Appendix D
TM #2B – Arrowsmith Lake Reservoir Water Supply

TM #2B – Arrowsmith Lake Reservoir Water Supply (FINAL)

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Introduction

The following technical memorandum (TM #2B) forms part of the technical deliverables for the design of the water supply intake for the proposed Englishman River Water Intake and Treatment Plant Project. The purpose of the memo is to outline the analysis carried out to assess capacity of the existing Arrowsmith Lake Reservoir to support recommended minimum downstream conservation flows in the Englishman River. The memo includes:

1. A brief overview of the Englishman River watershed and Arrowmsith Lake Reservoir
2. An outline of the water balance carried out for the Englishman River
3. Development of proposed operational Reservoir Rule Curves to support downstream flows

This memo follows from the Intake Hydrology and Hydraulics Technical Memorandum (TM#2A) dated Oct 7, 2013.

Background

The Englishman River is located on the east coast of Vancouver Island near the City of Parksville,BC. The watershed has a total area of 324 km^2 and rises from sea level at the estuary on Georgia Strait up to El. 1820 at Mount Arrowsmith. The main stem of the river is approximately 40 km long. Several small lakes are located within the watershed including Arrowsmith Lake, Hidden Lake, Fishtail Lake, Rowbotham Lake, Healy Lake, Shelton Lake, and Rhododendron Lake. Land use in the watershed is predominantly private forest land managed by Island Timberlands and Timberwest, with rural agricultural and suburban development in at lower elevations. Soils within the watershed range from thin soils over bedrock on steeper mountain slopes in the headwaters of the watershed to thicker fluvio-glacial sediments where the river crosses the Nanaimo lowlands.

Arrowsmith Lake is located in the headwaters of the Englishman River on the east facing slopes of Mount Arrowsmith about 25 km upstream of the mouth of the Englishman River. The lake has a surface area of about 0.3 km^2 and a watershed area about 5 km^2. A map of the watershed and the location of Arrowsmith Lake is shown in Figure 1.

The Arrowsmith Water Service (AWS) have been granted a water licence to store up to 9.0 million cubic meters at Arrowsmith Lake to support municipal water demand and to maintain conservation flows to support fish habitat in the Englishman River through the dry summer period (typically from June to October). Approximately 50% of the total volume is provided to maintain conservation flows in the Englishman River. The water licence for the water supply (C129710), dated January 17, 2013, supersedes licence C110050 dated March 4, 1997. The updated licence includes a Provisional Operating Order which requires that between June 1 and October 31 a flow of 1.6 m^3/s be maintained at the Water Survey of Canada Englishman River near Parksville Gauge (08HB002), which is located on the Highway 19A Bridge, downstream of the proposed water intake site. The purpose of the order is to maintain the required minimum flow release of 1.13 m^3/s below the current intake.

The concrete dam at Arrowsmith Lake was constructed in 1997 /1998 and it was formerly commissioned in September 2000. The dam is a concrete gravity structure with a free overflow spillway and two low level outlets. The

upper outlet is a 900 mm diameter pipe while the lower outlet is 600 mm diameter pipe which acts as a syphon when water levels fall below the upper outlet. Figure 2 shows the Arrowsmith Lake storage-elevation curve and the low level outlet discharge rating curves.

It should be noted that a flow of 1.6 m^3/s can only be released from the dam when lake levels are above an elevation of about 813.5 m GSC. At elevation 813.5 m GSC, the available storage volume is approximately 65% of the total storage of 9 million m^3. Therefore, in order to access the lower 35% of the total storage volume, the lease rate from the Arrowsmith Lake would be lower than 1.6 m^3/s. During initial design of the dam, preferred minimum flow of 1.13 m^3/s and an absolute minimum flow of 0.71 m^3/s in the Englishman River were used as the design criteria for flow releases from the dam. The dam was also designed to support these flows up to the 15-year return period drought condition. Therefore, the capacity of the low level outlet restricts the ability to maintain flows higher than those intended in the original dam design.

As indicated previously, Arrowsmith Lake has a relatively small watershed area of only 5 km^2, about 1.5% of the total Englishman River watershed. The annual runoff from the Arrowsmith Lake watershed is estimated to range from 8.2 Million m^3 to 24.9 million m^3 with an average of 14.6 million m^3 over the period from 2003 to 2013. Therefore, the reservoir can capture up to about 60% of the average annual runoff. Given the relatively large storage capacity in relation to the available watershed runoff, there are years where the dam cannot be refilled to its full supply level. The reservoir is supply limited such that increasing storage at the reservoir would not improve the reliability of supporting minimum flow of up to 1.6 m^3/s in the river during drought years. For that reason, the only viable option is to optimize use of the existing storage through development of an updated rule curve for the dam to support municipal water demands and conservation flows.

