GRAND RIVER WATERSHED
Water Management Plan

Grand River Watershed Water Management Plan

Low Flow Reliabilities in Regulated River Reaches in the Grand River Watershed

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Note that this report was formerly referred to as the Flow Reliabilities Report.

Acknowledgements

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Abbreviations

$7Q_{20}$	Minimum 7-day average flow with a recurrence period on average of once in 20 years and is equivalent to 95% reliability by occurrence
ADCP	Acoustic Doppler Current Profilers
cfs	Cubic feet per second
GRCA	Grand River Conservation Authority
m^3/s	Cubic metres per second (a flow rate)
MOECC	Ministry of Environment and Climate Change
Q_{99}	reliability of 99% by time
WSC	Water Survey of Canada

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Introduction

Knowledge of low river flow reliability is required for the regulated reaches in the Grand River watershed. Knowledge of low river flows helps to support the design and management of municipal wastewater treatment plants and municipal water supply withdrawal. In addition, knowledge of low river flows also inform decisions regarding the design and feasibility of small hydropower plants along the river; natural channel design and flows needed to sustain ecological needs. Consequently, hydrometric data collected throughout the year are critical to best characterize low river flows to inform water management decisions in the Grand River watershed.

In the Grand River watershed, seven large dams regulate, or control, the flows in portions of the Grand, Conestogo and Speed rivers, Canagagigue, Laurel and Mill creeks. These dams were built to provide two key functions: to (1) reduce flood damages particularly during the spring months as the reservoirs are filled as a result of large snowmelts or significant rainfall events; and (2) provide, or '*augment'* flows during low flow periods (e.g. summer, fall and winter).

The result is a more controlled and consistent flow in the river reaches downstream of these large dams. The flows provided by the upstream reservoirs and the operation of the large dams support the assimilation of treated effluent from 16 downstream municipal wastewater treatment plants and provide drinking water supplies for two municipal and one Six Nations water treatment plants. Ecological needs are also considered.

Figure 1 illustrates the regulated reaches in the Grand River watershed, the wastewater treatment plants that are dependent on the upstream reservoirs and operation of the large dams as well as the river drinking water intakes. It is important to note that the two functions of flood control and water supply have conflicting objectives. To provide flood control, as much available storage as possible is desired. To provide flow augmentation, as much water as can safely be stored in the reservoir is desired. Consequently, the Grand River Conservation Authority has an approved reservoir operating policy that balances these conflicting objectives.

This report provides a summary of the approach and assumptions used to operate the large dams and reservoirs in the Grand River watershed to meet the second key function – to provide flows during low flow periods. A summary of the approached used to reduce flood damages and manage flooding in the watershed is summarized in a separate report

Further, this report also provides a summary of the analysis to determine reliabilities of meeting specific low river flows for wastewater and municipal water supply planning. Given that it is a regulated river system, standard statistical approaches to determine the frequency of low flows is not appropriate. Therefore, three approaches were used to identify low flows for wastewater planning. The term '$7Q_{20}$ equivalents' was used and they are presented in the section *Low River Flow Reliabilities in a Regulated River System*. These river flows, or $7Q_{20}$ equivalents, will constitute the starting point for wastewater treatment plant and water supply master planning for watershed municipalities, the Ministry of the Environment and the Grand River Conservation Authority.

Reservoir Operations

The existing operating policy for the large water management reservoirs in the Grand River watershed dates back to early 1978. At that time, a committee comprised of the Regional Engineer, Ministry of Natural Resources, the Regional Director, Ministry of the Environment and the Assistant General Manager, Grand River Conservation Authority (GRCA), reviewed and recommended the general operating procedures and general operating guidelines that are used today. These procedures and operating guidelines incorporated recommendations from the 1974 Flood Inquiry summarized in the 1975 report: *Report of the Royal Commission Inquiry into the Grand River Flood*, *1974.*

The 1982 Grand River Basin Water Management Study (hereafter referred to as the Basin Study) recommended amendments to the reservoir operating procedures to incorporate the proposed *low flow targets.* The low flow targets would assist with balancing the need for flood damage reduction during the spring and low flow augmentation for wastewater planning and to provide municipal water supplies throughout the remainder of the year. These changes to the policy were piloted in 1983 and formally adopted in 1984. In 1988, a revised operating policy for the Guelph dam was adopted allowing for an additional 300 millimetre increase in reservoir operating level which provides additional water for flow augmentation. These changes remain in place today, with minor modifications, and are part of the current reservoir operating policy that was approved by the Grand River Conservation Authority Board in 2004 (see Appendix 1).

The existing reservoir and large dam operating policy (2004) specifies the following:

1. Target reservoir levels (elevations) for February 15th, April 1st, May 1st, June 1st and October 15th to balance flood control and low flow augmentation needs;

2. Minimum discharges from the Shand, Conestogo and Guelph Dams;

3. Minimum operational low river flow targets at Guelph (Edinburgh Road), Kitchener (Doon) and Brantford, for water quality and water supply.

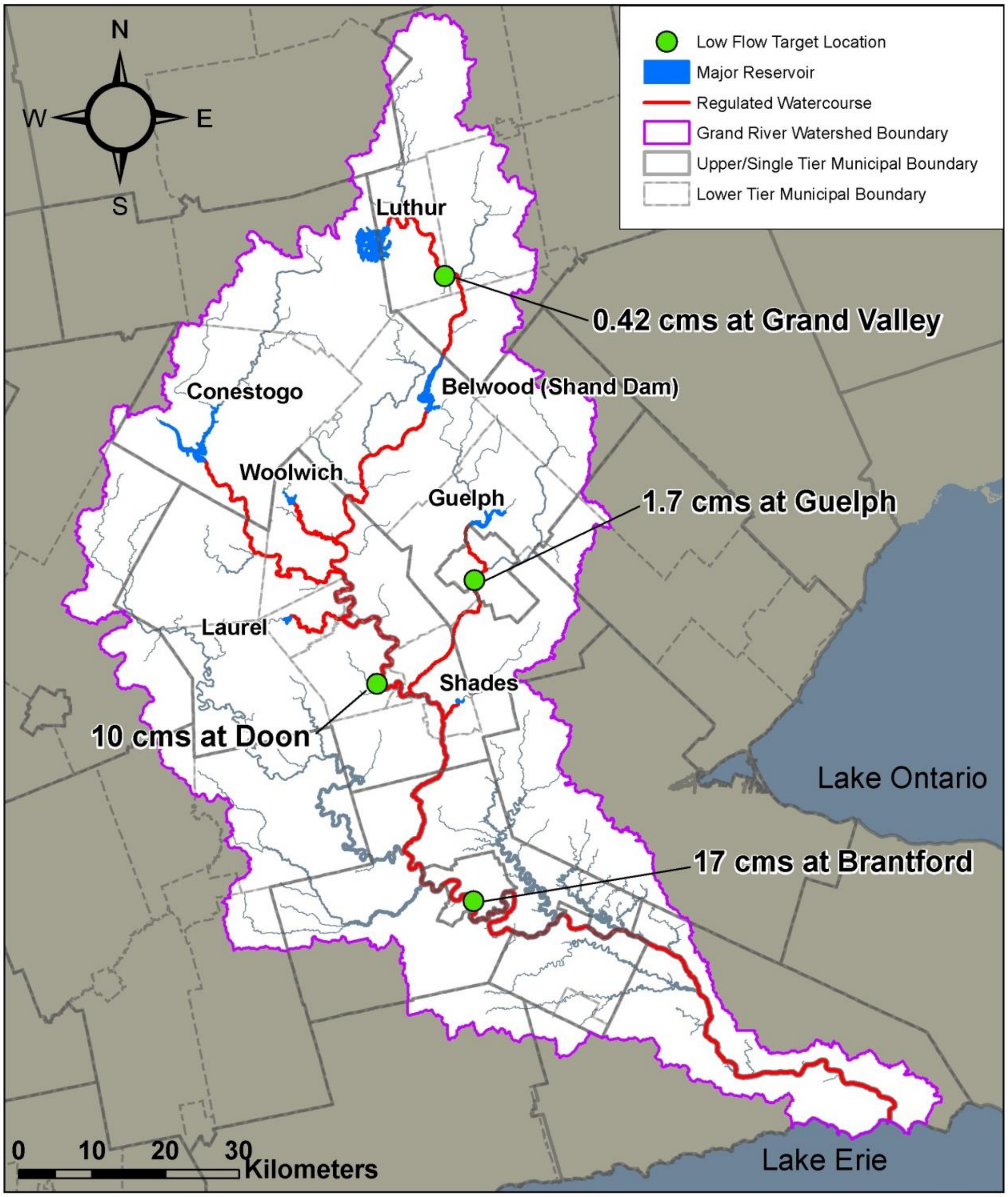


Figure 1. The location of the major multipurpose water management reservoirs and the location of the low flow operating targets.

Reservoir Rule Curves

A **Reservoir Rule Curve** specifies a target elevation of a reservoir for specific times of the year based on specific assumptions or considerations. The reservoir operating policy for the large water management reservoirs in the Grand River watershed is expressed on a Rule Curve for each of the seven multi-purpose reservoirs and reflects the need for flood control and low flow augmentation. Figure 2 illustrates a reservoir rule cure and the considerations for water management during the various seasons throughout the year.

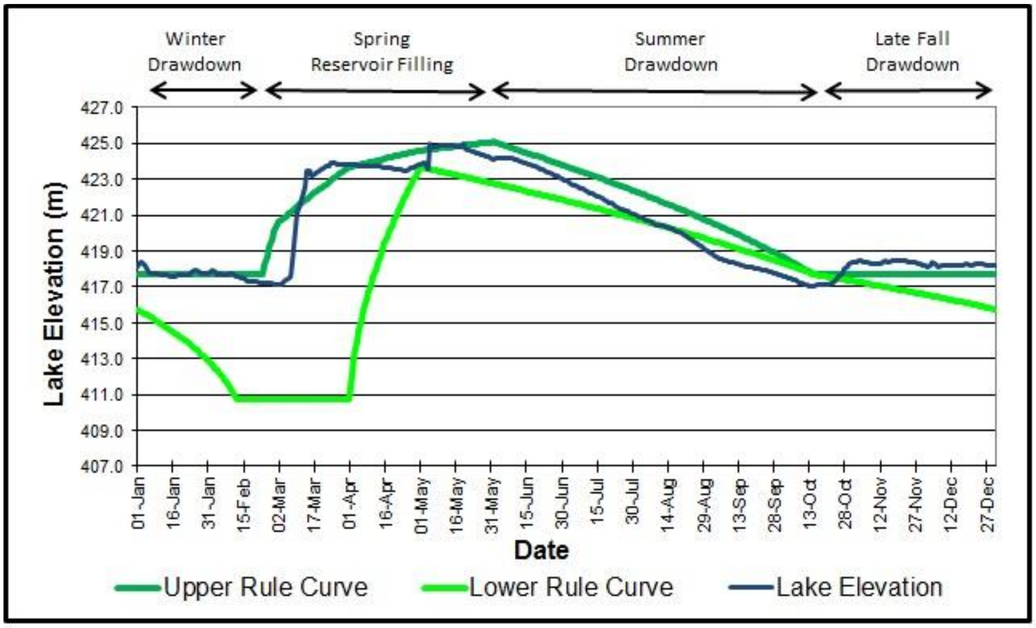


Figure 2. Rule Curve for Shand Dam describing the operating seasons.

The following are considerations that are reflected in the current Rule Curves for the large water management reservoirs:

1974 Flood Inquiry Recommendations

The 1974 Flood Inquiry investigated the mechanisms of flooding and the role reservoir operations and operating policy played in that flood. A separate sub-committee reviewed the reservoir operating policy and recommended minimum flood control storage requirements for April 1st, May 1st and June 1st. These recommendations were intended to balance the need for available flood control storage and the storage needed to provide low flow augmentation. The upper rule curve for the three large dams, Shand, Conestogo and Guelph, reflect these minimum storage requirements.

Floodline Assumptions

Regulatory flood design flows are used to establish flood lines in the Grand River downstream of the Shand Dam and the Conestogo River downstream of the Conestogo Dam. These floodlines are based on specific assumptions identified in the reservoir operating policy. These regulatory flood design flows assume a minimum amount of storage will be available in each reservoir by October 15th of each year. This storage assumption was used to estimate regulatory design flows. The reservoir minimum storage targets for October 15th satisfies storage requirements needed to achieve existing downstream regulatory flood design flows. Regulatory flood flows along the Grand River downstream of Shand Dam and along the Conestogo River downstream of Conestogo Dam assume specific amounts of flood control storage will be available by October 15th. This storage is used to route the Regulatory Flood flow. The Brantford dykes assume no flow regulation by upstream reservoirs and additional freeboard is included to assist with managing potential ice jam floods. Cambridge dykes assumes reservoir flow regulation downstream of Parkhill Dam and unregulated flows upstream of Parkhill dam. Bridgeport dykes assume flow regulation by upstream reservoirs. Regulatory floodlines downstream of Shand Dam and Conestogo Dam assume flow regulation by Shand and Conestogo Dams assuming October 15th available flood control storage. Floodlines downstream of Guelph Dam do not assume flood regulation by Guelph Dam however floodlines along the Grand River consider flow regulation by Guelph Dam.

Dyke Design Assumption

The dyke designs through the City of Kitchener (Bridgeport) and City of Cambridge (Galt) are based on the regulatory flood design flows therefore the dyke function assumes a minimum amount of storage will be available by October 15th of each year. However, the dykes through the City of Brantford were designed assuming unregulated flows and their function is not dependent on minimum reservoir storage assumptions and reservoir operations.

Physical Operating Constraints

Based on operating experience, winter levels at Shand Dam should be maintained above the 48 inch diameter valve to prevent icing of the valve. The 66 inch diameter valve at Shand Dam is not operated at lake elevation above 417.75 metres and is tested each fall after levels are below the 417.75 metres.

Chronology of Minor Revisions to the Reservoir Rule Curves since 1982

The January 1st to February 15th portions of the Rule Curve reflects the assumed drawdown during the winter months and available storage to provide flow augmentation during the winter months. Originally, Shand and Conestogo Dams were emptied by December 31st, providing no allowance for winter flow augmentation. In contrast, the Guelph Dam, built later in 1976, was designed to provide augmentation during the January 1st to February 15th period.

During the 1980's, a practice was developed to hold Shand reservoir levels above the 48” valves to prevent ice build-up in the valves. As a recommended outcome of the 1982 Basin Study, winter operation at Shand Dam was modified to stabilize winter reservoir levels at the gate sill and use the storage between the gate sill and the top of the 48" values to augment winter flows between January 1st and February 15th to maintain a discharge of $2.8 m^3/s$. This value is reflected as the Doon winter low flow target because the Doon gauge is affected by ice during winter months and is not operational. Further, over the 1990’s, and since 2000, a practice was developed on a year-by-year basis to hold reservoir operating levels above the sill at Conestogo Dam until there was sufficient snow pack to reliably fill the reservoir. It was acknowledged at the time as a necessary adaptation to climate change. This practice is reflected in the Rule Curves that are in the current Reservoir Operating policy that was updated in 2004.

In 2004, the upper Rule Curves at Shand, Conestogo and Guelph Dams were revised to allow up to the October 15th storage level (30% of the reservoir capacity) to be carried over through to February 15th the following year in those years when there is insufficient snow cover to reliably fill the reservoirs. It also allows for increased flexibility to capture and hold runoff from early winter melts that often result in the loss of the snow pack early in the operating season. Early winter melts may become more frequent under climate change and therefore, there is a need to be able to adapt to these conditions by being able to fill early or hold a portion of the runoff from mid-winter melts.

