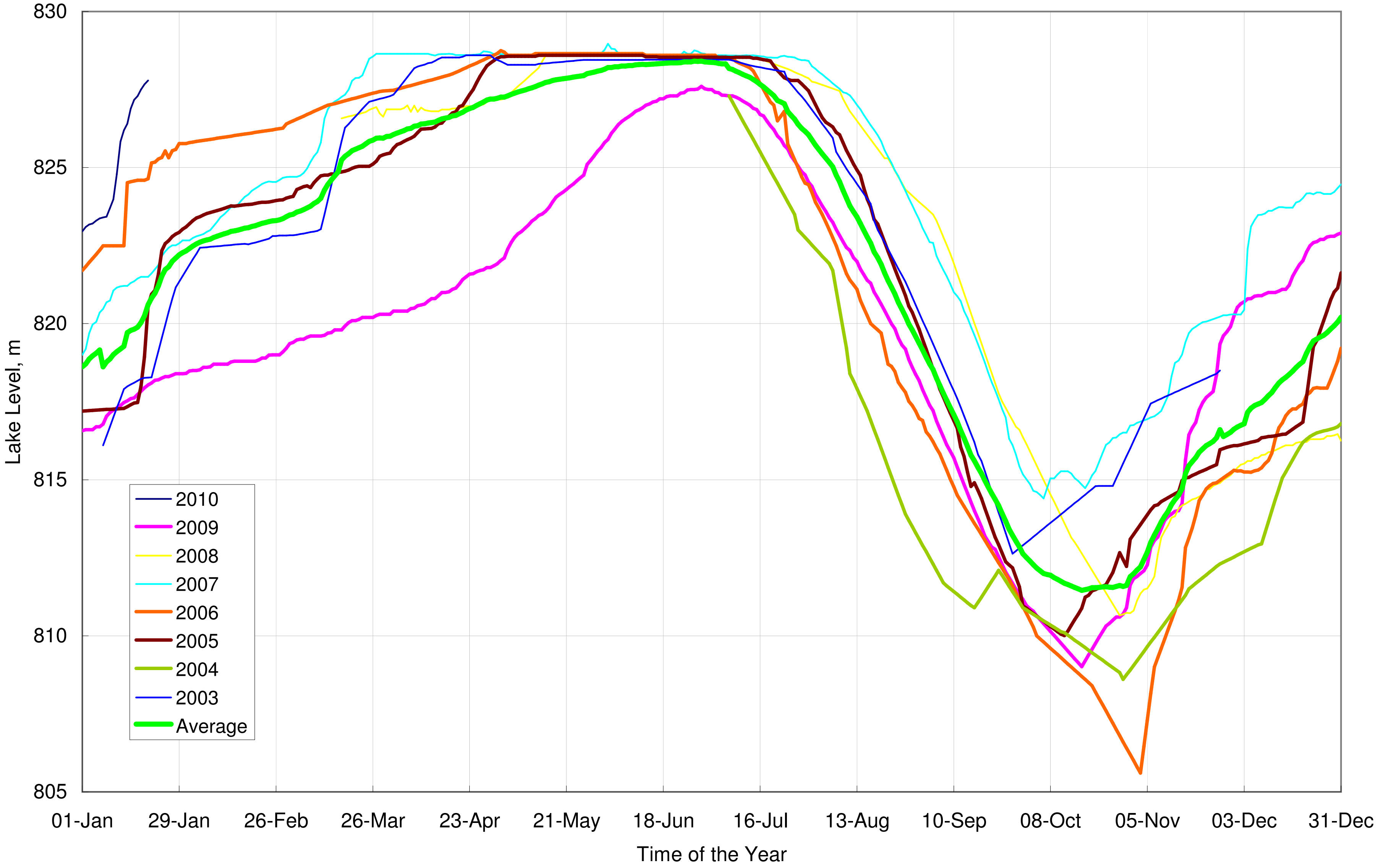

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FIGURE 2
Recorded Historical Arrowsmith Lake Levels