Englishman River Water Balance Assessment

Assessment of the capacity of the Arrowsmith Reservoir to support minimum conservation flows and municipal water supply demands requires completing a water balance of the watershed. The water balance involves comparing the required river flows with available water supply from the watershed. The required river flows include withdrawals from the river for the needs of the municipal water supply demands as well as to maintain conservation flows in the river downstream of the intake. The downstream conservation flow requirements and design municipal demands as well as the various supply/demand scenarios will be outlined in the following sections.

Natural Englishman River Supply

Water supply from the watershed has been estimated using available Englishman River discharge data, Arrowsmith lake water level records and Arrowsmith lake discharge records for the period from 2003 to 2013. In addition, discharge records for Englishman River at Parksville (WSC 08HB002) prior to construction of the dam in 1999 have also been included in the analysis. A summary of the data used in the analysis is included in Table 1.

Table 1: Hydrometric Data used in the Analysis

ID	Name	Source[1]	Period of Record	Watershed Area (km^2)
WSC 08HB002	Englishaman River near Parksville	WSC	1913 to 2013[2]	319
-	Arrowsmith Lake Reservoir Flow Release – Low Level Outlet Flow	AWS/ERWS	2003-2013	5
-	Arrowmsith Lake Reservoir Lake Levels	AWS/ERWS	2003-2013	N/A

Notes:
1- Data Sources WSC – Water Survey of Canada, AWS/ERWS – Arrowsmith Water Service/Englishman River Water Service
2- Englishman River near Parksville gauge has been regulated since 1999 by Arrowsmith Lake reservoir

The purpose of the analysis of the historical data is to develop a nearly continuous record of naturalized flow records. This synthetic data series removes the influence of past operation of the dam in the historical record and thus allows alternative scenarios for operation of the dam to be tested. The naturalized Englishman River discharge record has been calculated by:

1. Subtracting the recorded flow releases from Arrowsmith Lake Reservoir from the recorded discharges at Englishman River near Parksville Gauge;
2. Calculating inflow from the Arrowsmith Lake watershed to the Arrowsmith Lake reservoir using recorded lake levels, recorded flow releases, lake level versus storage relationship and lake level vs discharge relationships for the spillway;
3. Adding the calculated inflow to Arrowsmith Lake (Step 2) to the modified Englishman River record (Step 1) to estimate the naturalized Englishman River flows without influence of the Arrowsmith Lake dam.

The naturalized Englishman River flows have been calculated for the period from 2003 to 2013, the data recorded after the dam construction. The data has then been combined with the Englishman river discharge record prior to construction of the dam (prior to 1999) to form a nearly continuous record from 1979 to 2013. The data set has then been used to calculate the 1:2-year (average), 1:5-year (dry), 1:10-year and 1:20-year (extreme dry) drought condition flows for each month and each week from June to October for reservoir storage deficit assessment and rule curve development in this analysis.

Municipal Water Supply Demands

The municipal water supply demands used in the analysis have been developed based on water demand estimates carried out by Kerr Wood Leidal Associates Ltd which are summarized in Technical Memorandum #4A dated January 27, 2014. The river withdrawals at the treatment plant intake is calculated to be the additional demand required beyond that which can be supported by the City of Parksville groundwater wells. Three demand scenarios have been tested:

1. Above Average Flow Conditions

   The analysis carried out for average conditions is based on supporting the phase 1 installed capacity at the pump station of 24 ML/day. This provides an estimate of peak withdrawal conditions for the near term (estimated to be prior to year 2035)

2. Average and Dry Year (2-year return period and 5-year return period drought) Flow Conditions
   The analysis carried out for average and dry year conditions is based on supporting forecast municipal water demands for 2018. This provides an estimate of typical demand conditions for the near term.

3. Extreme Dry Year (20-year return period drought) Flow Conditions
   The analysis carried out for extreme dry conditions and assumes stage 4 watering restrictions have been implemented (no outdoor water use). The peak demand under water restriction has been estimated based on data collected from the Capital Regional District during stage 4 watering restrictions in 2001 which indicated that peak demand is approximately 1.4 times average demand.

The municipal water demands used in the analysis are outlined in Table 2.

Table 2: Municipal Water Demands (River Withdrawal) at Proposed Englishman River Intake

Scenario	Water Demand Description	Maximum Average Monthly Demand	
		ML/Day	m^3/s
Average (2-year Return Period) Year	Maximum Installed Capacity[1]	24	0.278
Dry (5-year Return Period) Year	2018 Water Demand Forecast[2]	18.9	0.218
Very Dry (20-year return period) Year	2018 Water Demand Forecast[3] (Stage 4 Water Restrictions)	13.7	0.159

Note:
1 - Maximum Installed Pump Capacity (accounting for one pump out of service)for Phase 1 development (planned until 2035)
2 – Forecast 2018 water demand forecast based on population forecasts (assumes entire demand supplied by river intake. No groundwater supply)
(KWL, 2014)
3 – Forecast 2018 water demands using peaking factor of 1.4 based on analysis of Stage 4 (no outdoor water use) conditions in Capital Regional District in 2001. (Assumes entire demand supplied by river intake. No ground water supply)

Minimum flow required for treatment process is 4 ML/Day (0.0463 m^3/s)
Maximum water licence withdrawal is 48 ML/day.