The upper rule curve at Guelph Dam was further revised in the 2004 update for the April 9th through August 14th period. The upper rule curve was adjusted from 347.5 to 348 metres for this period. A similar revision was made in 1988 for the May 1st to August 1st period. The upper rule curve was revised from 347.5 to 347.835 metres. This revision was in response to the dry summer of 1988 and intended to allow retention of runoff stored in the early spring to be held and discharged later in the summer.

The Rule Curve for Luther Dam was developed based on low flow augmentation and ecological considerations. Luther Dam primarily provides a flow augmentation function to the upper Grand River and to Shand Dam. While it does provide some benefits from a flood control perspective, these benefits are limited due to the small drainage area regulated by Luther Dam. The upper and lower rule curve between March 1st and September 30th define the operating range to meet downstream low flow targets. The lower rule curve defines the lowest operating range for flow augmentation before reducing downstream flow augmentation targets. The early winter, January 1st to March 1st, and late fall, October 1st to December 31st, upper rule curve is defined from ecologic considerations from the Luther Marsh Master Plan (1991). The highest portion of the upper rule curve defines the maximum operating level from a dam safety perspective.

Current Rule Curves for the Shand, Conestogo, Guelph and Luther dams are shown in Appendix 2 .

Low River Flow Targets

As part of the 1982 Basin Study, flow augmentation alternatives were considered to determine what low river flows could reliability be met downstream of large water management reservoirs. These low flow targets were developed primarily with the intention to ensure that there was enough water in the river to dilute treated wastewater effluent and ensure summer dissolved oxygen levels were sufficient for aquatic life (GRIC 1982).   Low flow targets were identified for the Grand River at Kitchener (Doon) and Brantford and the Speed River downstream of the City of Guelph (Hanlon Expressway). Subsequent studies were completed to determine low flow targets for Grand Valley downstream of the Luther Marsh and for the Canagagigue Creek through Elmira.

The low flow targets at some locations vary with season while the low flow targets are the same throughout the year at other locations. Existing low flow targets are summarized in Table 1 along with the source or basis that was used to establish these targets. These operational low river flow targets are designed to have a flow reliability of 95%. This means that the operational low river flow target will be met or exceeded 95% of the time.

Low flow augmentation assumptions assume straight-line drawdown from the May 1st and June 1st storage elevations through to October 15th. These assumptions form the upper and lower Rule Curves from May 1st and June 1st through October 15th. Water in storage after October 15th is drawn down to meet downstream fall low flow targets and to reduce levels to the winter holding levels at the major dams.

During the winter when ice forms on the river, the Shand Dam is operated to avoid river flows that have tended historically to create ice jams. Discharge from the Shand dam is managed where possible to encourage a smooth stable ice cover in the Grand River through the West Montrose reach downstream of the Elora Gorge.

Table 1. Low flow operation targets for the large water management reservoirs.

Location	Operational Low Flow Target			Basis	Last Confirmed / Revised
	Jan-Apr (m^3/s)	May-Sept (m^3/s)	Oct-Dec (m^3/s)		
Grand Valley	0.42	0.42	0.42	1986 Reservoir Yield Study	2004 Grand Valley Master Waste Water Plan
Below Shand Dam[1]	2.8	2.8	2.8	1982 Basin Study	1996
Doon[2 5]	2.8[4]	9.9	7.1	1982 Basin Study	1999 Region of Waterloo Master Water Supply
Brantford		17		1982 Basin Study	1999 Region of Waterloo Master Water Supply
Below Conestogo Dam[1]	2.1	2.1	2.1	1982 Basin Study	1982
Below Guelph Dam[1]	0.57	0.57	0.57	1982 Basin Study	1982
Edinburg Road City of Guelph[3]	1.1	1.7	1.1	1982 Basin Study	2004 City of Guelph Master Water Supply Plan
Elmira	0.3	0.3	0.3	Operations Manual Woolwich Dam	1980

[1] Lessor of flow target or inflow to the dam

[2] Flow before the Mannheim surface water taking of 0.9 m3/s, Doon gauge is located downstream of taking

[3] Summer operating season for the Speed River is June 1 to Sept 30, fall/winter season is Oct 1 to May 31

[4] Winter low flow target estimated based on available winter augmentation storage below gate sill at Shand Dam

[5]. The fall Doon flow target was modified in 1999 to start on October 1st instead of November 1st.

The only revision to the flow targets made since 1982 was to the Grand River at Doon and Brantford. The fall operating target start date was moved from October 30th to September 30th to reflect the cooler water temperatures in the fall and the diminishing need for flow augmentation as water temperatures cool down and the growth and photosynthesis and respiration of aquatic plants decreases. This was in response to operating challenges in the fall of 1998. During 1998, augmentation of the river from the large water management reservoirs was required throughout the year and into the winter because of persistent low precipitation. This dry period extended into 1999 with near record levels of augmentation during the summer of 1999.

Reservoir Operating Seasons

The operating considerations for the major reservoirs vary with season. Water quality stressors, ecology and human needs all vary with operating season as do the reservoir management options.

May 1st to September 30th

Augmentation of low flows during the May 1st to September 30th period of the year is one of the primary purposes of the large dams. Although the large dams still provide a flood management function in this period, the frequency of floods during this period of the year is much less than in the spring filling period.

From a water quality perspective, a primary stressor to river water quality at this time of year is aquatic plant growth and the impact these plants have on overnight oxygen levels in the river. Warm air and water temperatures during this period puts further stress on river water quality and the ability of the river to assimilate treated wastewater effluent. It is recognized that groundwater discharge is an important moderator to these stressors.

From an ecosystem perspective, a key consideration during this period of the year is maintenance of habitat and water quality. The littoral zone along the fringe of the river is an import zone for younger fish to grow and seek protection. Maintaining flow through this zone is an important consideration to avoid anoxic conditions.

From a geomorphic perspective, flushing fine sediment is an important consideration at this time of year in concert with maintaining sufficient flows to connect habitat.

October 1st to December 31st

During this period of the year, water temperatures cool down in response to cooler air temperatures, particularly cooler overnight air temperatures.

The stress to water quality from a dissolved oxygen perspective diminishes and the system as a whole becomes more tolerant of lower flows during the fall period. The metabolism of the river slows down.

Typically, there is less water available in the reservoirs during the fall unless fall rains or remnant tropical events generate runoff, in which case, the fall can be an active flood season.

A consideration during the fall period is flushing of dead aquatic vegetation through the river system. A flushing flow in the fall is beneficial to help move dying aquatic vegetation out of the river system and flush sediment from riffles along the river.

From an ecology perspective, migration of certain fish species is triggered by fall flow increases in concert with water temperature triggers. These triggers are typically weather dependent and are not affected by reservoir operations.

January 1st to February 15th

During the winter months, storage between the upper and lower rule curves is used to augment winter flows. Flows can become extremely low during this period of time if the summer and fall leading into winter is dry and a cold winter sets in. This was the case in early 2003.

From a water quality perspective, the metabolism of the river is at a near dormant state due to the cold water temperatures. Ammonia discharged to the river when ice cover is present is a stressor to water quality during winter months. Winter flow augmentation is intended to assist with this issue by reducing ammonia concentrations. The impact of ammonia on river water quality is being addressed through planned wastewater plant upgrades.

A key function of flow augmentation in the winter is to maintain habitat and provide sufficient water for drinking water supplies. While the available flow dilutes treated effluent discharged to the river, the cold water temperatures limit aquatic plant growth during the winter months and the associated water quality impacts. Maintenance of habitat for fish and other aquatic organisms is a key ecological function during the winter months.

February 15th to May 1st

The filling portion of the operating season is weather dependent and is related to when the spring freshet occurs. Snowmelt and rainfall are used to fill major reservoirs to their April 1st storage level. Rain in April is used to fill reservoir levels to their May 1st operating level. Rainfall in May can be used to fill reservoirs beyond the May 1st operating level to June 1st operating levels in most years.

A key water quality consideration during the filling cycle is to try and achieve at least a bank full flow through the regulated reach. This bank full flow helps flush the river channel of accumulated aquatic vegetation and helps re-sort the river bed sediments. This improves the resiliency of the river for the coming summer.

From an ecological perspective, flooding of low lying floodplain flats or wetlands is important for spawning and to support the life cycle of certain warm water fish species. Spawning of these species is triggered by flow and temperature changes.

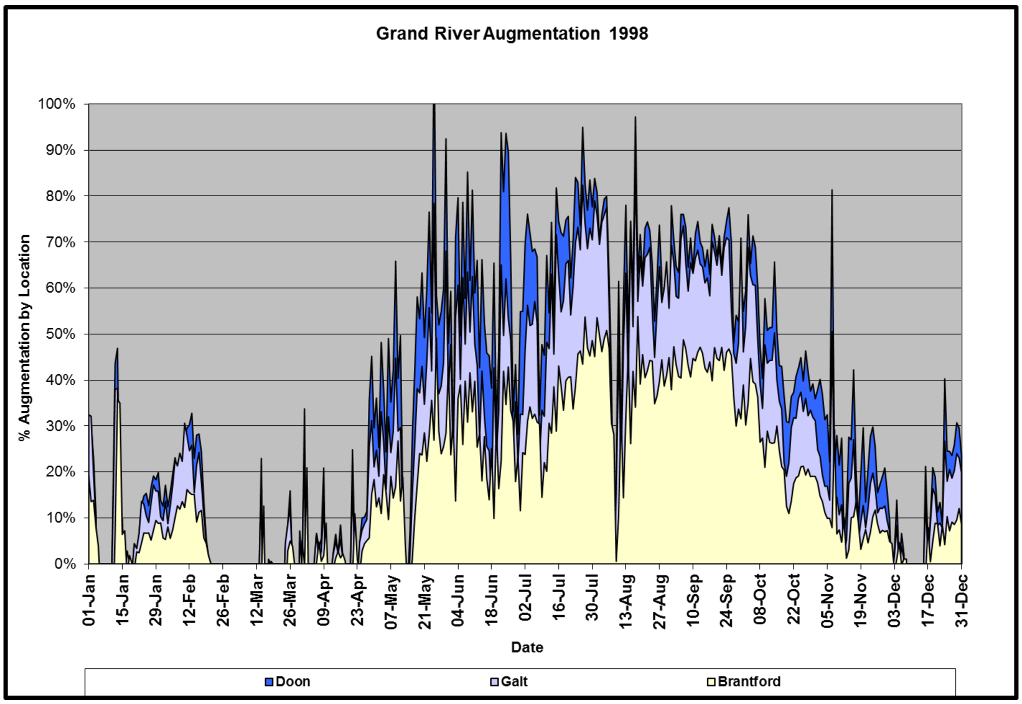
A primary high flow management objective during this period of the operating season is to reduce flood damages and risk to life.

River Flow Augmentation

Reservoir discharge adds flow to the river system throughout the year. The main period of augmentation is during the May to September period when downstream flow targets are highest. Average augmentation since 1984 during the July to September period is approximately 50% at Doon, 30% at Brantford and 30% below Guelph. During dry periods, augmentation has reached persistent levels of 80% of the flow at Doon, 50% of the flow at Brantford and 70% of the flow below Guelph. For short periods, augmentation levels have approached 90% of the flow at Doon on the Grand River and below Guelph on the Speed River.

In many years, reservoir discharges often contribute a large portion of flow in the regulated river system during the fall period, with more augmentation in October compared to November. In dry years, winter augmentation can be crucial to maintaining flow in the river system.

Figure 3 is an example of the augmentation levels during 1998 which was one of the recent prolonged dry periods. During this year augmentation was required throughout the year and into the winter season because of persistent low precipitation. This dry period extended into 1999 with near record levels of augmentation during the summer of 1999.



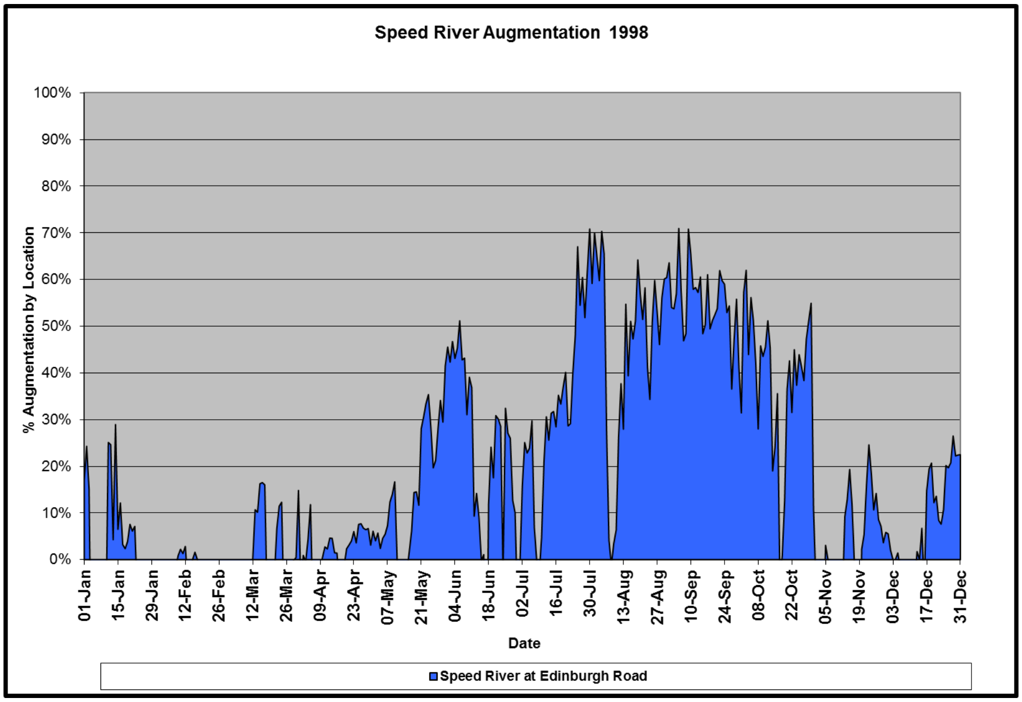


Figure 3. Percent of river flows provided by the large water management reservoirs through augmentation in Grand and Speed rivers in 1998

Low Flow Reliability of Regulated River Reaches

Reliabilities discussed in this section are based on time. They are calculated using the 7-day running average and are reported over a multi-year period (e.g. 1984 to 2010). Flow reliability typically uses an occurrence approach. However for a regulated river, the occurrence approach is not suitable since values are not statistically independent and operational constraints such as dam maintenance or repairs may cause short term violations that are not drought or shortage related, resulting in a skewed estimate of reliability. For these reasons, a time based method of calculating the reliability of achieving downstream flow targets has historically been used for water management in the Grand River watershed.

The reliability of meeting the existing operational low flow targets was reviewed with both observed flow data and modeled results from the Reservoir Yield Model. The reliabilities were then compared against those developed for the 1982 Basin Study. Downstream flow targets were set in the 1982 Basin Study based on meeting them with a reliability of 95% of the time or greater.

Reservoir Yield Model

The Reservoir Yield Model was developed as part of the 1982 Basin Study. The original model was further adapted and revised in the early 1990’s to assess the reliability of river flows for the Region of Waterloo Water Supply Master Plan (1991). It was further revised in the mid-1990’s to complete an updated assessment of the Region of Waterloo river supply option.

The Reservoir Yield Model is a simulation model that simulates reservoir operations based on observed daily inflows and downstream local contributions between the reservoirs and flow target locations. The current model uses an observed daily flow data set covering the 1950 to 2010 period of record. The long period of record provides 60 years of data and is used to assess the reliability of meeting downstream operational low flow targets and reservoir operating levels. The model can be used to test changes to operating procedures and report on implications to the reliability of achieving downstream operational low flow targets. The current model includes the three large reservoirs: Shand, Conestogo and Guelph. The effect of Luther Dam is reflected in the daily inflow data set assigned to Shand Dam. A separate Luther reservoir yield model is used to assess the reliability of meeting the flow target in the Grand River at Legatt. A study on flow reliability for Luther Dam was completed in 2004 and, except for climate change considerations, has not been reassessed as part of the 2014 Water Management Plan update (see report in Appendix 4).