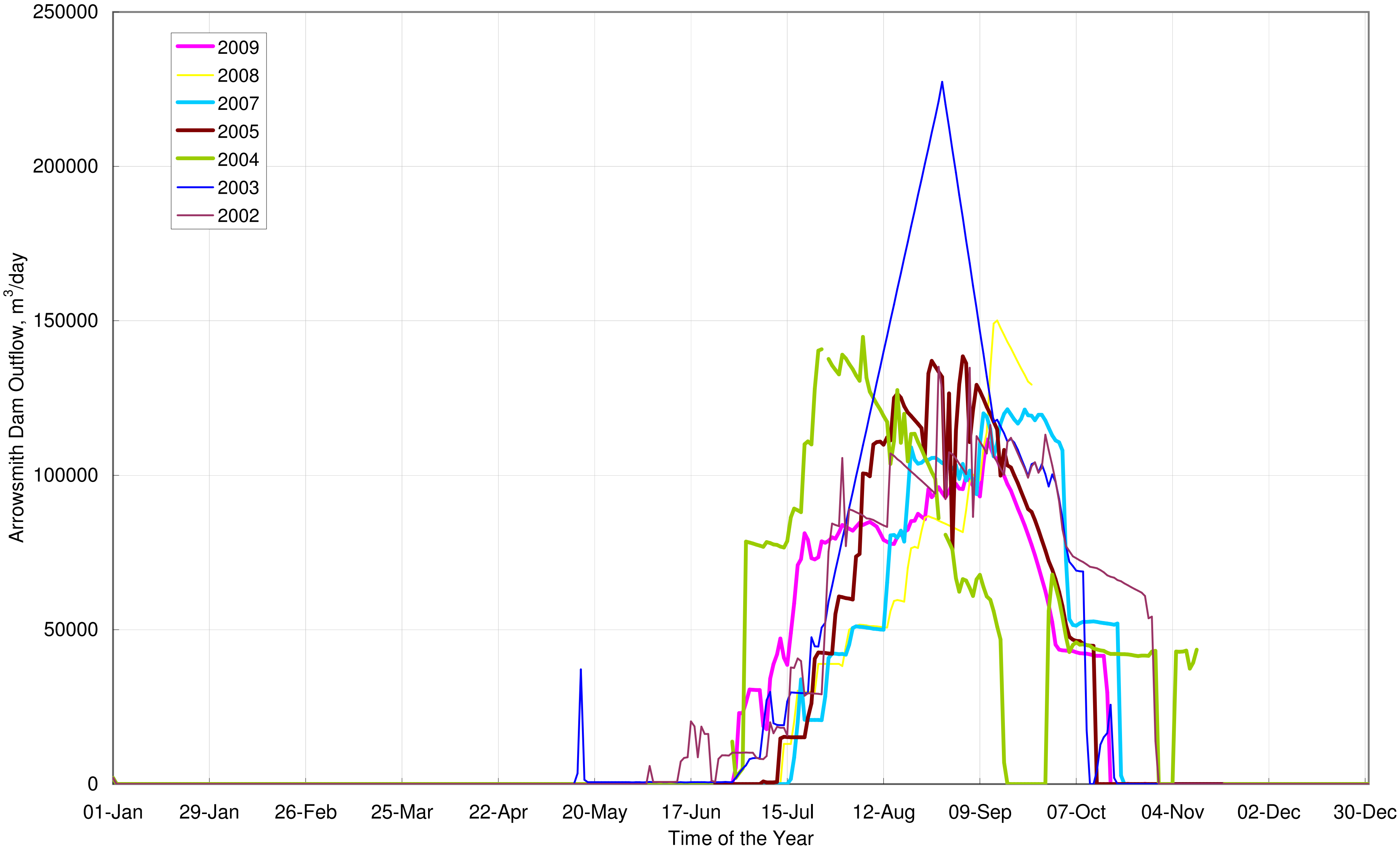

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FIGURE 3
Arrowsmith Dam Outlet Flows