Downstream Conservation Flows

The downstream conservation flows, which are the river discharge to be maintained in the river downstream of the intake, have been selected based on low flow aquatic habitat assessment carried out by LGL Ltd, outlined in the report dated April 22, 2014. The flows were determined using RHYHABSim habitat simulation modelling to assess weighted useable area at various discharges for fish species present in the Englishman River. The downstream conservation flows used in the assessment are outlined in Table 3.

Table 3: Downstream Conservation Flows

Scenario	Downstream Conservation Flow
Above Average Year	1.6 m^3/s
Below Average Year (2-year Return Period to 5-year Return Period Drought) r	1.4 m^3/s
Dry Year (5-year Return Period to 20-year Return Period Drought)	1.2 m^3/s
Very Dry (greater than 20-year return period drought)	0.9 m^3/s
Current conservation flow downstream of existing intake is 1.13 m^3/s	

Available Storage Analysis Using the Monthly Data

The monthly drought flows have then been used to compare demands with available natural water supply. When available supply is greater than demand, no storage is required, but when demand is greater than available supply then a storage deficit is calculated. This comparison has been completed on a monthly basis and the total annual storage deficit has been calculated for each drought/demand scenario. The total storage deficit is compared with the storage available in the reservoir and if the storage deficit is greater than available storage then the existing dam is considered to be unable to support that

An analysis has been carried out to assess the ability of Arrowsmith Lake to support combinations of the river conservation flows and required withdrawals under various drought/demand scenarios. When available supply is greater than demand, no storage is required, but when demand is greater than available supply then a storage deficit is calculated for each month. The total annual storage deficit has been calculated by combined the storage deficit volumes of each month. The total annual storage deficit is then compared with the storage available in the reservoir. If the storage deficit is greater than available storage then the existing dam is considered to be unable to support the required demands.

The analysis indicates that Arrowsmith Reservoir can support both downstream conservation flows and maximum water licence withdrawals (48 ML/day) under average conditions. However, downstream conservations flows would have to be reduced under drought conditions. The results are shown in Table 4.

Table 4: Monthly Water Balance Results

Flow Conditions	Target Flow at Hwy 19 (m^3/s)	
	24 ML/day	48 ML/day
1 in 2 yr Drought	1.6	1.6
1 in 5 yr Drought	1.2	0.9
1 in 20 yr Drought	0.9	<0.9

A summary of the monthly water balance for Englishman River is included in Appendix A.

Updated Arrowsmith Lake Rule Curve

A rule curve is a tool which provides guidance to reservoir operator for metering storage during the dry summer draw down period. A rule curve consists of a series of water levels at specified dates during the drawdown period. It indicates if there is sufficient storage to maintain minimum downstream flows and municipal demands, if lake levels are above the curve then there is sufficient storage to maintain flow even if there is no additional inflow to the reservoir.

A series of rule curves have been developed for the Arrowsmith Lake Reservoir to provide guidance on when flows should be considered to be adjusted depending on lake levels in relation to the curves. Curves have been plotted based on the following

1. Supporting Maximum Installed Capacity water demands under above average inflow conditions
2. Supporting 2018 water demands under 2-year return period drought conditions
3. Supporting 2018 water demands under 5-year return period drought conditions
4. Supporting Stage 4 water conservation (no outdoor water use) demands under 20-year drought conditions

The curves are plotted in Figure 3 with historical recorded water levels.

The zones between the curves indicate the target flows that should be maintained below the proposed intake. Flows should be adjusted in accordance with which zone water levels fall during the draw down period. If water levels in the reservoir change zones, then consideration to changing flows to flows required for that zone should be given. However, other operational considerations such as snowpack accumulation estimates, and weather forecasts should also be used to assist with the decision to change downstream flows.

Climate Change

The rule curves presented in this document reflect current climate and short term demand forecast conditions (2018 forecast). Given the uncertainty of climate change projections and water demand forecasts, an adaptive approach is recommended such that the curves be adjusted over time based on operational experience rather than forecasts. The curves should be reviewed every 10 years or as necessary.