Operational flow targets are assigned to the reservoir discharges and four downstream target locations. Three downstream target locations include the Grand River at Kitchener (Doon), Cambridge (Galt) and Brantford. The fourth flow target location is the on the Speed River at Edinburgh Road in the City of Guelph.

It is important to note that the reservoir yield model does not have foresight and the operation of the large water management reservoirs requires a great deal of situational assessment that incorporates current watershed and forecasted weather conditions. The model assesses discharge requirements at each reservoir and available storage to supply the required discharge to the downstream flow target locations on a day by day basis. In real operating situations, reservoir managers have some foresight and weather forecasts and can adapt operations to anticipated conditions. Therefore, it should be kept in mind that the reservoir yield model provides an approximation of how the reservoir could be operated and the flow reliability that would result. The reservoir yield model shows reasonable performance during the summer, fall and winter operating seasons. The model has difficulties with the filling cycle due to the lack of foresight and other ancillary information available to reservoir managers during the filling cycle.

Reliability of the May 1st Assumption

The reservoir model assumes that the May 1st upper rule curve storage target is achieved on May 1st of each year. This assumption has implications to downstream low flow target reliability. Observed reservoir levels from 1984 to 2010 were investigated to see how closely this assumption is achieved during normal operations. At Shand and Conestogo Dams, there are storage target levels on April 1st, May 1st and June 1st. Usually the maximum storage each year falls between the May 1st and June 1st targets. The Guelph reservoir has a single spring filling target.

Storage at Shand Dam has always reached the April 1st target. The May 1st target has always been achieved at some point within the April to June period, but not always by May 1st. The June 1st target is only achieved about 25% of the time. For the Conestogo Dam, the April 1st target has been achieved for all but one year from 1984 to 2010. The target was not achieved in 1999 because of limited runoff during the spring. The May 1st target has been achieved at some point in the spring about 90% of the time, but is often not achieved by May 1st. The June 1st target has only been achieved about 14% of the time. For the Guelph Dam, the spring target has been achieved close to 100% of the time at some point in the spring, but only about 80% of the time by May 1st.

Based on the historical record the assumption of achieving the May 1st storage target is a reasonable assumption. It is recommended that future updates to the Reservoir Yield model include both a function to carry forward April 30th storage into the next operating year and the ability to specify yearly May 1st storage levels based on observed data to account for inaccuracies in the modeling of the filling cycle.

Reliability of the Existing Operational Low Flow Targets

Two time periods are included in the analysis of existing operational flow targets. The 1950 to 2010 period is the total period available with the Reservoir Yield Model and it is used to see the variability over time. The 1984 to 2010 period is for comparison with observed values since it coincides with the same time period as the current operating procedure of the reservoir system. The reservoir yield model uses the current operating procedures for both time periods.

Grand River Low Flow Reliability

The reliability of meeting the Grand River flow targets downstream of the major reservoirs is presented in **Table 2** along with the number of years that the targets were not met.

The reliability in meeting the Doon target for each of the seasonal periods is at or above 95% and the observed record had greater than 98% reliability. The winter period has the highest reliability followed by the summer period, with the fall period having the lowest reliability. The number of years the Doon target was not met was similar between the observed record and the reservoir yield model results. The fall Doon flow target was modified in 1999 to start on October 1st instead of November 1st. The observed record will include both periods, while the modeling results are based on the fall target starting on October 1st for the entire time period. This change to operating policy is documented in a report to the GRCA board.

The Brantford flow target was originally intended to be used for the summer period only as part of the 1982 Basin Study, but in practice it has become the year round operational flow target. This target has been met with a high reliability of 99%. The Reservoir Yield model gives a lower reliability during the fall period than the observed record. The modeling results were similar to the observed record for number of years with violations. Flows in the winter months were also higher in the observed record compared to modeling results. The fall and winter periods would present the greatest challenge to meet a flow target of 17 m^3/s year round.

While the statistics indicate the winter period has the highest reliability, this is the season that has the highest risk of failure, summer and fall augmentation can cause the reservoirs to run dry and flow augmentation would no longer be possible. The winter period starts with low reservoirs levels especially in years with a dry fall, such as in 2002-2003. In that situation, if the winter is cold and produces little runoff from mid-winter melts then there is a high chance of running out of water for winter augmentation. This is coupled with the fact that winter flow information is always an estimate given the difficulty in measuring winter flows and affecting decision making. Changes to winter operations in the mid 1990's and formal adoptions of modified rule curves in 2004 to store more water over the winter has helped to lower this risk, but long periods of drought still present risk.

Table 2. Reliability in reaching existing flow targets at Doon and Brantford

	Doon			Brantford		
	Jan-Apr	**May-Sep**	**Oct-Dec**	**Jan-Apr**	**May-Sep**	**Oct-Dec**
	Percent Reliability					
1982 Basin Plan	100	98.9	94.5	NA	99.6	NA
Reservoir Yield (1950-2010)	99.8	99.5	95.2	97.7	99.9	94.3
Reservoir Yield (1984-2010)	99.6	99.6	96.6	99.1	99.9	97.0
Observed (1984-2010)	**100**	**98.7**	**98.9**	**99.2**	**99.7**	**98.9**
	Years with Target Violations Compared to Period of Record Analyzed					
Reservoir Yield (1950-2010)	2/60	5/60	8/60	8/60	3/60	11/60
Reservoir Yield (1984-2010)	1/27	2/27	2/27	2/27	1/27	2/27
Observed (1984-2010)	**0/27**	**2/27**	**4/27**	**2/27**	**2/27**	**2/27**

Observed data for Doon is from the GRCA gauge at Doon with the RMOW water taking accounted for and correction for under ice flow; Observed data at Brantford is from the Water Survey of Canada gauge at Brantford

Speed River Flow Reliability

The reliability of meeting the Speed River operational low flow target at the Below Guelph gauge (Edinburgh Road) is given in Table 3**Error! Reference source not found.**. The Below Guelph summer flow target has the lowest reliability of any of the flow targets in the watershed. The 1982 Basin Plan presented a 93% reliability of meeting the summer target. Based on the observed record, the target has had a 94% reliability since 1984, but results of the Reservoir Yield Model show that a higher than 95% reliability by time is achievable.

Table 3. Reliability in meeting existing operational flow targets Speed River

	Percent Reliability			Years with Violations Compared to period of record analyzed		
	Jan-May	**June-Sep**	**Oct-Dec**	**Jan-Apr**	**May-Sep**	**Oct-Dec**
1982 Basin Plan	100	93.0	95.5			
Reservoir Yield (1950-2010)	100	96.8	99.3	0/60	11/60	3/60
Reservoir Yield (1984-2010)	100	96.7	99.2	0/27	5/27	2/27
Observed (1984-2010)	**100**	**93.9**	**100**	**0/27**	**7/27**	**0/27**

Observed data is from the Water Survey of Canada gauge Speed River below Guelph

Operations at Guelph Dam have changed over the observed period, which may account for the differences between the Reservoir Yield modeling results and the observed record. The rule curve at the dam was slightly modified in a November 1989 board report and slot gates were installed in the early 1990's to allow for more water to be stored in the early spring. These operational changes since 1984 may be the reason the reservoir yield model shows a higher reliability and may be more indicative of future reliability.

Minimum Dam Discharge Reliability

The Reservoir Yield model was designed to evaluate downstream flow targets and simulates the operation of Shand and Conestogo Dams in a combined fashion. For the flow targets on the Grand River it first tries to meet the target with discharges from Shand Dam, keeping Conestogo Dam at minimum discharge and if Shand Dam reservoir is low only then does it take additional water from Conestogo. This method takes into account the additional augmentation provided by Luther Dam upstream of Shand Dam. Although the Damascus Reservoir is upstream of the Conestogo Dam, it has very little storage. Further, the Damascus reservoir is not able to recover if levels drop too quickly. On the other hand, Shand Dam has water available from augmentation from the Luther Dam in dry years. To put this in context Luther Dam has approximately 180 m^3/s/days for augmentation capacity, while Damascus Dam has an augmentation capacity of approximately 8 m^3/s/days.

Although this procedure results in an approximation of reliability for the downstream targets, it does not give a good approximation of minimum dam discharge reliability since it is not fully representative of operational practices. Water managers have foresight and make operational decisions based on a variety of monitoring data and knowledge of conditions. The reservoir yield model does not incorporate human judgment or additional monitoring data when decisions are made. For these reasons it is better to use observed reservoir discharges to analyze and calculate minimum discharge reliability.

Observed dam discharge reliability results, annually and by operating season, are given in Table 4 Shand Dam has a minimum discharge of the lesser of 2.8 m^3/s or inflow; Conestogo Dam has a minimum discharge of the lesser of 2.1 m^3/s or inflow; and Guelph Dam has a minimum discharge of 0.57 m^3/s. Not meeting minimum discharges at the dams can be due to water shortages, forecast water shortages, planned dam maintenance or operational issues. These issues rarely occur. Forecast water shortages refer to times that minimum discharges were not met even though water was available in an effort to conserve water in storage and prolong augmentation into the winter period. This approach is used to avoid completely emptying the reservoirs.

Reliability of meeting or exceeding minimum discharges at the dams is at or higher than 95% except during the fall period. Shand Dam has a flow reliability of 93% during the fall season with 4 years with discharge violations, while Conestogo Dam had a fall minimum discharge reliability of approximately 95% with 3 years with flow violations. Guelph Dam minimum discharge reliability was 96% with 3 years with flow violations. Low fall minimum discharge reliability is a function the cyclic nature of reservoir operations with low reservoir levels during the fall period when augmentation may still be required and inflows can be low.

Table 4. Observed percent reliability in maintaining minimum discharges from dams

	Percent Reliability			Years with Violations		
	Shand	Conestogo	Guelph	Shand	Conestogo	Guelph
Jan – Apr	97	97	99	3/27	3/27	2/27
May – Sept	~100	99	100	1/27	3/27	0/27
Oct – Dec	93	95	96	4/27	3/27	3/27
Annually	97	97	99	7/27	9/27	5/27

Values in Table 4 were calculated using the 1984 to 2010 period of record. This period is considered to be fairly consistent in how the reservoirs were operated, but there were some changes during this period that should be noted. The rule curves were adjusted in the revised operating policy (2004) to store more water into the winter period for winter augmentation purposes. The revised operating policy reflects operating practices that evolved previously. As well operational practices have changed particularly at Conestogo Dam where historically the reservoir was emptied on an annual basis. Since 1995, water has been held over winter for augmenting flows and the reservoir is only emptied in extreme cases. For the Guelph dam, the ability to manage the slot flow was added in 1989 to increase storage.

Considerations for Changes to Operations

One advantage of using a model such as the Reservoir Yield model is that different scenarios can be run to test changes or challenges to the operating systems. Some of the key questions that have come up in regards to the reservoirs have been:

1. Can low flow targets be met if the reservoirs are not filled in the spring?
2. Can downstream flow targets be raised with the current reservoir operating system?
3. What operation challenges can be expected with a changing climate?

Reductions in Spring Water Levels

Scenarios were developed to evaluate whether downstream flow targets can be met with reduced spring filling levels. Shand and Conestogo reservoirs have spring filling targets for April 1st, May 1st, and June 1st. The current reservoir yield model assumes the May 1st target level is reached in each reservoir and then the rule curves are followed to take in water up to June 1st target levels.

For the first scenario (May 1st only), the May 1st water level is reached but then no additional water is taken into storage after May 1st.

For the second scenario (April 1st), the April 1st filling target is achieved on May 1st and any additional water after May 1st is taken into storage according to the current rule curves, so storage could be taken up to June 1st levels if water was available.

Table 5 shows the reliabilities for meeting downstream flow targets for these scenarios along with the reservoir yield results from the existing operations case. There was no change to winter reliabilities (not shown). There was also no change to the Below Guelph reliabilities since the Guelph reservoir has a single spring filling target that was not changed in these scenarios.

Table 5. Reliability for Spring Filling Scenarios (1950 to 2010)

	Doon		Brantford		Below Guelph	
	May-Sep	**Oct-Dec**	**May-Sep**	**Oct-Dec**	**May-Sep**	**Oct-Dec**
Scenario	**Percent Reliability**					
Existing Case	99.5	95.2	99.9	94.3	96.8	99.3
May 1st only	99.4	94.8	99.9	94.0	96.8	99.3
April 1st	96.7	94.4	98.7	93.6	96.8	99.3
Scenario	**Years with Target Violations**					
Existing Case	5/60	8/60	3/60	11/60	11/60	3/60
May 1st only	6/60	10/60	4/60	12/60	11/60	3/60
April 1st	10/60	10/60	7/60	11/60	11/60	3/60

The Grand River downstream flow target reliabilities dropped by a small amount with the first scenario (May 1st only target) with additional years with flow target violations. In other words the reliability by time was slightly affected, but the reliability by occurrence was affected to a greater extent. In the second scenario reliabilities were further reduced and there were more years with flow target violations in the summer period. These results indicate that there is some robustness to the filling cycle, but that it is important to reach the May 1st filling targets to maintain downstream flow reliabilities at or above 95%. Taking in more water after May 1st increases the reliability of meeting downstream flow targets.

Winter Target at Doon

The winter target at Doon was originally set based on minimum discharge from Shand Dam. This approach is used because winter river ice cover affects the accuracy of the data collected at the flow gauge at Doon. In practice, winter flow rates are much higher than the 2.8 m^3/s target and it was felt that a winter flow target should be developed using the same assumptions as the other seasonal flow targets.

The 95% percentile flow during the winter period was estimated based on a modified flow data set at Doon that was corrected for winter ice cover. Ice corrected flows from the Water Survey of Canada Galt gauge were used estimate flows at the Doon gauge. This value was then used in the reservoir yield model to confirm reliability over a longer period. A winter flow target of 5.8m^3/s had a reliability of 98% over the 1950 to 2010 period and a reliability of 99% over the 1984 to 2010 period. These reliabilities are much higher than the 95% reliability normally used to set flow targets, but because of the inaccuracies of winter flow data it is recommended that a winter flow target not be set higher than 5.8m^3/s to ensure that it is met similar to the observed record.

Changes to Flow Targets - Summer

The next three scenarios looked at changes to the summer flow targets, in particular the target at Doon. Under existing conditions the reservoir yield model uses a summer target of 9.9 m^3/s at Doon, but if there is water available it increases the flow rate at Doon to 11 m^3/s. Three scenarios were run to look at changes to summer flow targets.

1. The first scenario (Doon 11 m^3/s) increased the summer flow target at Doon to 11 m^3/s.
2. The second scenario (Summer to Oct 15) uses the existing summer targets but extends them to October 15th instead of September 30th.
3. The third scenario (Doon 11 m^3/s to Oct 15) is a combination of previous two scenarios with a summer target at Doon of 11 m^3/s and all summer targets extended to October 15th.

The target on the Speed River was only changed for the last two scenarios which extended the summer target to October 15th. Each of these scenarios used the current rule curves and assumed the May 1st filling target was reached each year. Results for these scenarios are given in Table 6.