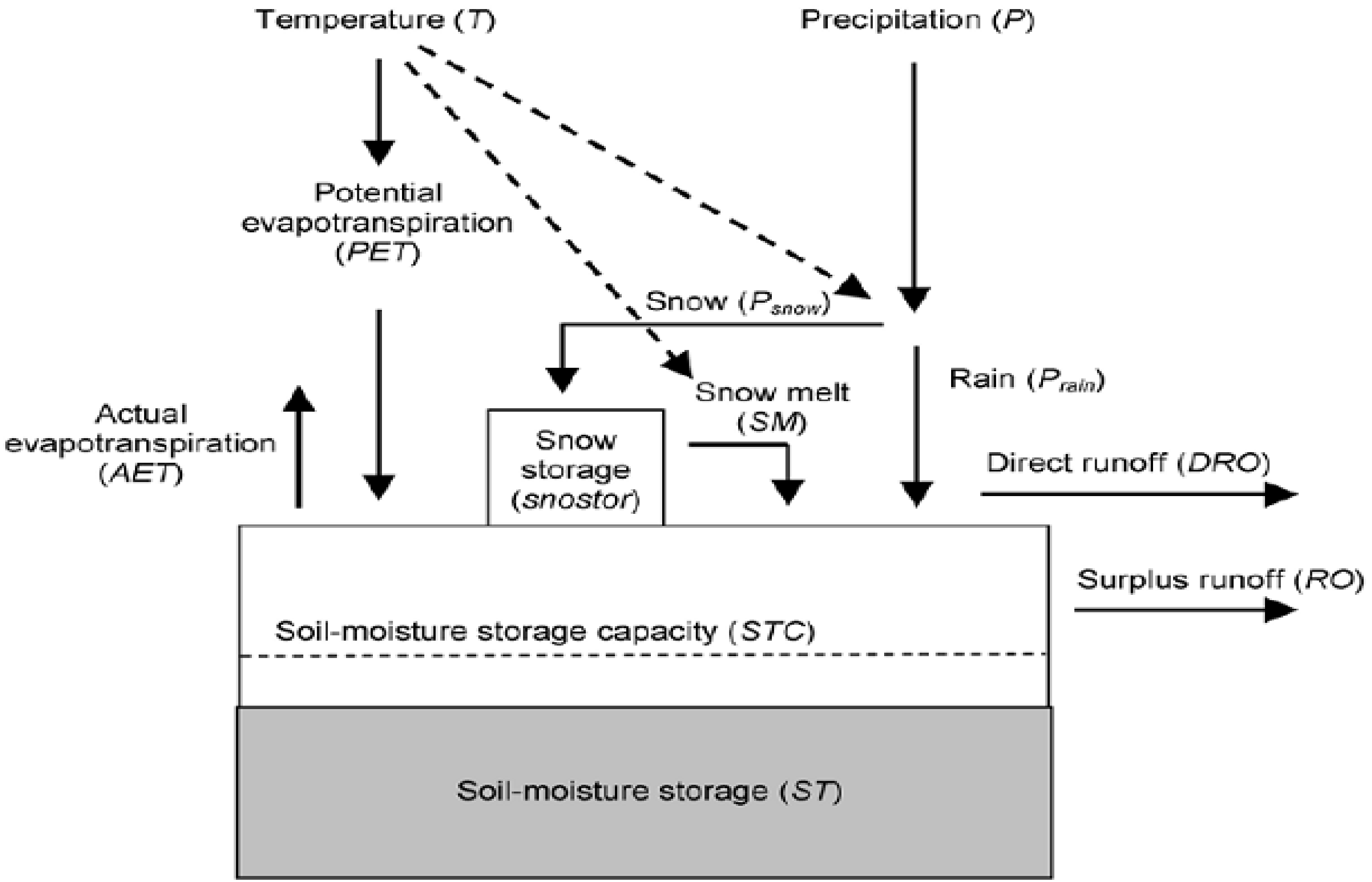

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FIGURE 4
USGS Monthly Water Balance Model