Summary

The water balance assessment carried out for the Arrowsmith Lake Reservoir has indicated that the reservoir is capable of maintaining minimum conservation flow of 1.6 m^3/s given a withdrawal equal to the maximum installed intake capacity of 24 ML/day under above average flow conditions. However, downstream flows would have to be reduced to 1.4 m^3/s for 2-year return period up to 5-year return period drought conditions, 1.2 m^3/s up to 20-year return period drought conditions and 0.9 m^3/s under greater than 20-year return period drought conditions. This is similar to the original design criteria of meeting 0.9 m^3/s under 15-year return period drought conditions for larger water supply demands.

It is recommended that the rule curves presented in this technical memorandum form the basis for an updated operating protocol to be issued for Water Licence C129710 by the Ministry of Forest Lands and Natural Resource Operations.

Submission

If you have any questions regarding the hydrological or river hydraulic analysis carried out for the Englishman River Intake design, please contact the undersigned at (250) 595-4223.

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Wendy Yao, P.Eng.
Technical Review

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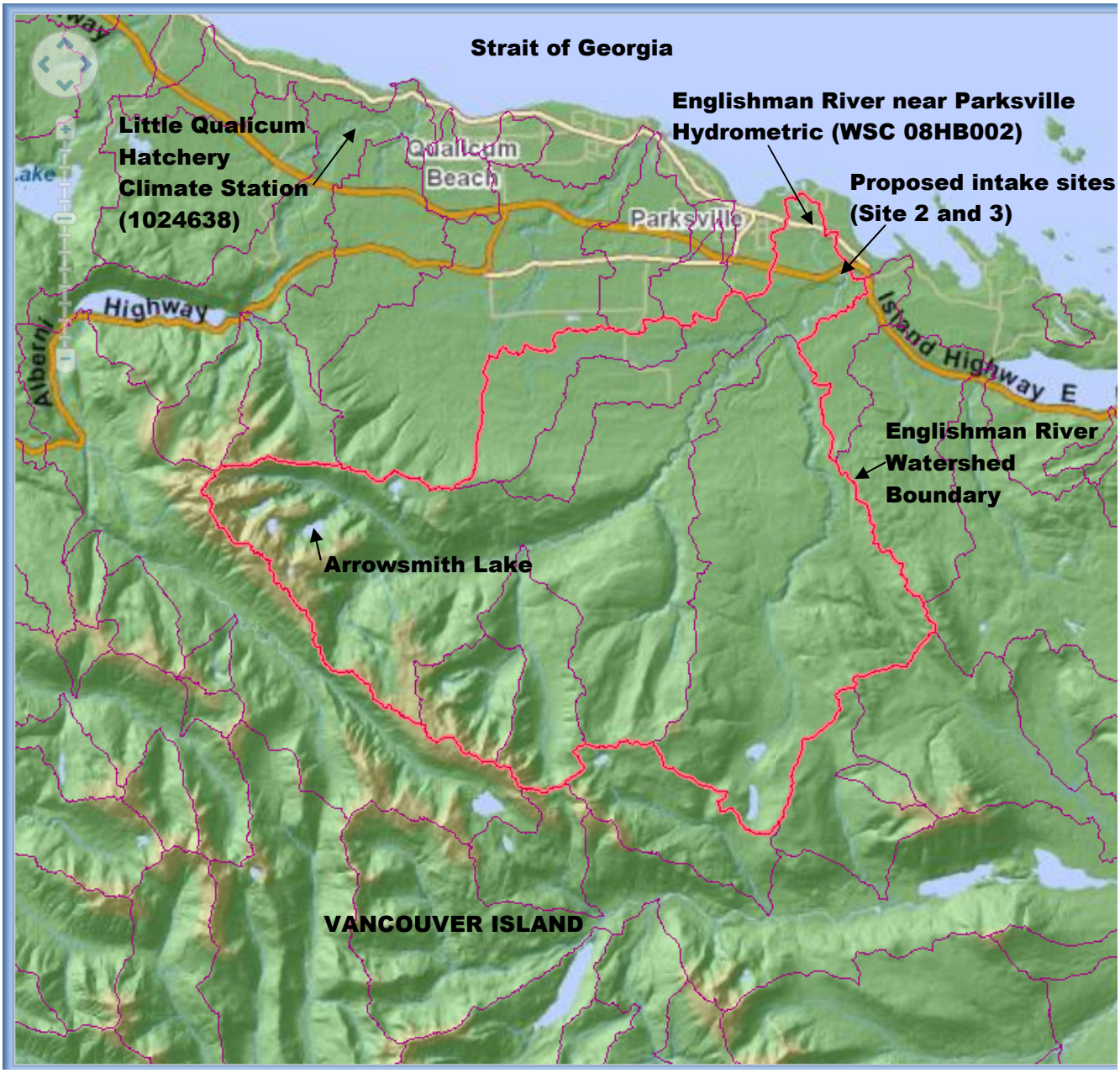
Revision History