Table 6: Reliability for Flow Target Change Scenarios (1950 to 2010)

	Doon		Brantford		Below Guelph	
	May-Sep	Oct-Dec	May-Sep	Oct-Dec	May-Sep	Oct-Dec
Scenario	**Percent Reliability**					
Existing Case (50-10)	99.5	95.2	99.9	94.3	96.8	99.3
Doon 11 cms	98.5	94.6	99.9	93.9	96.8	99.3
Summer to Oct 15	99.5	93.4	99.9	94.6	96.8	98.4
Doon 11 to Oct 15	98.9	92.4	99.9	94.2	96.8	98.4
Scenario	**Years with Target Violations**					
Existing Case (50-10)	5/60	8/60	3/60	11/60	11/60	3/60
Doon 11 cms	7/60	11/60	4/60	12/60	11/60	3/60
Summer to Oct 15	5/60	13/60	3/60	12/60	11/60	8/60
Doon 11 to Oct 15	7/60	14/60	4/60	12/60	11/60	8/60

* Manheim taking is not included in this analysis

The results of the scenarios show that modifying the summer flow targets results in a decrease in reliability for achieving the fall flow targets. Increasing the Doon target to 11 m^3/s resulted in a small decrease in reliabilities for the Grand River targets and resulted in more years not meeting the Doon target, but had less of an effect for the Brantford target. Extending the period of the summer flow target to October 15th resulted in a bigger decrease in reliability for the fall target at Doon, with the reliability dropping below 95%. The Speed River target reliability also dropped, but stayed well above 95% reliability. The combined scenario had the largest drop in reliabilities with both Grand River targets below 95% reliability and an increase in occurrence of flow target violations.

Increasing or extending the summer flow targets will lower the reliability in meeting the fall flow targets outside of acceptable levels, therefore no change in flow targets is recommended. Although no change is recommended it is standard practice to operate above the minimum target flow if water is available and often this is the case in the fall season.

Climate Change Scenarios

A study was completed that evaluated ten different climate change scenarios through the continuous stream flow model of the Grand River watershed to investigate changes to stream flow, runoff, recharge and evapotranspiration (Shifflett 2014). The continuous GAWSER model for the Grand River watershed was used to simulate flows under versus climate change scenarios. The results of these climate change runs suggested that there would be more mid-winter melts, more winter precipitation and a good chance of a longer, hotter and drier low flow season during the summer months. These conditions result in a greater demand on the reservoirs for augmentation during the summer months and may affect the filling cycle of the reservoirs.

It is important to note that there is a great deal of uncertainty in climate change predictions as they relate to predicting impacts on surface or ground water resources. The science is continuously evolving. Further, the climate data sets typically used in modelling Climate Change impacts are based on Global Circulation Models which do not simulate local scale weather patterns such as convective storms. These models also do not consider local landscape influences such as the Great Lakes. Both of these localized weather patterns play an important role in the hydrology of the Grand River watershed. Research is ongoing to improve the climate data sets that will better represent local weather patterns.

Output from the surface water model was incorporated into ten separate scenarios for the Reservoir Yield model to investigate potential challenges to reservoir operations under a changing climate. Each of the ten climate change scenarios covered a 30 year period, used the current rules curves and assumed the May 1st filling target was reached.

Table 7 gives the reliabilities of meeting low flow targets, number of years with target violations and the flow at 95% reliability for the historic climate and the ten climate change scenarios. There was no significant change to the reliabilities of meeting winter flow targets. Winter flows with 95% reliability for the target locations were well above the target flow for all of the climate change scenarios.

The summer and fall periods had more instances of not meeting the flow target with 95% reliability. For the Grand River targets most of the scenarios suggested that meeting the summer targets would have similar reliabilities to the historic climate data set. Only two scenarios produced reliabilities below 95%: scenario 65 and 66 had very dry summer conditions with a 20% decrease in summer precipitation. These scenarios were part of the lowest 9% of all of the scenarios for summer precipitation.

Approximately half of the scenarios had flow reliabilities below 95% for the fall with some very low flow results. Higher summer augmentation needs resulted in less water available for fall augmentation. It should be noted that the modelled fall flows were generally less than observed fall flows was likely due to the lack of human foresight and active management of the flows.

On the Speed River there may be challenges meeting the summer flow target, but little change in the reliability in meeting the fall flow target.

The results from the reservoir yield climate change scenarios assumed that the May 1st filling level in each reservoir was achieved. However, the results from the Climate Change Scenario Modelling study highlighted the tendency of more winter precipitation and more frequent winter snow melts which could affect the normal filling cycle of the reservoirs. Although the model assumes that the May 1st level is reached it also gives the percent of the May 1st level that was achieved on May 1st. This output is valuable in investigating challenges to the reservoir filling cycle as well as the summer augmentation season. If current reservoir rule curves are used with a changed climate there is a greater chance of not filling the reservoirs to May 1st levels since much of the higher winter flows will not be taken into storage.

for a period of time. Flexibility in winter operations should be incorporated into the reservoir operating procedures to capture mid-winter melt water while continuing to manage flood risk.

Table 8 shows, based on Reservoir Yield model output, the number of years that the reservoirs were not filled to 90% and 95% of the May 1st target by May 1st with the current rule curves. In many of the years in which the May 1st target was not reached there was water available early in the spring or during the winter to fill the reservoir, but water was released to maintain flood storage. The winter operating procedures of the large dams were modified in 2004 to hold more water into the winter period as a slight adaptation to climate change. Further refinements to rule curves may be required during the filling cycle January through April 1st to adapt to more frequent mid-winter melts and possibly earlier spring conditions as climate warms and snow packs are lost earlier in the season.

Winter precipitation is stored on the landscape in the snowpack and then becomes runoff during spring melts which helps to fill the reservoirs. If winter precipitation is not stored in the snowpack or is released throughout the winter with mid-winter melts it will not be available in the spring to fill the reservoirs. In practice, the operation of the large reservoirs is already adapting to this condition. Typically the large reservoirs are filled to April 1st storage levels with runoff from the snow pack and rainfall. If the snowpack is lost before April 1st there is consideration of holding water in storage above the upper rule curve and if the snowpack redevelops water is released to reduce flood risk. In the winter of 2012, for example, there was very little snowpack, it melted early and the reservoirs were held above the upper rule curve

Table 7: Reliability for Climate Change Scenarios

	Doon			Brantford			Below Guelph		
	Jan-Apr	May-Sep	Oct-Dec	Jan-Apr	May-Sep	Oct-Dec	Jan-Apr	May-Sep	Oct-Dec
Scenario	**Percent Reliability [a]**								
Historic Climate [b]	**100**	**99**	**96**	**99**	**100**	**96**	**100**	**98**	**99**
Scenario 30	100	100	99	98	100	98	100	99	100
Scenario 31	100	100	99	100	100	97	100	96	99
Scenario 34	100	98	**90**	100	97	**86**	100	**93**	98
Scenario 52	100	100	99	100	100	97	100	97	99
Scenario 53	100	99	96	99	99	**93**	100	96	98
Scenario 58	100	100	**90**	99	98	**82**	100	**90**	98
Scenario 65	100	**93**	**89**	100	**90**	**79**	100	**88**	98
Scenario 66	100	**94**	**90**	100	**90**	**84**	100	**88**	98
Scenario 71	100	99	**95**	100	99	**93**	100	96	99
Scenario 72	100	100	98	100	100	**95**	100	**93**	99
Scenario	**Years with Target Violations [a]**								
Historic Climate [b]	**0**	**2**	**3**	**3**	**1**	**4**	**0**	**4**	**1**
Scenario 30	0	0	1	3	0	1	0	3	1
Scenario 31	0	1	2	0	1	3	0	5	2
Scenario 34	0	7	9	2	9	16	0	9	3
Scenario 52	0	1	1	2	2	4	0	5	2
Scenario 53	0	3	7	3	4	8	0	5	2
Scenario 58	0	5	14	6	8	18	0	13	5
Scenario 65	0	17	15	2	18	22	0	12	5
Scenario 66	0	17	12	1	16	17	0	12	3
Scenario 71	0	2	6	2	5	9	0	6	2
Scenario 72	0	2	3	1	2	8	0	7	2
Scenario	**Flow at 95% Percent Reliability [a]**								
Flow Target	**2.8**	**9.9**	**7.1**	**17.0**	**17.0**	**17.0**	**1.1**	**1.7**	**1.1**
Scenario 30	10.1	11.0	8.6	18.4	18.3	17.0	2.0	1.7	1.6
Scenario 31	11.9	10.7	8.4	20.8	17.3	17.0	2.2	1.7	1.7
Scenario 34	11.8	10.0	**5.7**	19.4	17.0	**13.4**	2.1	1.7	1.4
Scenario 52	11.6	10.6	8.5	20.7	17.0	17.0	2.1	1.7	1.7
Scenario 53	11.1	10.2	7.1	19.5	17.0	**15.5**	2.0	1.7	1.6
Scenario 58	10.5	9.9	**5.7**	17.0	17.0	**14.0**	1.9	**1.6**	1.3
Scenario 65	11.6	**9.5**	**5.4**	19.4	**14.6**	**12.7**	2.1	**1.6**	1.3
Scenario 66	11.7	**9.6**	**5.7**	19.2	**14.7**	**13.2**	2.1	**1.6**	1.4
Scenario 71	11.0	10.2	7.1	19.9	17.0	**15.5**	2.1	1.7	1.6
Scenario 72	12.0	10.3	8.0	20.2	17.2	**16.7**	2.0	1.7	1.6

a. based on 30 years of modeled flow data

b. modeled output based on observed climate data for a period of time. Flexibility in winter operations should be incorporated into the reservoir operating procedures to capture mid-winter melt water while continuing to manage flood risk.

Table 8: Model output for the years reservoirs were not filled (30 years total)

	95% of May 1st			90% of May 1st		
	Shand	**Conestogo**	**Guelph**	**Shand**	**Conestogo**	**Guelph**
*Historic Climate	3	6	1	0	1	0
Scenario 30	5	1	0	1	0	0
Scenario 31	8	8	0	5	5	0
Scenario 34	9	10	0	5	4	0
Scenario 52	7	7	0	3	5	0
Scenario 53	6	7	1	3	2	0
Scenario 58	7	8	0	2	3	0
Scenario 65	11	10	0	6	6	0
Scenario 66	13	14	0	8	8	0
Scenario 71	6	6	0	2	2	0
Scenario 72	12	10	0	7	6	0

* modeled output based on observed climate data

A selection of five climate change scenarios (Scenarios 30, 52, 65, 66 and 14) were also analysed using the Luther Reservoir Yield model to investigate considerations for the Legatt low flow target. Assessing the effects of climate change on the ability of the Luther Reservoir to provide flow augmentation is not a straight forward exercise due to a difference in the inflow calculation method and accuracy limitation in low flow modeling with the current hydrologic model. A modified approach was used to assess the five climate change scenarios, using both the Luther Dam reservoir yield model and an analysis of the inputs and outputs.

Results of the reservoir yield modeling indicate that the current flow target of $0.42m^3/s$ at Legatt can be maintained in a future climate, but the hydrologic model results generally had higher inflows to the reservoir than were expected. Further analysis that compared the changes to the amount of inflow and the amount of discharge needed to meet the Legatt flow target for future climate conditions showed that for the driest year, there would be an increase in the need for augmentation of about 35% during the summer season. For the same scenario, there would be a decrease in inflows to the reservoir by about 20%; however, the total inflow would still be much higher than what is needed to augment the river to meet the Legatt flow targets.

Using the existing operating procedures and flow targets gave the highest reliabilities in meeting the flow targets based on historical climate data. Adoption of an operational winter flow target at Doon of $5.8m^3/s$ will ensure some flexibility in winter operations while increasing winter flows. Increases in summer flow targets or decreases in spring filling levels will decrease the reliability of meeting flow targets. Decreased reliabilities may still be above 95% under historic climate conditions, but there will be little capacity to adapt to a changing climate. The climate change scenarios suggested that meeting low flow targets in the future may be more challenging as well as filling the reservoirs in the spring.

Flexibility in the spring filling cycle may be needed to ensure adequate storage to meet fall flow targets. Operations during the spring filling cycle have evolved over time in response to changing winter conditions. There will be a need for adaptive management as the climate continues to change to ensure flow targets can continue to be met into the future.

Low Flow Reliabilities for Wastewater Treatment Planning

Values for low flows are needed in planning for treated wastewater discharges, water takings and ecological flow requirements within a river system. Different uses of the river will require different low flow evaluations. The focus of this section is to evaluate $7Q_{20}$'s or equivalents for the regulated river system. The $7Q_{20}$ is the basic design flow for continuous point source discharges used by the Ministry of the Environment and Climate Change in Ontario and is the starting point for treated effluent assimilation studies. The $7Q_{20}$ can also be used in the assessment of surface water taking reliability.

A $7Q_{20}$ is the minimum 7-day average flow with a recurrence period on average of once in 20 years and is equivalent to 95% reliability by occurrence. The $7Q_{20}$ is calculated using frequency analysis on high quality stream flow data. Frequency analysis is the process of using a past record of hydrologic events to determine future probability of occurrence of these events. The analysis requires the data to fit a theoretical probability distribution and to follow statistical criteria including randomness, independence, homogeneity and stationary (Watt et. al. 1989). However, rivers that are controlled or regulated through the operation of a dam to release water according to specific rule curves violate the randomness criteria making traditional frequency analysis more complex as the data may contain established trends that need to be accounted for. It is important; however, that the flow data used in the derivation of a $7Q_{20}$ for a regulated river reach be evaluated for changes to reservoir operations and should be of a similar or longer period than the probability range of interest.

Detailed analysis of the historic flow data, reservoir operation and flow target reliability is needed to determine low flow statistics, especially a $7Q_{20}$ or equivalent. Description of reservoir operations and an analysis of flow target reliability have been included in previous sections. This section focuses on calculating $7Q_{20}$'s by analysing the historic flow record within the regulated river reaches. Three different methods are used in this report to estimate a $7Q_{20}$ or equivalent for regulated river reaches. The resulting $7Q_{20}$'s are evaluated in terms of occurrence and duration to arrive at one value per season for each gauge site.

Methodology

Three different methods have been used to determine $7Q_{20}$ or equivalent flows in the regulated reaches of the Grand River watershed: 1. frequency analysis, 2. flow targets, and 3. flow duration. A total of nine stream gauge locations were used in the analysis. Six of the gauges are low flow target locations and three are between target locations, but close to wastewater treatment plants. A seasonal $7Q_{20}$ or equivalent flow was calculated for each gauge location and method. The seasons are based on reservoir operations with winter/spring from January to May, summer from June to September and the fall season from October to December. Low flows for the winter/spring period were calculated using the winter months of January to March only. A description of the available flow data is given in Table 9.

Table 9: Description of flow data

Gauge	Operator	Notes
Legatt	GRCA	The flow target was adopted in 2004 giving a short record for analysis. To expand the period of record flow records from the reservoir yield analysis were used. No frequency analysis was conducted. A valve was installed in 1989 giving better discharge control.
Doon	GRCA	Flows are affected by the Region of Waterloo Municipal Supply taking. Takings have been added back in to make a consistent record for analysis and then subtracted afterwards for final $7Q_{20}$ values. (1984 to 2008 corrected flow data available)
Below Guelph	WSC	The gauge was offline in 1997 during bridge reconstruction. Flows from this period were replaced with output from reservoir yield modeling.
Speed at Cambridge, St. Jacobs	WSC/GRCA	Operation of these gauges changed in 2002 from the GRCA to Water Survey of Canada. 1984-2002 record from GRCA operated gauges and 2003-2010 record from WSC operated gauges. No winter correction for GRCA data sets.
Elmira	WSC/GRCA	The GRCA operates a flow gauge in Elmira, but there have been issues with the accuracy of low flows in the rating curve. Flows from the Water Survey of Canada gauge downstream was used as the observed record for Elmira. (This gauge includes sewage treatment plant discharges and pump and treat discharges)
Below Shand, Galt, Brantford	WSC	Data used as provided by the Water Survey of Canada.

1. *Frequency Analysis*

The first method uses frequency analysis to determine the appropriate low flow statistic, or $7Q_{20}$. A graphical method was used to estimate the $7Q_{20}$ in this study because the nature of the regulated flow series made it difficult to fit the data to common theoretical probability distributions. The graphical technique used the lowest 7 day average flow for each season and the Cunnane plotting position formula as given in Watt et. al. (1989). Flow records were used as given in Table 9, except for the Below Shand gauge. Maintenance at Shand Dam in the fall of

1991 affected the recorded flow series at the gauge. To fill in this record the entire fall period in 1991 was replaced with output from the reservoir yield model for the Below Shand gauge.