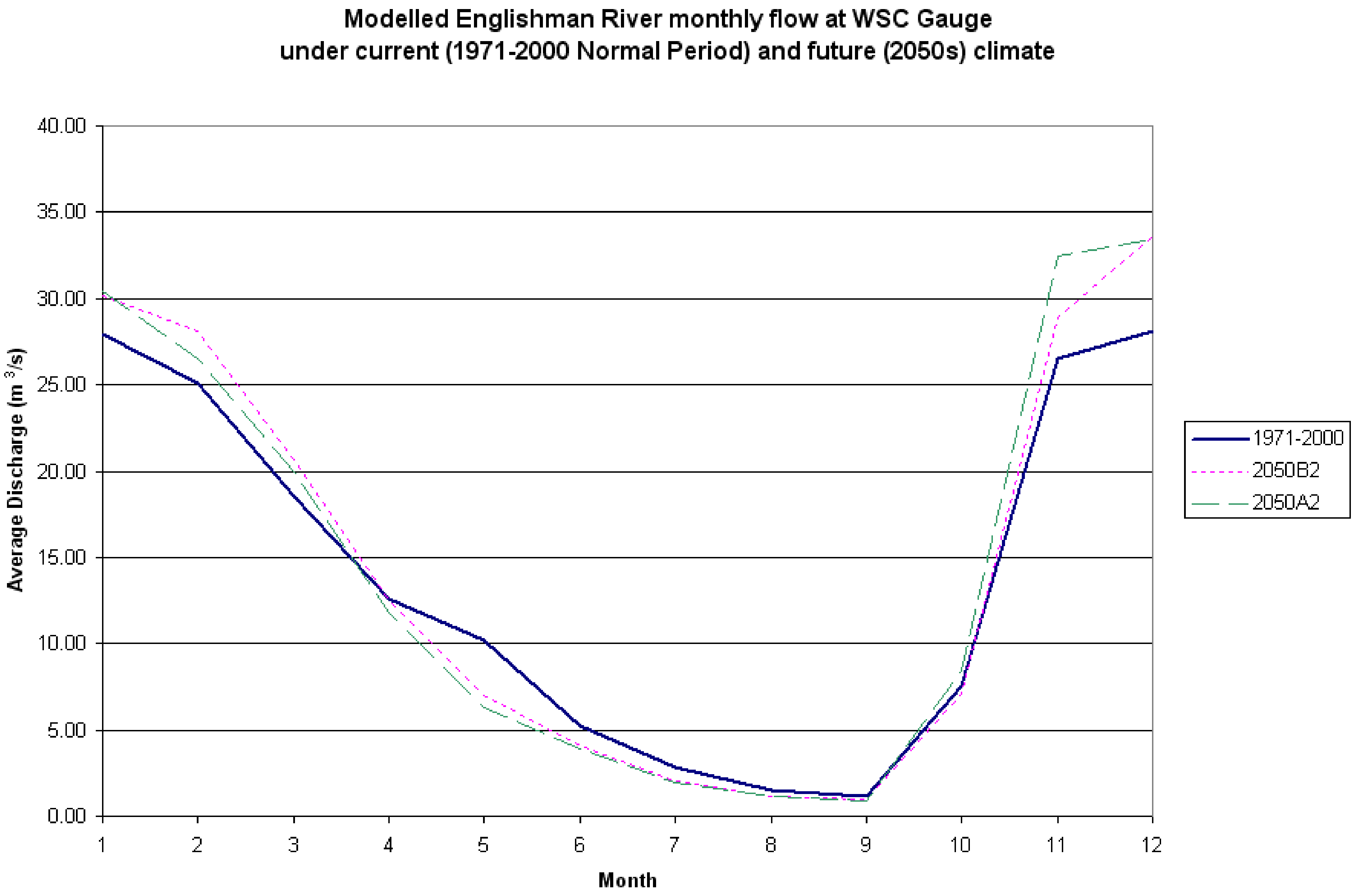

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FIGURE 5

Table 5:English River Peak Flows

Return Period (yr)	Peak Instantaneous Flow (m^3/s)	Maximum Daily Average (m^3/s)
10	441	276
100	589	368
200	625	391

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Table 6: Englishman River Hydrology Assessment Results Summary

	Storage Deficit in m^3			Number of Days Max. Lake Outflow is less than the desired flow		
	To meet Min. 1.2 cms Conservation flow including Demand	To meet Min. 1.2 cms Conservation flow + 2050 Demand	To meet Ideal 1.4 cms Conservation flow + 2050 Demand	To meet Min. 1.2 cms Conservation flow including Demand	To meet Min. 1.2 cms Conservation flow + 2050 Demand	To meet Ideal 1.4 cms Conservation flow + 2050 Demand
2004-2005 Water Year Flow Condition	0	0	0	0	0	2
2006-2007 Water Year Flow Condition	0	0	0	0	0	0
2008-2009 Water Year Flow Condition	0	105,386	2,057,429	0	36	68
10-year Return Period Flow Using the 2004-2005 Water Year Flow Pattern	0	0	91,965	0	8	30
10-year Return Period Flow Using the 2006-2007 Water Year Flow Pattern	0	0	0	0	1	9
10-year Return Period Flow Using the 2008-2009 Water Year Flow Pattern	0	0	1,204,084	0	22	63
100-year Return Period Flow Using the 2004-2005 Water Year Flow Pattern	0	1,942,351	3,795,257	18	72	81
100-year Return Period Flow Using the 2006-2007 Water Year Flow Pattern	0	0	1,101,071	0	16	59
100-year Return Period Flow Using the 2008-2009 Water Year Flow Pattern	0	2,510,014	4,465,962	33	77	87
10-year Return Period Flow Using the 2008-2009 Water Year Flow Pattern With Climate Change Impact (Severe)	0	1,513,708	3,473,874	14	68	79
10-year Return Period Flow Using the 2008-2009 Water Year Flow Pattern With Climate Change Impact (Moderate)	0	1,338,093	3,291,040	12	65	77
100-year Return Period Flow Using the 2008-2009 Water Year Flow Pattern With Climate Change Impact (Severe)	1,682,954	4,431,777	6,470,542	72	92	98
100-year Return Period Flow Using the 2008-2009 Water Year Flow Pattern With Climate Change Impact (Moderate)	1,532,346	4,285,649	6,306,732	69	90	97

Note: 2050 Demand Required from the River up to 0.34 m^3/s