Revision #	Date	Status	Revision	Author
0	June 2, 2014	FINAL	Revised as per comments	CS
A	April 30, 2014	DRAFT	Issued for review	CS



Scale: 1:150,000 Source: iMapBC

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Englishman River Water Service

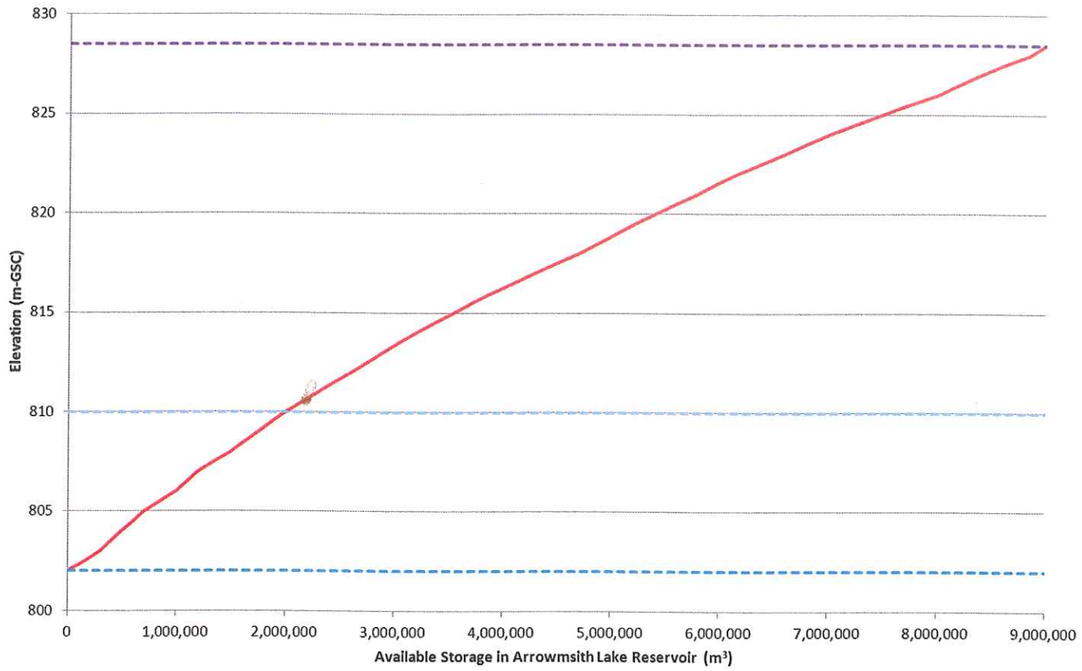
Project No.	Date
0468.010	June 2014

Englishman River Water Intake/Treatment Plant

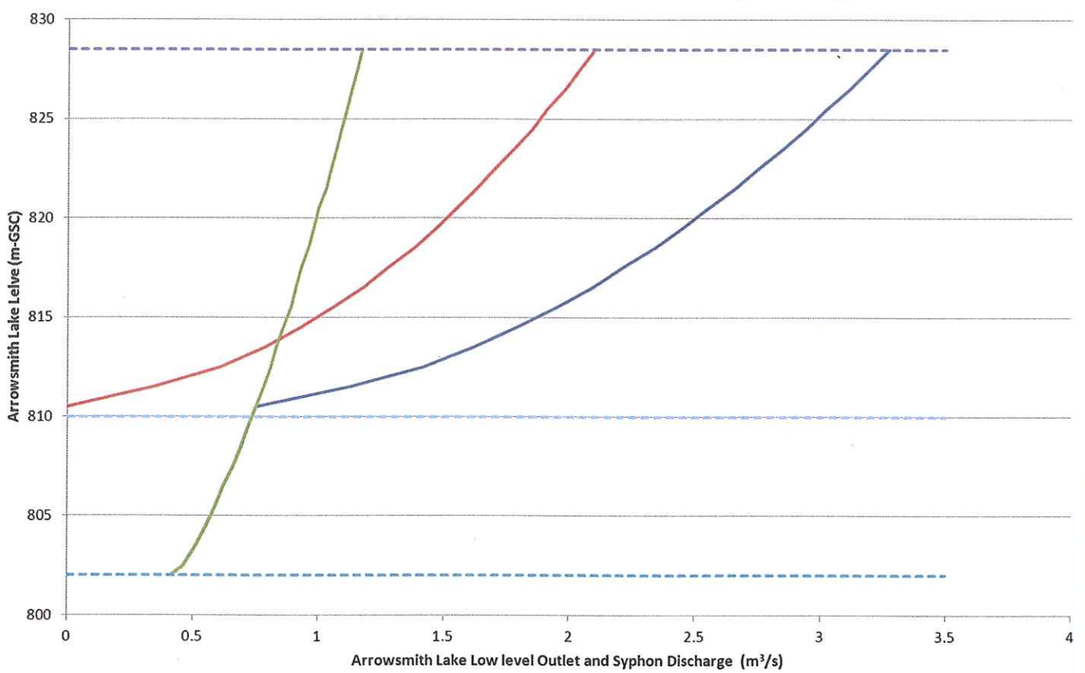
Englishman River Watershed Map

Figure 1

Arrowsmith Lake Reservoir - Storage-Elevation