Flows at the Legatt gauge were not used in this analysis since the period of record for current reservoir operations at Luther Marsh is too short. Reservoir yield data was investigated to fill out the period however it contained too many instances of the flow equalling the minimum target causing the resulting low flow series to not fit available probability distributions.

2. *Flow Targets*

The second method uses the low flow targets as set out in the reservoir operating policy (2004) as $7Q_{20}$ equivalents. Gauges that are between low flow target locations are assigned the upstream low flow target plus an estimate of the $7Q_{20}$ for local inflows. The equivalent $7Q_{20}$ flows using this method take into account flow target reliability, proximity to flow target location and flow series analysis for local inflows. Low flow targets are important to sewage treatment plant design and assessment of assimilative capacity. Lowflow targets originally established in the 1982 basin study were used in waste water planning in the 1982 study.

The Doon and reservoir discharge target locations were given $7Q_{20}$ equivalents less than the flow targets. The target at Doon is to be met before the Region of Waterloo's Municipal taking of approximately $0.9m^3/s$ at the Manheim Water Treatment Plant intake. Given this, the $0.9m^3/s$ flow is not available for waste assimilation and was therefore removed from the flow target.

The discharge targets at the large dams are different than other locations. Discharge can be reduced to inflows regardless of the flow target in cases of low reservoir levels. Low reservoir levels may be the result of major maintenance work or prolonged drought conditions. The proposed $7Q_{20}$ equivalents during the fall and winter periods have been reduced to take this into account. All other locations use the flow targets or the upstream target location's $7Q_{20}$ equivalent with local inflows accounted for. Waste water plant in close proximity to large dams, for example the Elora and Fergus plants are very dependent on minimum dam low flow targets.

3. *Flow Duration*

The third method is to calculate $7Q_{20}$ equivalent flows based on flow duration analysis and uses a nearby non-regulated river to determine appropriate flow duration statistic to describe a $7Q_{20}$. The $7Q_{20}$ in a nearby natural river is calculated using frequency analysis and then a flow duration analysis is used to calculate the equivalent flow duration statistic that equates to the $7Q_{20}$. The flow duration statistic is then calculated for the regulated reaches to estimate the $7Q_{20}$ equivalent flow.

The Nith River at Canning was chosen to represent a nearby non-regulated river. The Nith River is a large tributary of the Grand River, is not regulated and has a high quality flow data record. Seasonal $7Q_{20}$'s were calculated for the Canning gauge for the 1984 to 2010 period to coincide with the current operating procedures at the reservoirs. Seasonal $7Q_{20}$ flows at the Canning gauge were equivalent to the seasonal $Q_{99.6}$ flow (i.e. had a reliability of a certain flow occur

Table 10: Effects of outliers to $7Q_{20}$ equivalent calculations

Conditions in 1998/1999	Location	Not Modified		Modified	
Low water conditions in 1998 and 1999 were some of the worst on record. Targets were not met. Decisions were made to deviate from flow targets to manage available water. Lessons were learned from this period and the reservoirs will be operated differently in future dry periods. Operational procedures are being added to the Drought Contingency Plan to help guide future reservoir operations during dry periods.	Doon Galt Brantford St. Jacobs	Summer Fall Winter Fall Winter Fall Summer Fall	8.2 4.2 5.8 7.9 9.4 13.8 2.4 1.2	No 1999 No 1998 No 1999 No 1998	8.8 5.2 7.0 9.7 14.5 15.4 2.9 1.4
Incorrect Flow Data					
Reservoir discharges were 0.42m^3/s but the downstream gauge read 0.3m^3/s. Gauge values were incorrect.	Legatt	Fall	0.3	No 2007	0.4
Heavy ice cover in 2003 elevated the level reading compared to ice free conditions giving incorrect flow data in real time. Corrected flow data was significantly lower than operational flow data.	Guelph Guelph	Winter Summer	0.8 1.3	No 2003 No 2001	1.1 1.4
Reservoir Maintenance					
Shand Dam was drawn down for maintenance work. Downstream flow targets were met with increased discharge from Conestogo Dam	Below Shand	Fall	0.8	No 1991	1.5

99.6% of the time.) This is consistent with findings of Pyrce (2004) that found the $7Q_{20}$ for eleven gauges in Ontario was equivalent to flow durations of $Q_{99.5}$ to $Q_{99.9}$.

The flow records described in **Table 9** form the "not modified" or baseline flow record. In addition there are some years that have been outliers and the data from those years skew the data set. Outlier years are periods that are outside of normal operations and there is a reduced likelihood of these conditions occurring again because of changes in equipment, operations or procedures. Each issue is presented in **Table 10** along with the $Q_{99.6}$ for both the modified and not modified flow records, including a description of the circumstances.

In each of the cases in **Table 10** removing a single year of data greatly changed the $7Q_{20}$ equivalent value and shows the significance of short extreme dry periods and periods of incorrect gauge readings on low flow statistics calculations. The $7Q_{20}$ equivalents from the modified flow series were used for further analysis.

Results

Results for the three methods are given in **Table 11** for 9 gauge locations on the regulated portion of the river system. Values were similar between the three methods for the smaller water courses, such as at Legatt and Elmira. There is a greater difference in values for the larger river gauges particularly at Brantford and Doon with the low flow statistics calculated from observed flow data much lower than the low flow target. Summer $7Q_{20}$ equivalent values were higher than the fall and winter period for the regulated system, in contrast to a natural system where the summer season typically has the lowest flow.

Table 11: Estimated $7Q_{20}$ equivalent flows for regulated river system using observed flows

Gauge	Winter/Spring			Summer			Fall		
	Freq.	Target	Q99.6	Freq.	Target	Q99.6	Freq.	Target	Q99.6
Legatt [a]	--	0.42	0.42	--	0.42	0.40	--	0.42	0.40
Below Shand	1.5	2.5	1.5	2.8	2.8	3.0	1.5	1.6	1.5
Doon [b]	3.1	4.9	3.4	8.4	9.0	8.8	4.5	6.2	5.2
Galt	6.5	7.2	7.0	11.0	12.2	11.2	9.2	9.1	9.7
Brantford [c]	13.2	17.0	14.5	16.1	17.0	16.2	14.2	17.0	15.4
Below Guelph	1.1	1.1	1.1	1.4	1.7	1.4	1.2	1.1	1.2
Speed at Cambridge	2.2	1.8	1.9	2.5	2.7	2.6	1.9	2.4	2.0
St Jacobs	3.4	2.1	2.6	2.8	3.1	2.9	1.7	1.7	1.4
Near Elmira	0.2	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3

a. period of record with current reservoir operations is too short for frequency analysis
b. flow data covered 1984 to 2008; all values have the Region of Waterloo Municipal Taking of 0.9 m^3/s subtracted.
c. after the City of Brantford Municipal Taking

The number of occurrences below the $7Q_{20}$ equivalent in the 1984 to 2010 period is given in **Table 12** with the longest number of days in a season below the given $7Q_{20}$ equivalent provided in brackets. An occurrence is counted if at any time in the season the 7 day average flow drops below the $7Q_{20}$ equivalent. Only one occurrence is counted per year/season regardless of the number of times the flows fluctuate around the low flow value. The longest number of days in a season below the $7Q_{20}$ equivalent is not necessarily consecutive days, so the flow can fluctuate above and below the value within the season. In cases of multiple occurrences only the season with the highest number of days is given to show the worst case scenario.

Table 12: Number of year's 7-day flow dropped below estimated 7Q20 from 1984 to 2010

	Winter/Spring			Summer			Fall		
Gauge	**FA**	**Target**	**Q99.6**	**FA**	**Target**	**Q99.6**	**FA**	**Target**	**Q99.6**
Legatt [a]	--	1 (25)	1 (25)	--	3 (28)	3 (18)	--	1 (32)	1 (29)
Below Shand	1 (11)	5 (81)	1 (11)	1 (1)	1 (1)	3 (5)	1 (11)	1 (41)	1 (11)
Doon [b]	1 (7)	2 (58)	2 (12)	1 (24)	3 (72)	2 (61)	1 (23)	3 (60)	3 (40)
Galt	1 (13)	2 (15)	2 (14)	1 (1)	3 (46)	2 (6)	1 (44)	1 (39)	1 (58)
Brantford [c]	1 (17)	2 (48)	2 (18)	1 (9)	3 (25)	1 (11)	1 (17)	2 (62)	2 (28)
Below Guelph	1 (23)	1 (23)	1 (23)	1 (21)	6 (42)	1 (21)	1 (15)	0 (-)	1 (15)
Speed at Cambridge	1 (34)	0 (-)	1 (3)	1 (2)	3 (19)	2 (10)	1 (4)	3 (51)	2 (10)
St Jacobs	2 (13)	1 (1)	2 (7)	2 (20)	6 (26)	3 (22)	2 (68)	2 (68)	2 (41)
Near Elmira	1 (11)	3 (69)	3 (69)	3 (33)	3 (33)	3 (33)	3 (14)	3 (14)	3 (14)

*number in brackets is the max number of days (non-consecutive) in one season below the estimated $7Q_{20}$

Climate Change Considerations

The $7Q_{20}$ equivalents provided are based on the past observed record and assume that future flows will be similar. With a changing climate, that assumption may not be valid. To investigate if the proposed $7Q_{20}$'s are robust enough under different climate change conditions 99% reliability flows from the climate change scenarios were calculated and compared with proposed $7Q_{20}$ equivalent flows for the three low flow target locations on the lower Grand and Speed Rivers, **Table 13**. Climate change investigations for the Legatt target indicated that there would most likely not be an issue in meeting the flow target in the future and therefore Legatt was not included in this section.

For Doon, there were two scenarios in the summer and four scenarios in the fall period where Q_{99} flows were below the proposed $7Q_{20}$. The summer scenarios predicted a 20% drop in summer precipitation and represented the driest 9% of all 76 scenarios available for analysis. The Q_{99} flows were quite low, but the Q_{95} flows, given in **Table 7**, were only slightly below the target flows. The Reservoir Yield model does under predict flows and reliability in the fall period so even though the fall flows appear to be low for the 4 scenarios these results may be underestimated. It is not recommended to change the proposed $7Q_{20}$'s for Doon based on the results of the climate change scenario modeling, but the flow values should be reviewed on a regular basis.

For the Brantford target, half of the scenarios produced summer Q_{99} flows below the proposed $7Q_{20}$, but two of these were similar to the $7Q_{20}$. For the fall period, all of the scenarios had Q_{99} flows below the proposed $7Q_{20}$. The reservoir yield model predicts lower fall flows for Brantford than have been observed, most likely because of the model's lack of foresight. That being said, the reduction in fall flows is a strong trend with all 10 scenarios producing Q_{99} flows

Table 13: Flow at 99% reliability in climate change scenarios

	Doon			Brantford			Below Guelph		
	Jan-Apr	May-Sep	Oct-Dec	Jan-Apr	May-Sep	Oct-Dec	Jan-Apr	May-Sep	Oct-Dec
7Q20 Equivalent [a]	3.4	8.8	5.2	14.5	16.2	15.4	1.1	1.4	1.1
Flow at 99% Percent Reliability [b]									
Scenario 30	7.5	10.2	7.1	15.5	17.0	**13.2**	1.7	1.7	1.3
Scenario 31	8.6	9.9	7.1	17.0	17.0	**14.6**	1.8	1.6	**1.0**
Scenario 34	8.1	9.4	**4.0**	17.0	**15.1**	**9.3**	1.5	1.5	**1.0**
Scenario 52	9.1	9.9	7.1	17.0	17.0	**14.0**	1.7	1.6	1.1
Scenario 53	8.2	9.9	5.8	15.9	**16.0**	**11.8**	1.6	1.5	**1.0**
Scenario 58	6.4	9.9	**4.7**	**14.1**	**15.7**	**10.4**	1.5	1.5	**1.0**
Scenario 65	8.5	**7.3**	**4.0**	17.0	**12.5**	**9.8**	1.6	1.4	**1.0**
Scenario 66	8.0	**7.3**	**4.1**	17.0	**12.5**	**9.7**	1.6	1.4	**1.0**
Scenario 71	9.2	9.9	5.5	17.0	**16.1**	**11.9**	1.6	1.6	1.1
Scenario 72	8.4	9.9	6.6	17.0	17.0	**13.1**	1.7	1.5	**1.0**

a. draft proposed 7Q20 equivalents
b. based on 30 years of modeled flow data

well below the proposed $7Q_{20}$ equivalent. It is recommended that there is a reduction of 10% in the proposed $7Q_{20}$ to account for a higher chance of not meeting the fall flow target at Brantford in the future. The resulting value would be 13.9m^3/s.

The Guelph proposed $7Q_{20}$'s for winter and summer were equal to or greater than the Q_{99} flows for all scenarios. In the fall about half of the scenarios were slightly below the proposed $7Q_{20}$. These results show that climate change may result in flows closer to the $7Q_{20}$ more often, but it is not recommended to change the proposed $7Q_{20}$'s for the Below Guelph target based on these results.

Accuracy in Low Flow Measurements

Herman Goetz, the manager of the Water Survey of Canada (WSC) office out of Burlington, was consulted with respect to the accuracy of stream flow measurements and rating curves used to convert water levels at gauge stations to flow. Herman indicated traditional methods use 20 panels to divide the cross section where the flow is obtained. This method has been used for many decades. Research used to establish this method indicates measured flows can be expected to be within 5% of the actual flow using this method. Modern Acoustic Doppler Current Profilers (ADCP's) are starting to be used by WSC. Research is indicating the ADCP's can achieve measured flows within 2 to 3% of the actual flow. Based on the above manually measured flows can be expected to be within 5% of the actual flow.

Rating curves are used to estimate flow from water levels. The quality of the gauge control affects the accuracy of the flow versus level relationship. A gauge with a stable gauge control (cross section) that isn't subject to backwater from weed growth or subject to shifts due to erosion or deposition of sediment can be expected to produce accuracies within 5% similar to the flow measurement.

Most of the flow targets in the Grand River watershed are based on data from Water Survey of Canada gauges, which have a high level of accuracy. It is recommended that proposed $7Q_{20}$'s are reduced by 5% to account for measurement inaccuracies.

7Q20 Equivalents

The $7Q_{20}$ equivalents for each gauge were chosen from one of the calculated values based on evaluating the number of occurrences, length of occurrence, and climate change considerations. Then each value was reduced by 5% to account for measurement inaccuracies and rounded to one decimal place. The $7Q_{20}$ equivalents are given in

Table 14.

For the Doon gauge, all three proposed $7Q_{20}$ equivalent flows are the second lowest estimates and were calculated with flow duration using the modified flow series. Although the flow duration values were not the lowest estimates, the additional occurrences below that flow rate were for short durations of approximately 3 days each.

The winter $7Q_{20}$ for Galt gauge is 0.5 m^3/s higher than the lowest estimated $7Q_{20}$. This increase in the winter $7Q_{20}$ results in one additional occurrence for a short time period in the 27 years of observed data reviewed. A review of winter flows from 1965 to 1984 at the Galt gauge showed no additional occurrences of flows below the $7m^3/s$.