Arrowsmith Lake Dam - Low Level Outlet Discharge Rating Curves



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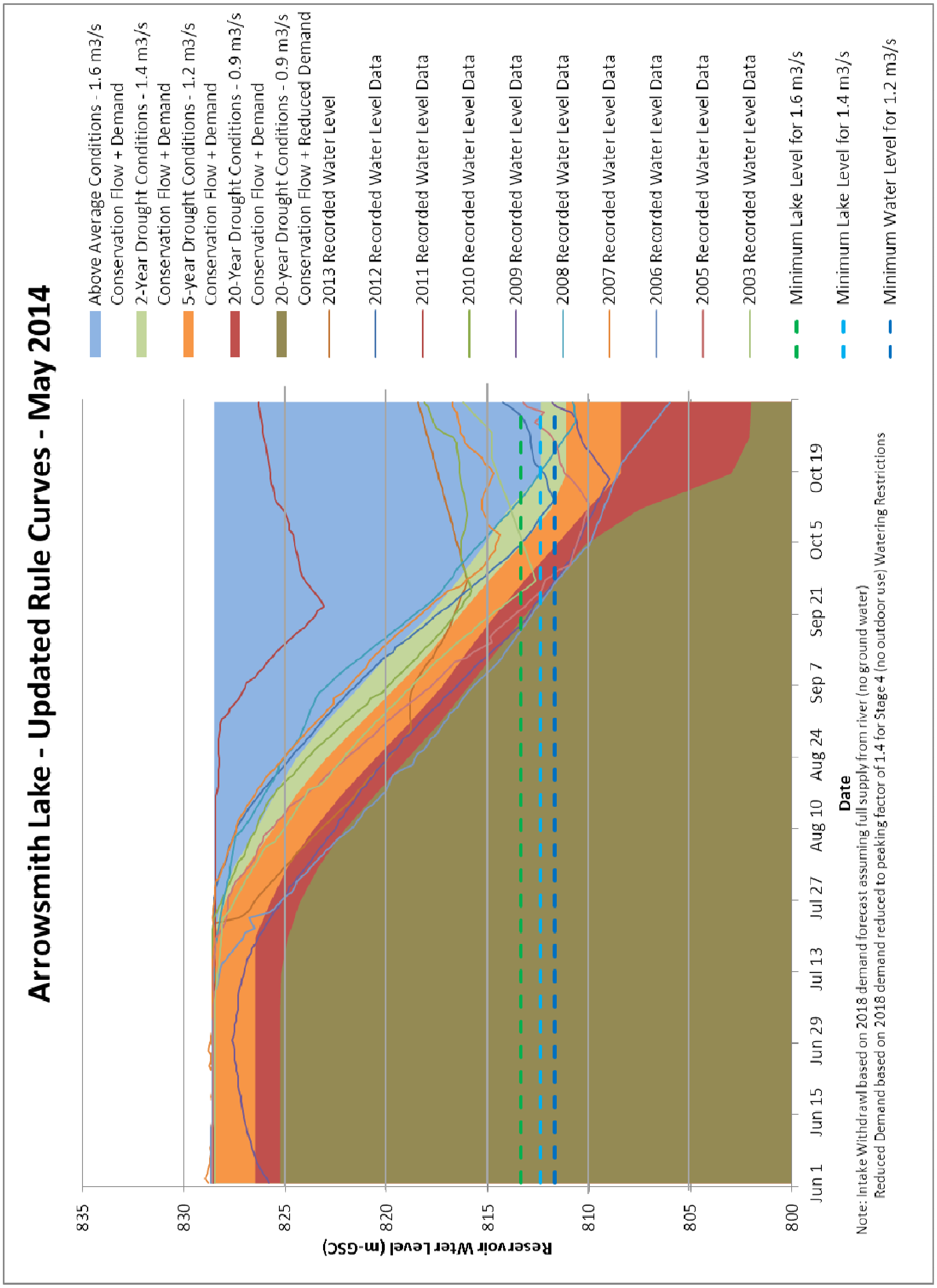
Arrowmsith Lake Reservoir Storge Elevation and Low Level Outlet Rating Curves

Figure 2



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Englishman River Water Service

Project No.	Date
0468.010	June 2014

Englishman River Water Intake/Treatment Plant
Arrowmsith Lake Reservoir – Rule Curve
Figure 3