Table 14: $7Q_{20}$ equivalent flows for regulated river system

Gauge	Winter/ Spring	Summer	Fall
Legatt	0.4	0.4	0.4
Below Shand	1.4	2.7	1.5
Doon	3.2	8.4	4.9
Galt	6.7	10.5	8.6
Brantford	13.8	15.4	13.2
Below Guelph	1.0	1.3	1.0
Speed at Cambridge	1.7	2.5	1.9
St Jacobs	2.0	2.7	1.3
Near Elmira	0.2	0.3	0.3

For the Brantford gauge, the second lowest value was chosen for all three seasons. The proposed winter and fall values are over $1.0m^3/s$ higher than the lowest value, but resulted in only one additional occurrence in 27 years and not a large increase in the length of time below the flow value. The proposed summer $7Q_{20}$ is $0.1m^3/s$ higher than the lowest value, did not result in any additional occurrences and only 2 additional days below the $7Q_{20}$. The fall target was then reduced by 10% to account for climate change considerations. Reservoir reliability calculations for the Brantford target show a very high reliability in meeting the flow target at Brantford.

There are 16 wastewater treatment plants discharging into regulated river reaches in the Grand River watershed. Final recommended $7Q_{20}$ equivalent values for the 16 wastewater treatment plants are given in Table 15. For plants between gauge locations, local inflows were taken into account when good quality data about the local inflows were known.

Table 15: Proposed $7Q_{20}$ equivalent flows for regulated river system

WWTP	Winter/ Spring (m³/sec)	Summer (m³/sec)	Fall (m³/sec)	Notes
Grand Valley	0.4	0.4	0.4	Legatt gauge
Fergus	1.4	2.7	1.5	Below Shand gauge
Elora	1.7	2.8	1.6	Below Shand plus $7Q_{20}$ from Irvine River
Waterloo	3.2	8.4	4.9	Doon after the Region of Waterloo Municipal taking
Kitchener	3.2	8.4	4.9	Doon after the Region of Waterloo Municipal taking
Preston	6.7	10.5	8.6	Galt gauge
Galt	6.7	10.5	8.6	Galt gauge
Paris	12.4	14.9	12.4	Brantford gauge minus $7Q_{20}$ from Whitmans Creek
Brantford	13.8	15.4	13.2	After City of Brantford municipal taking
Caledonia	13.8	15.4	13.2	Used the Brantford gauge $7Q_{20}$ for York
Cayuga	14.3	15.5	13.4	Same as Caledonia plus $7Q_{20}$ from Mckenzie Creek
Dunnville	14.3	15.5	13.4	Same as Caledonia plus $7Q_{20}$ from Mckenzie Creek
Guelph	1.0	1.3	1.0	Below Guelph gauge
Hespeler	1.7	2.5	1.9	Speed at Cambridge gauge
St. Jacobs	2.0	2.7	1.3	St. Jacobs gauge
Elmira	0.2	0.3	0.3	Near Elmira gauge

*municipalities should consult with the MOECC and GRCA to confirm these values before beginning a wastewater assimilation study

Summary and Recommendations

The current GRCA reservoir operating policy balances the two priority water management objectives of the reservoirs – to provide flood control during times of high flows and to provide enough flow in the river system to meet downstream low flow targets. Historically these low flow targets considered the need for providing sufficient municipal water supply as well as wastewater assimilation. Further, practices and procedures are in place to update and inform municipal and provincial water managers on the current state of reservoir operations and river conditions. These practices and procedures allow for municipalities to implement activities such as water conservation measures or other actions (e.g. low water response) to actively manage water and wastewater within the watershed.

Low flow targets have been and can be met in the future with the same reliability. The operational low flow targets in the Grand River watershed are set based on flow reliability by time of 95% or higher. The current operational low flow targets downstream of the reservoirs are reliable with 95% or greater reliability by time as shown both by observed data and reservoir yield modeling. Increases to the summer low flow targets are not recommended as it would not leave capacity to adapt to a changing climate and could result in more instances of flows below the low flow targets. Adoption of an operational winter target at Doon of 5.8 m^3/s is recommended since it will not greatly affect the flow reliability and leaves room for flexibility in light of climate change.

There is a lot of uncertainty in climate change predictions. However, there is likely to be an increase in mid-winter melts that will cause a greater need for active adaptive management with reservoir operations especially during the spring filling period. Flexibility will need to be maintained in reservoir operations during this period to ensure the reservoirs have sufficient water in storage to meet augmentation demands, while balancing flood risk.

Three different methods have been presented to estimate low flow equivalents in the regulated river system for wastewater planning. The resulting proposed $7Q_{20}$ equivalents combine information from observed flow data, reservoir reliability, inaccuracy in measurements, climate change considerations and reservoir operations. Most of the proposed $7Q_{20}$ equivalents are close to but less than the operational low flow targets. This gives a balance between reservoir reliability and allowing some capacity to adapt to changing climate conditions. It is recommended that the proposed $7Q_{20}$ equivalents be included in the Grand River Water Management Plan for future wastewater assimilation studies and that these values be reviewed in consultation with the Ministry of the Environment and Climate Change (MOECC) on a regular basis.

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Appendix 1. Current GRCA Reservoir Operating Policy (2004)

GRAND RIVER CONSERVATION AUTHORITY

Reservoir Operating Policy

February 17, 2004

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1.0 INTRODUCTION

This report outlines the operating rules for the seven multi-purpose reservoirs owned by the Grand River Conservation Authority. The multi-purpose reservoirs serve two key functions: flood control, and supplying water to the river in periods of low flow (flow augmentation). Auxiliary functions like hydro production and recreation result from the operation of the reservoirs. Figure 1 shows the location of the multi-purpose reservoirs.

The reservoirs are filled in the spring with the runoff from the melting snow pack and the spring rains. Water is released over the summer and fall period, to supply sufficient flow to the river to dilute effluent from the sewage treatment plants and maintain the river's ecological functions.

The two functions of flood control and water supply have conflicting objectives. To provide flood control, as much available storage as possible is desired, to provide flow augmentation, as much water as can safely be stored in the reservoir is desired. To resolve these conflicting objectives, a reservoir operating policy has been developed. The operating policy is expressed on the rule curves for each of the seven multi-purpose reservoirs. From time to time the operating policy is reviewed and modified.

2.0 HISTORY OF EXISTING RESERVOIR RULE CURVES AND OPERATING POLICY

The existing rule curves and operating policy for Authority Reservoirs date back to early 1978. At that time, a committee made up of representatives of the Ministry of Natural Resources, the Ministry of the Environment and the Grand River Conservation Authority reviewed and recommended the present day general operating procedures and general operating guidelines. These procedures and operating guidelines incorporated recommendations of the 1974 Flood inquiry. The GRCA adopted and implemented the policies and procedures.

In 1982, changes to the reservoir operating policy, dealing with low flow targets, were approved for use in 1983 on a trial basis. The 1982 review implemented the recommendations of the 1982 Grand River Basin Management Study. These changes were adopted and continue to this day. In 1988 a revised operating policy for Guelph Dam was adopted, allowing for a 300 millimeter increase in reservoir operating level, which provides additional water for flow augmentation.

The existing operating procedures and guidelines specify:

- Target reservoir levels for February 15th, April 1st, May 1st, June 1st and October 15th to balance flood control and low flow augmentation needs.
- Minimum low flow targets at Guelph (Edinburgh Road), Kitchener (Doon) and Brantford, for water quality and water supply.

Together these specifications form the operating policy for major dams operated by the Grand River Conservation Authority.

3.0 RESERVOIR RULE CURVES

The reservoir rule curves reflect the following assumptions and criteria:

a) 1974 Flood Inquiry Recommendations
The inquiry in the 1974 flood investigated the mechanisms of flooding and the role reservoir operations and operating policy played in that flood. A separate sub-committee reviewed the reservoir operating policy and recommended minimum flood control storage requirements for April 1st, May 1st and June 1st. These recommendations were intended to balance the need for available flood control storage and the storage needed to provide low flow augmentation. The upper rule curve for the three large dam Shand, Conestogo and Guelph reflect these minimum storage requirements.

b) Floodline Assumptions
The Regulatory flood design flows used to establish flood lines downstream of Shand Dam along the Grand River and the downstream of Conestogo Dam on the Conestogo River are based on reservoir operation assumptions. These design flows assume a minimum amount of storage will be available by October 15th of each year. This storage assumption was used to estimate Regulatory design flows. The reservoir minimum storage targets for October 15th , satisfy storage requirements needed to achieve existing downstream Regulatory flood and dyke design flows.

c) Dyke Design Assumption
The dyke design through the City of Cambridge Galt area is based on the Regulatory design flows. Therefore the dyke function assumes a minimum amount of storage will be available by October 15th of each year. The dykes through the City of Brantford were designed assuming unregulated flows and their function is not dependant on minimum reservoir storage assumptions and reservoir operations.

e) Physical Operating Constraints
Based on operating experience, winter levels at Shand Dam should be maintained above the 48 inch diameter valve, to prevent icing of the valve. The 66 inch diameter valve at Shand dam is not operated at lake elevation above 417.75 meters and is tested each fall after levels are below the 417.75 meters.

f) Flow Augmentation Assumptions
As part of the Grand River Basin Study (MOE 1982), flow augmentation alternatives were considered. This study examined what low flow targets could be reliability met downstream of GRCA reservoirs through Kitchener and Brantford on the Grand River and at the Hanlon expressway on the Speed River downstream of the City of Guelph. The minimum flow targets are summarized in Table 1

The flow augmentation assumptions assume straight-line drawdown of May 1st and June 1st storage through to October 15th. These assumptions form the upper and lower rule curves from May 1st and June 1st through October 15th. Water in storage after October 15th is drawn down to meet downstream fall flow targets and to reduce levels to the winter holding levels at the major dams.

Table 1 – Minimum Flow Targets

River	Location	Timing	Minimum target (m^3/s)
Grand	Grand Valley	Annual	0.42 at Leggatt gauge
	Shand Dam	Annual	Lesser of 2.8 or inflow
	Doon	May 1 – Sept 30	9.9 before Mannheim water-taking of 0.9
		Sept 30 – Dec 31	7.1 before Mannheim water-taking
		Dec 31 – Feb 29	2. 8 before Mannheim water-taking
	Brantford	May 1 – Oct 31	17.0
Conestogo	Conestogo Dam	Annual	Lesser of 2.1 or inflow
Speed	Guelph Dam	Annual	0.57
	Edinburgh Rd	June - Sept	1.7
		Oct - May	1.1
Canagagigue	Woolwich Dam	Annual	0.3

During the freeze-up period, Shand Dam is operated to avoid flows rates where ice jams have been historically observed. Discharge is managed where possible to encourage a smooth stable ice cover through the West Montrose reach downstream of the Elora gorge.

4.0 GENERAL OPERATING PROCEDURE

In the operation of multi-purpose reservoirs, the relative amounts of storage for flood control and flow augmentation vary with the season. In general, water available for flow augmentation is at a minimum in late winter or early spring and at a maximum in late spring or early summer. Available storage space in the reservoirs for flood control is at a maximum in late winter or early spring and at a minimum in late spring or early summer. Flood control planning in the Grand River Watershed has two focal points: spring runoff and fall extra-tropical storms. Authority operational policy provides maximum capacity for the spring runoff and approximately 65 percent of this capacity by mid-October. Table 2 outlines the volume of water being stored when the reservoirs are full.

Table 2 – Water in storage when reservoirs are full

	Normal High Water Level		Maximum High Water Level	
Dam	***Water Level (meters)***	***Water in Storage (x 1000m^3)***	***Water Level (meters)***	***Water in Storage (x 1000m^3)***
Shand	425.074	61,410	425.379	63,746
Conestogo	393.192	57,214	393.497	59,422
Guelph	348.0	16,944	348.996	22,363

Operational details vary from year to year, depending on weather conditions. After the spring runoff from snowmelt, Belwood and Conestogo reservoirs are stabilized at a level approximately

1.52 meters below the normal level. As spring progresses, the reservoirs are gradually raised to a point approximately 0.61 meters below normal level by early May and, if possible, to the full level by the end of May. Table 3 shows the target lake levels through the spring period, along with the amount of space available in the reservoirs for flood management.

Table 3 – Target Lake Levels and available storage volume for flood control

	April 1		**May 1**		**June 1**		**October 15**	
Dam	***Target Lake level (meters)***	***Available Storage (x 1000m³)***	***Target Lake level (meters)***	***Available Storage (x 1000m³)***	***Target Lake level (meters)***	***Available Storage (x 1000m³)***	***Target Lake level (meters)***	***Available Storage (x 1000m³)***
Shand	423.698	12335	424.574	6,044	425.074	2,336	417.010	45,000
Conestogo	391.973	10,361	392.579	6,414	393.192	2,208	386.205	38,574
Guelph	347.472	7,125	347.853	5,894	347.853	5,894	346.000	11,366
Small Dams*		3,824	varies	3,824	varies	3,824	varies	3,824
Total		33,644		22,176		14,262		98,764

*Small Dams include: Laurel Creek, Woolwich, Shade's Mills

Figures 2 through 8 show the operating rule curves for the seven multi-purpose reservoirs. Figure 9 shows the operating rule for Damascus Dam.

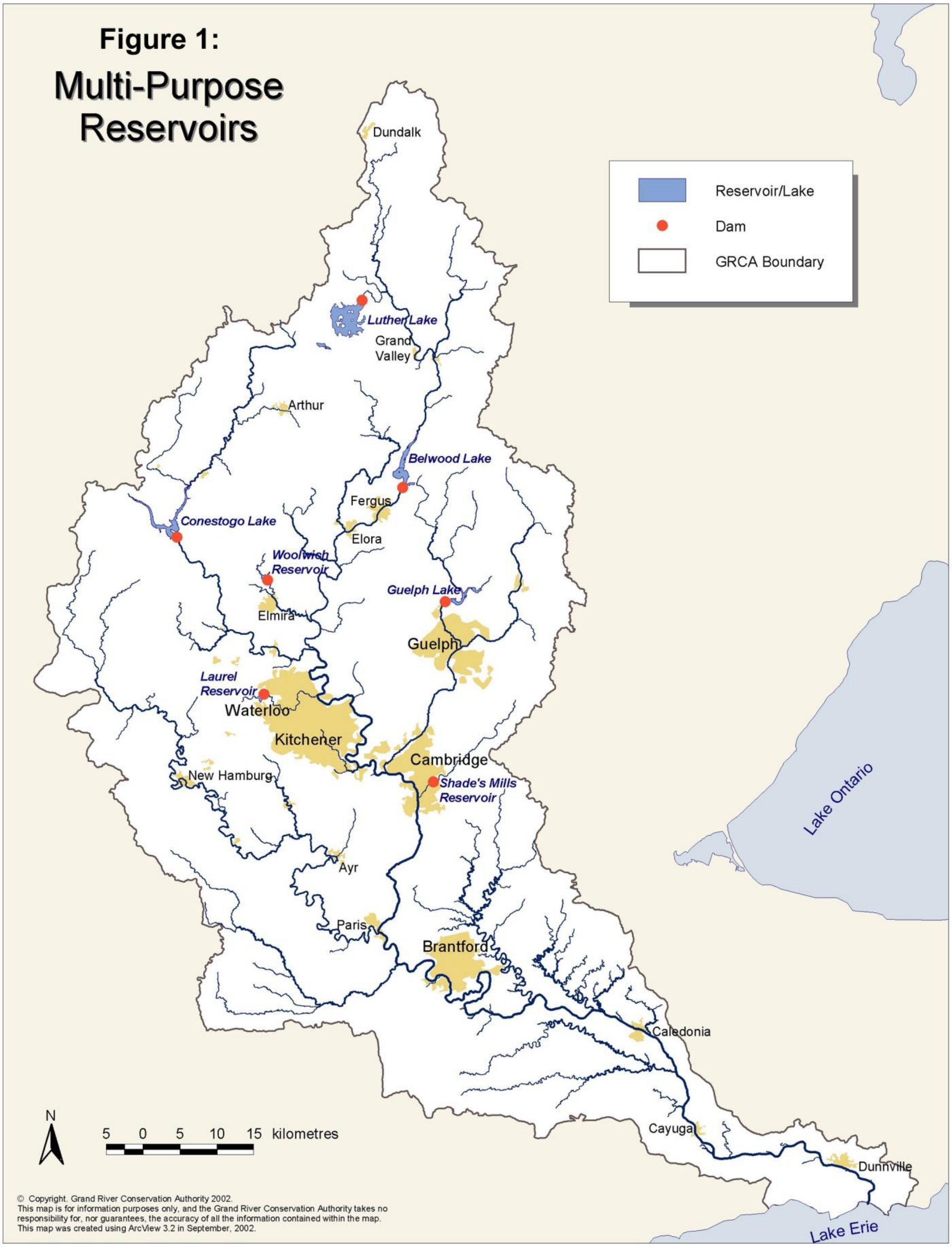
Figure 1:
Multi-Purpose Reservoirs
Reservoir/Lake
Dam
GRCA Boundary
Dundalk
Luther Lake
Grand Valley
Arthur
Belwood Lake
Fergus
Elora
Conestogo Lake
Woolwich Reservoir
Guelph Lake
Elmira
Guelph
Laurel Reservoir
Waterloo
Kitchener
Cambridge
Shade's Mills Reservoir
New Hamburg
Ayr
Paris
Brantford
Caledonia
Cayuga
Dunnville
Lake Ontario
Lake Erie
N
5 0 5 10 15 kilometres
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This map is for information purposes only, and the Grand River Conservation Authority takes no responsibility for, nor guarantees, the accuracy of all the information contained within the map.
This map was created using ArcView 3.2 in September, 2002.