Appendix A - Englishman River Monthly Water Balance and Storage Assessment

Arrowsmith Lake Storage Check - 1:2-Year Return Period Drought Condition

	Required Englishman River Flow, cms						Required Discharge from Arrowsmith Lake - Lake Inflow, cms						Requried Storage m^3	Minimum Lake level to Discharge Desired Flow, m	Available Live Storage, m^3	Storage Shortage, m^3
	Jun	Jul	Aug	Sep	Oct	Nov	Jun	Jul	Aug	Sep	Oct	Nov				
Ph1 + Conservation Flow of 0.9 cms	1.12	1.18	1.16	1.11	1.06	1.02	0.00	0.00	0.23	0.11	0.00	0.00	908,438	802.00	9,000,000	-
Ph1 + Conservation Flow of 1.2 cms	1.42	1.48	1.46	1.41	1.36	1.32	0.00	0.00	0.53	0.41	0.00	0.00	2,489,558	804.11	8,478,333	-
Ph1 + Conservation Flow of 1.4 cms	1.62	1.68	1.66	1.61	1.56	1.52	0.00	0.00	0.73	0.61	0.00	0.00	3,543,638	809.98	7,005,556	-
Ph1 + Conservation Flow of 1.6 cms	1.82	1.88	1.86	1.81	1.76	1.72	0.00	0.00	0.93	0.81	0.00	0.00	4,597,718	810.99	6,704,474	-
Ph2 + Conservation Flow of 0.9 cms	1.34	1.46	1.42	1.32	1.22	1.14	0.00	0.00	0.49	0.32	0.00	0.00	2,140,358	803.15	8,669,333	-
Ph2 + Conservation Flow of 1.2 cms	1.64	1.76	1.72	1.62	1.52	1.44	0.00	0.00	0.79	0.62	0.00	0.00	3,721,478	810.61	6,816,316	-
Ph2 + Conservation Flow of 1.4 cms	1.84	1.96	1.92	1.82	1.72	1.64	0.00	0.00	0.99	0.82	0.00	0.00	4,775,558	811.14	6,658,421	-
Ph2 + Conservation Flow of 1.6 cms	2.04	2.16	2.12	2.02	1.92	1.84	0.00	0.06	1.19	1.02	0.00	0.00	5,978,438	811.72	6,485,172	-

Arrowsmith Lake Storage Check - 1:5-Year Return Period Drought Condition

	Required Englishman River Flow, cms						Required Discharge from Arrowsmith Lake - Lake Inflow, cms						Requried Storage m^3	Minimum Lake level to Discharge Desired Flow, m	Available Live Storage, m^3	Storage Shortage, m^3
	Jun	Jul	Aug	Sep	Oct	Nov	Jun	Jul	Aug	Sep	Oct	Nov				
Ph1 + Conservation Flow of 0.9 cms	1.12	1.18	1.16	1.11	1.06	1.02	0.00	0.00	0.75	0.62	0.00	0.00	3,599,280	810.44	6,866,667	-
Ph1 + Conservation Flow of 1.2 cms	1.42	1.48	1.46	1.41	1.36	1.32	0.00	0.21	1.05	0.92	0.00	0.00	5,736,912	811.29	6,614,474	-
Ph1 + Conservation Flow of 1.4 cms	1.62	1.68	1.66	1.61	1.56	1.52	0.00	0.41	1.25	1.12	0.00	0.00	7,326,672	811.91	6,427,586	899,086
Ph1 + Conservation Flow of 1.6 cms	1.82	1.88	1.86	1.81	1.76	1.72	0.00	0.61	1.45	1.32	0.00	0.00	8,916,432	812.64	6,207,500	2,708,932
Ph2 + Conservation Flow of 0.9 cms	1.34	1.46	1.42	1.32	1.22	1.14	0.00	0.19	1.01	0.82	0.00	0.00	5,328,192	811.18	6,647,368	-
Ph2 + Conservation Flow of 1.2 cms	1.64	1.76	1.72	1.62	1.52	1.44	0.00	0.49	1.31	1.12	0.00	0.00	7,712,832	812.11	6,367,241	1,345,591
Ph2 + Conservation Flow of 1.4 cms	1.84	1.96	1.92	1.82	1.72	1.64	0.00	0.69	1.51	1.32	0.00	0.00	9,302,592	812.93	6,120,000	3,182,592
Ph2 + Conservation Flow of 1.6 cms	2.04	2.16	2.12	2.02	1.92	1.84	0.00	0.89	1.71	1.52	0.00	0.00	10,892,352	814.01	5,796,569	5,095,783

Arrowsmith Lake Storage Check - 1:10-Year Return Period Drought Condition

	Required Englishman River Flow, cms						Required Discharge from Arrowsmith Lake - Lake Inflow, cms						Requried Storage m^3	Minimum Lake level to Discharge Desired Flow, m	Available Live Storage, m^3	Storage Shortage, m^3
	Jun	Jul	Aug	Sep	Oct	Nov	Jun	Jul	Aug	Sep	Oct	Nov				
Ph1 + Conservation Flow of 0.9 cms	1.12	1.18	1.16	1.11	1.06	1.02	0.00	0.18	0.92	0.76	0.00	0.00	4,912,224	810.96	6,713,158	-
Ph1 + Conservation Flow of 1.2 cms	1.42	1.48	1.46	1.41	1.36	1.32	0.00	0.48	1.22	1.06	0.04	0.00	7,399,536	811.82	6,453,448	946,088
Ph1 + Conservation Flow of 1.4 cms	1.62	1.68	1.66	1.61	1.56	1.52	0.00	0.68	1.42	1.26	0.24	0.00	9,524,976	812.52	6,245,000	3,279,976
Ph1 + Conservation Flow of 1.6 cms	1.82	1.88	1.86	1.81	1.76	1.72	0.00	0.88	1.62	1.46	0.44	0.00	11,650,416	813.52	5,944,118	5,706,298
Ph2 + Conservation Flow of 0.9 cms	1.34	1.46	1.42	1.32	1.22	1.14	0.00	0.46	1.18	0.97	0.00	0.00	6,888,144	811.68	6,496,552	391,592
Ph2 + Conservation Flow of 1.2 cms	1.64	1.76	1.72	1.62	1.52	1.44	0.00	0.76	1.48	1.27	0.20	0.00	9,799,536	812.81	6,157,500	3,642,036
Ph2 + Conservation Flow of 1.4 cms	1.84	1.96	1.92	1.82	1.72	1.64	0.00	0.96	1.68	1.47	0.40	0.00	11,924,976	813.86	5,841,176	6,083,800
Ph2 + Conservation Flow of 1.6 cms	2.04	2.16	2.12	2.02	1.92	1.84	0.00	1.16	1.88	1.67	0.60	0.00	14,050,416	815.07	5,424,479	8,625,937

Arrowsmith Lake Storage Check - 1:20-Year Return Period Drought Condition

	Required Englishman River Flow, cms						Required Discharge from Arrowsmith Lake - Lake Inflow, cms						Requried Storage m^3	Minimum Lake level to Discharge Desired Flow, m	Available Live Storage, m^3	Storage Shortage, m^3
	Jun	Jul	Aug	Sep	Oct	Nov	Jun	Jul	Aug	Sep	Oct	Nov				
Ph1 + Conservation Flow of 0.9 cms	1.12	1.18	1.16	1.11	1.06	1.02	0.00	0.34	1.02	0.84	0.30	0.00	6,625,565	811.21	6,637,368	-
Ph1 + Conservation Flow of 1.2 cms	1.42	1.48	1.46	1.41	1.36	1.32	0.00	0.64	1.32	1.14	0.60	0.00	9,813,725	812.15	6,354,138	3,459,587
Ph1 + Conservation Flow of 1.4 cms	1.62	1.68	1.66	1.61	1.56	1.52	0.00	0.84	1.52	1.34	0.80	0.00	11,939,165	813.00	6,101,000	5,838,165
Ph1 + Conservation Flow of 1.6 cms	1.82	1.88	1.86	1.81	1.76	1.72	0.00	1.04	1.72	1.54	1.00	0.00	14,064,605	814.08	5,770,490	8,294,115
Ph2 + Conservation Flow of 0.9 cms	1.34	1.46	1.42	1.32	1.22	1.14	0.00	0.62	1.28	1.05	0.46	0.00	9,025,565	812.01	6,397,241	2,628,323
Ph2 + Conservation Flow of 1.2 cms	1.64	1.76	1.72	1.62	1.52	1.44	0.00	0.92	1.58	1.35	0.76	0.00	12,213,725	813.29	6,013,500	6,200,225
Ph2 + Conservation Flow of 1.4 cms	1.84	1.96	1.92	1.82	1.72	1.64	0.00	1.12	1.78	1.55	0.96	0.00	14,339,165	814.43	5,650,392	8,688,773
Ph2 + Conservation Flow of 1.6 cms	2.04	2.16	2.12	2.02	1.92	1.84	0.00	1.32	1.98	1.75	1.16	0.00	16,464,605	815.70	5,205,833	11,258,771

Note:
Ph1 - Phase 1 Water Withdrawls - 24 ML/day
Ph2 - Phase 2 Water Withdrawls - 48 ML/day
Assessment based on recorded daily flows from 1913 to 1917 and 1970 to 2013 (Recorded flows after construciton of dam in 1999 have been "naturalized" to account for Arrowsmith Lake storage and releases)