Figure 2 - Shand Dam Rule Curve (Revised February 2004)

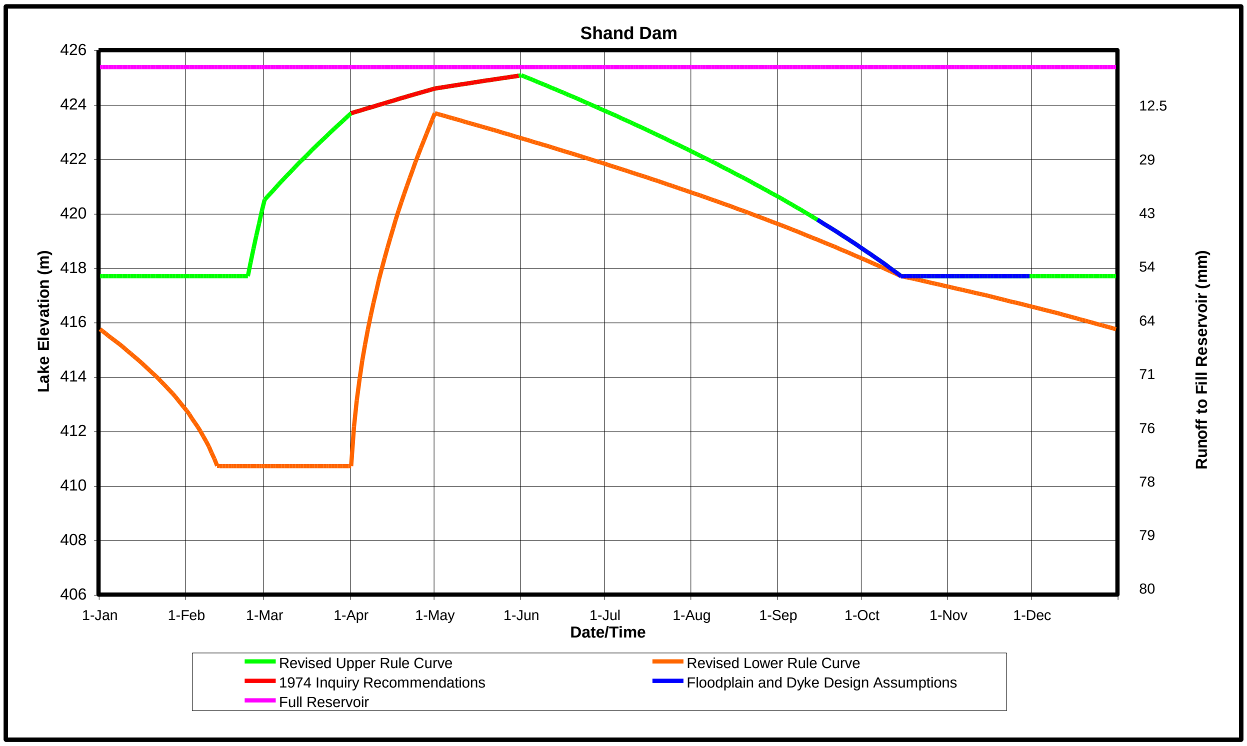


Figure 3 – Conestogo Dam Rule Curve (Revised February 2004)

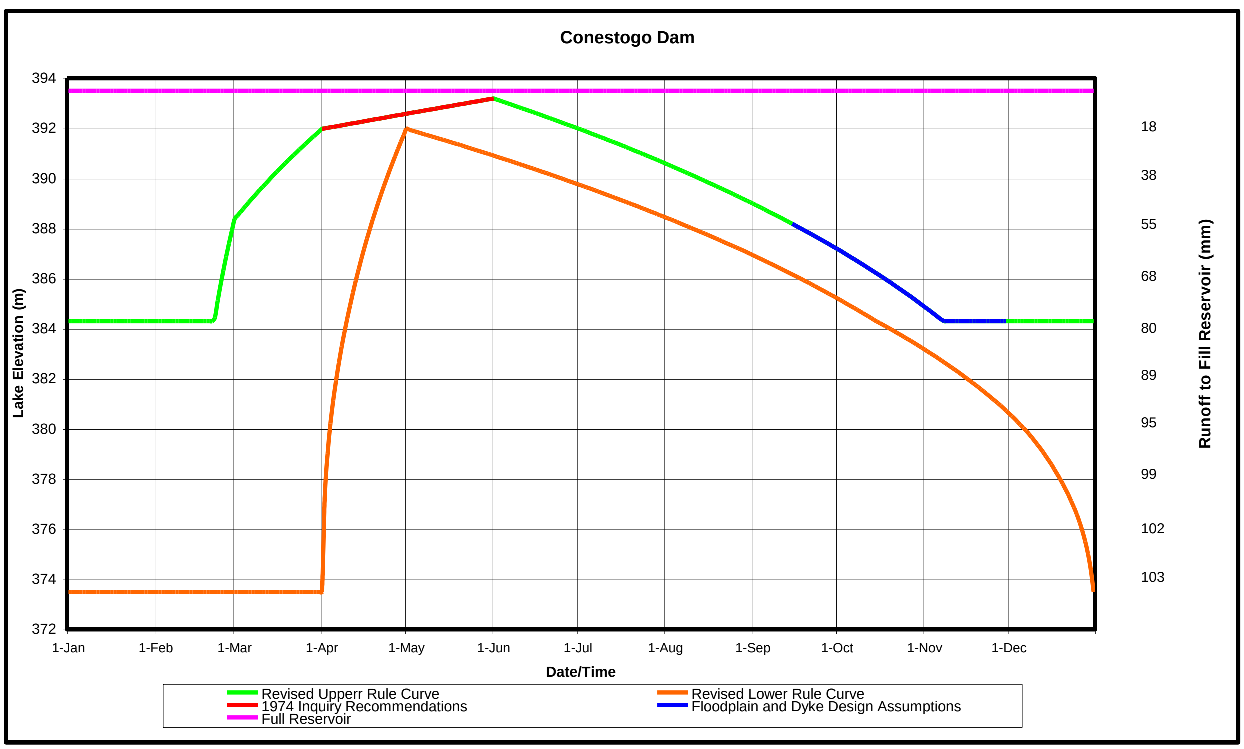


Figure 4 - Guelph Dam Rule Curve (Revised February 2004)

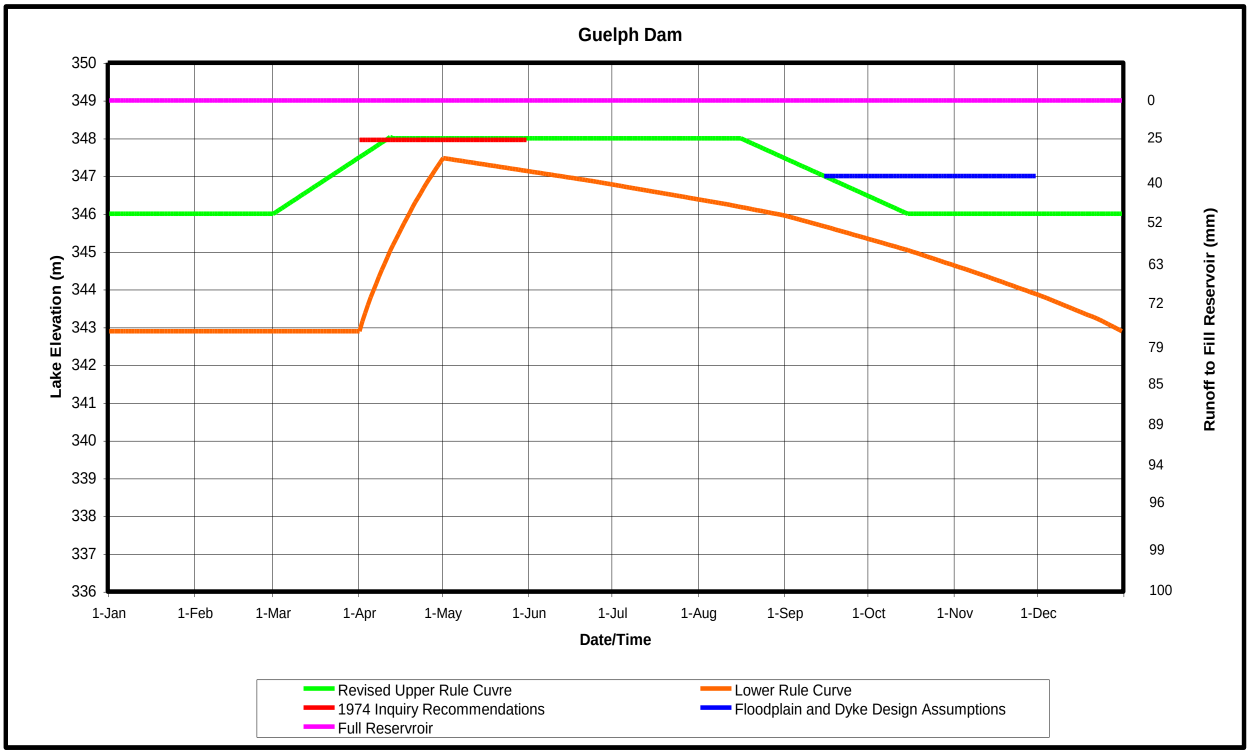


Figure 5 - Luther Dam Rule Curve

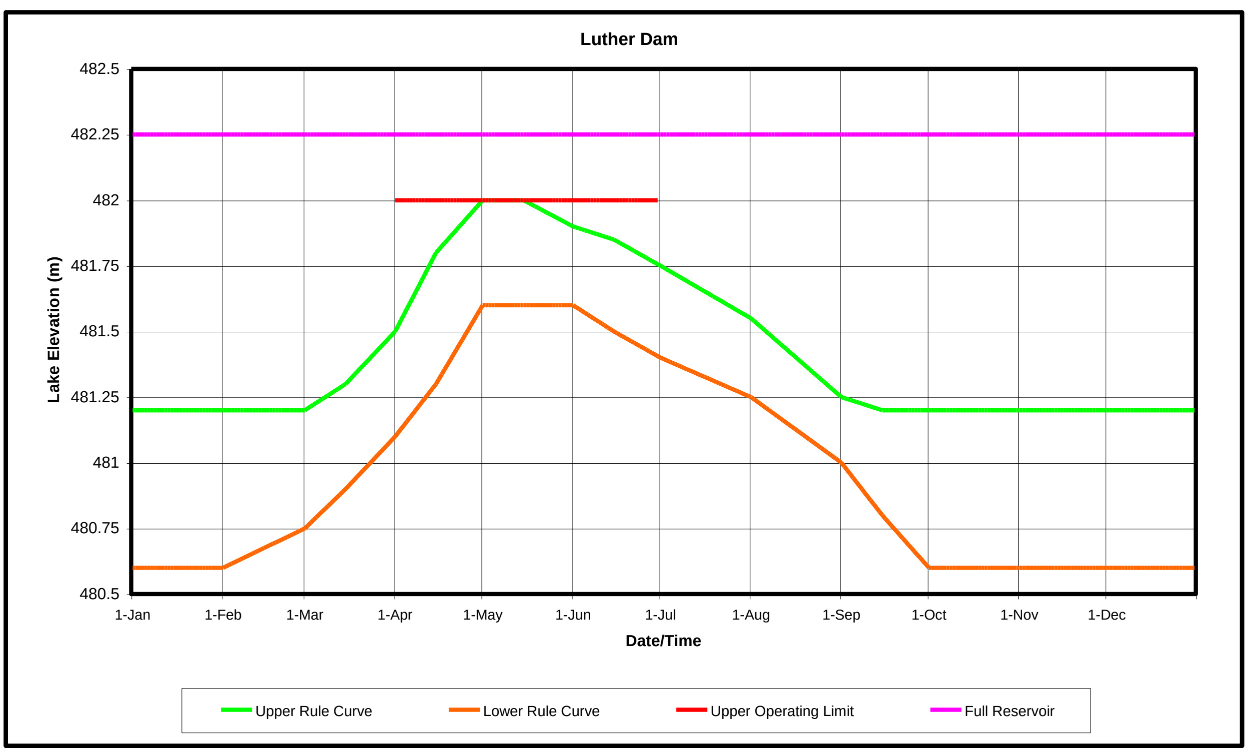


Figure 6 - Woolwich Dam Rule Curve

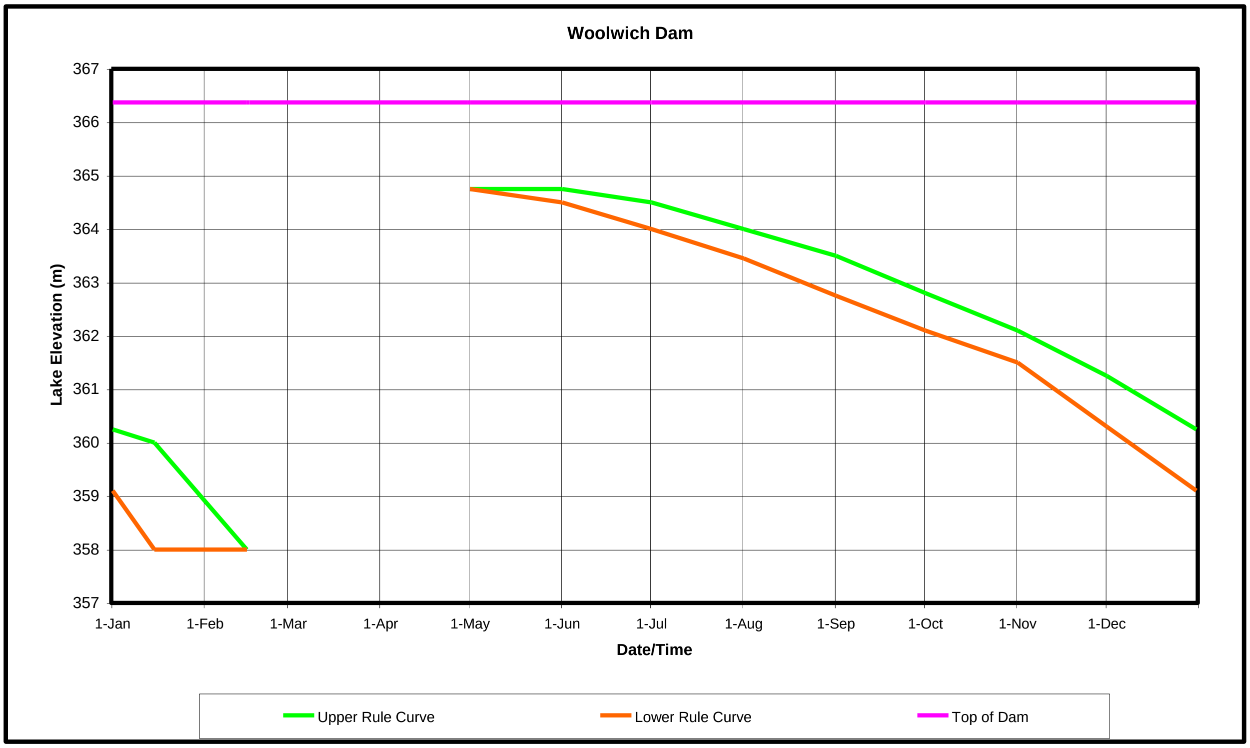


Figure 7 - Laurel Creek Dam Rule Curve

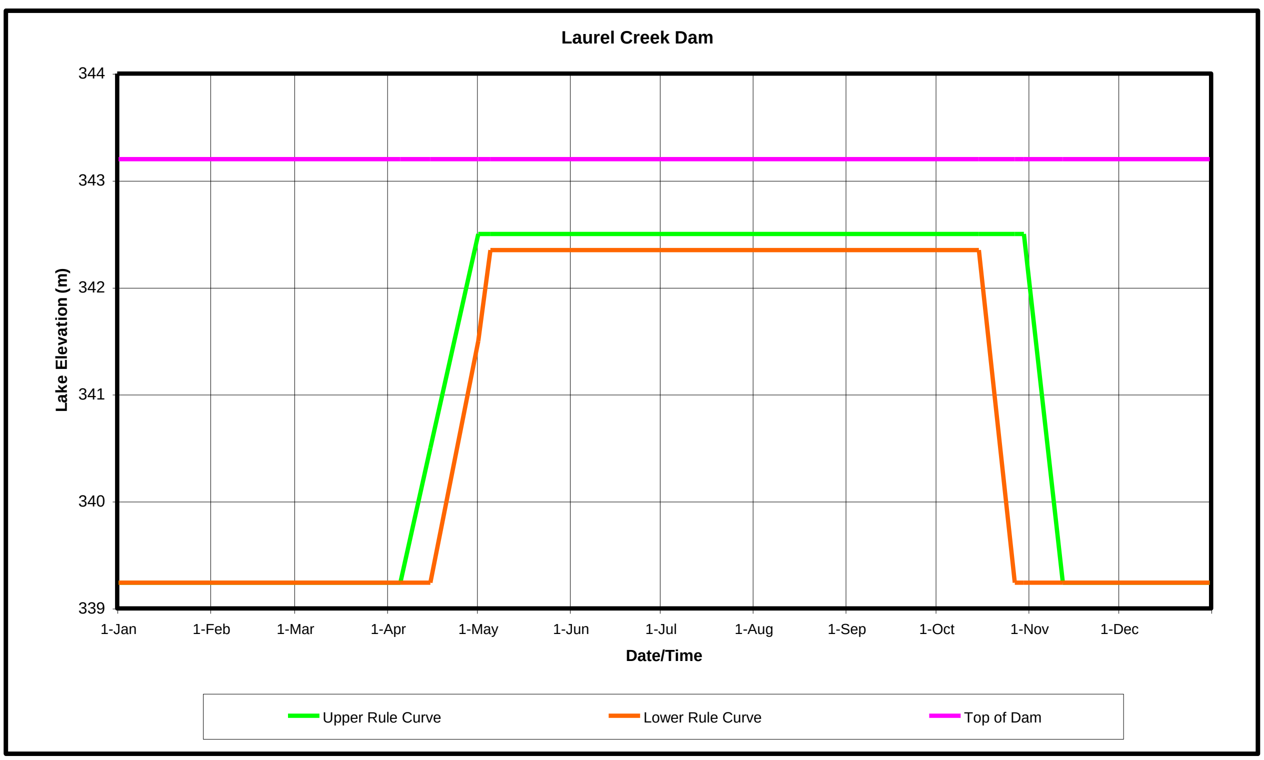


Figure 8 - Shades Mill Dam Rule Curve

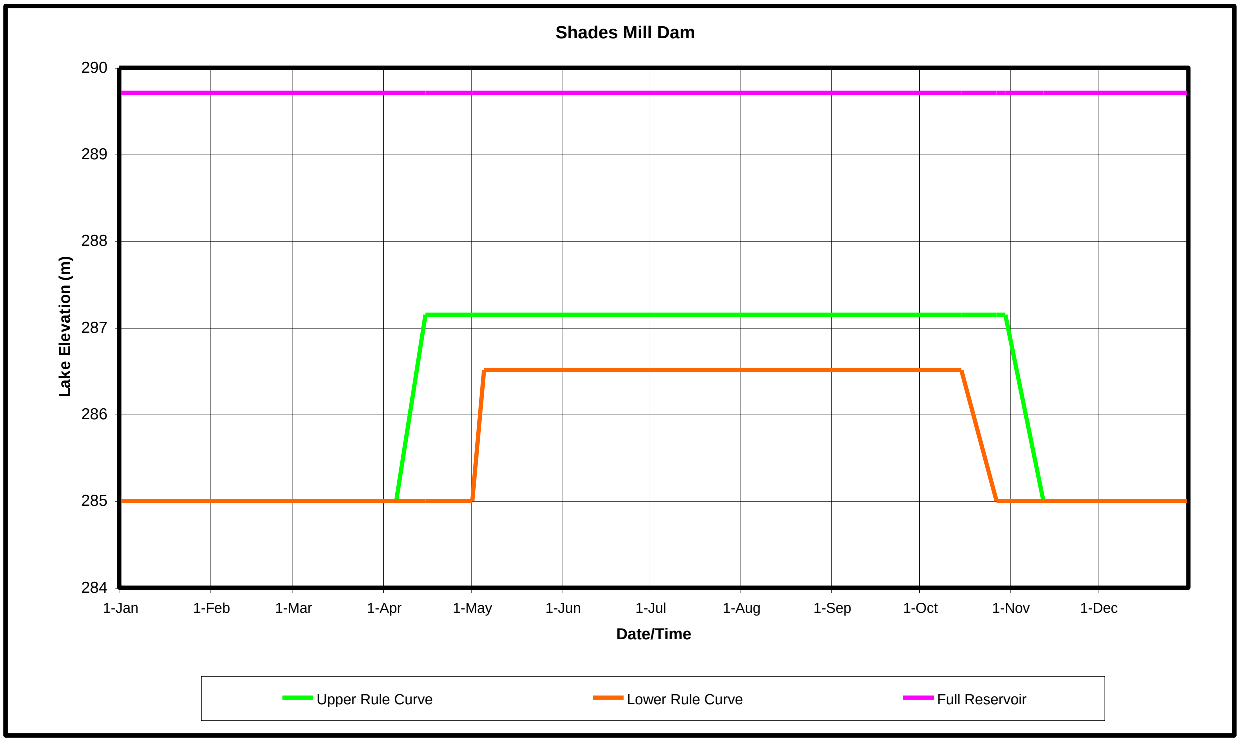
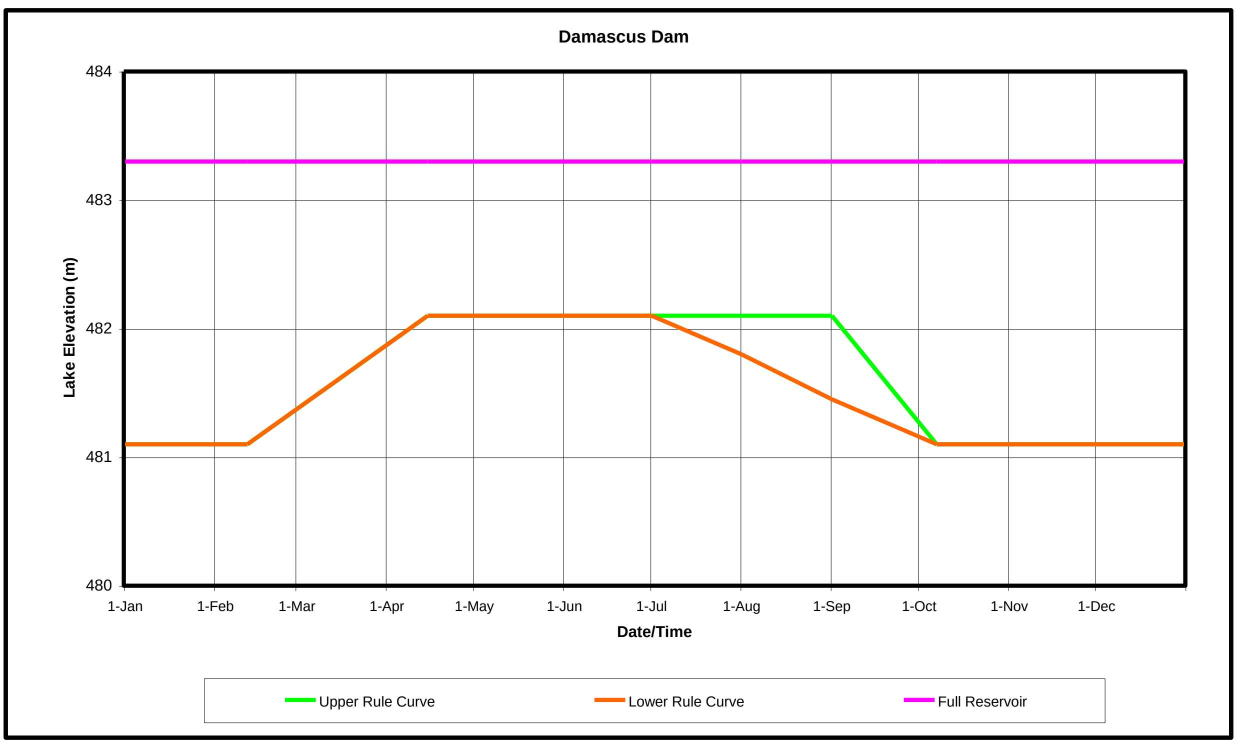


Figure 9 - Damascus Dam Rule Curve



Appendix 2. Rule Curves for the Shand, Conestogo, Guelph and Luther dams.

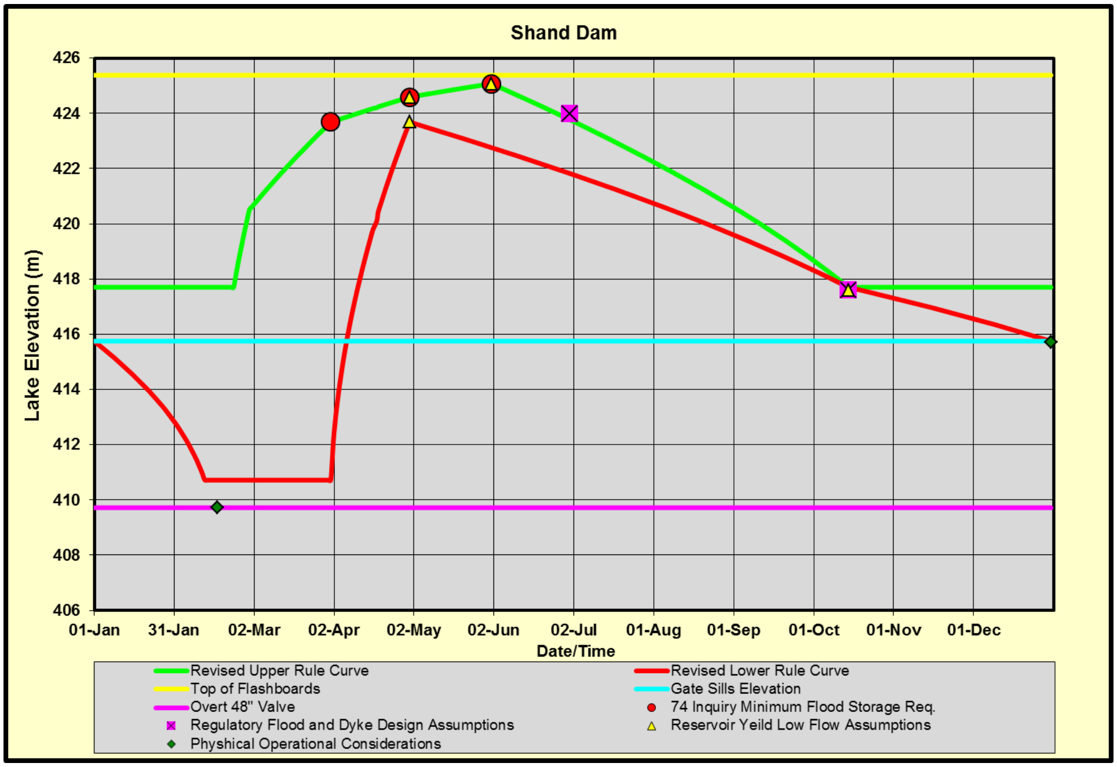


Figure 2: Shand Dam Operational Rule Curve

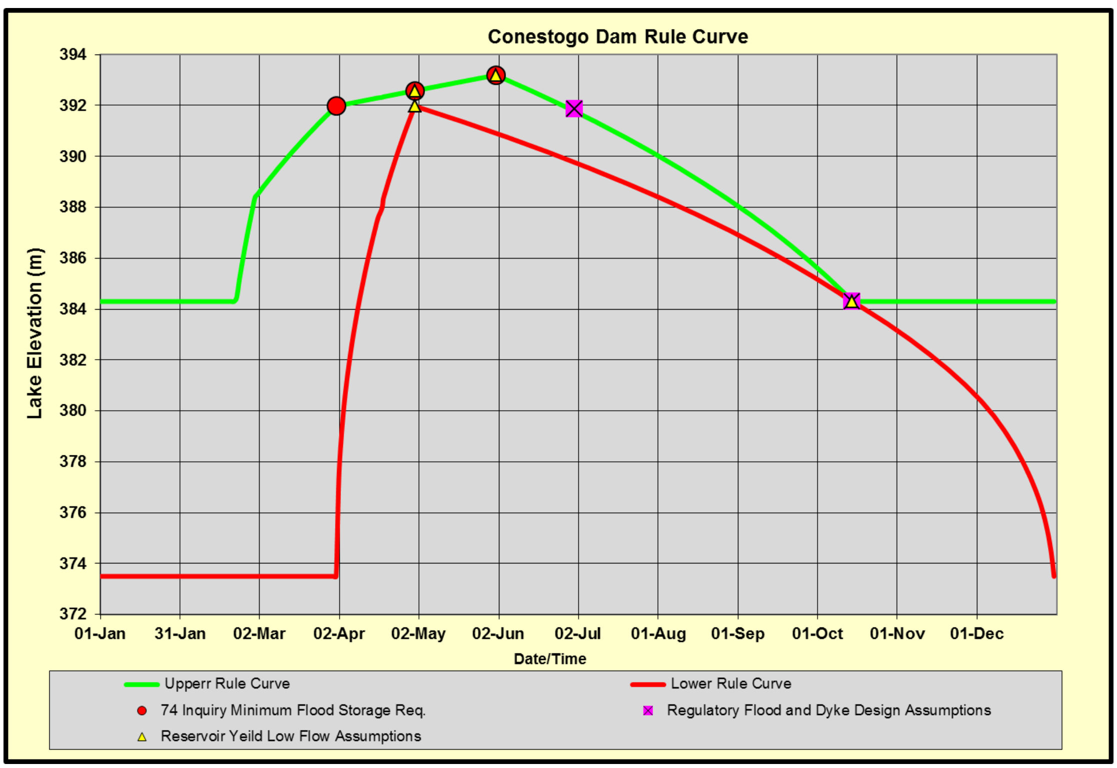


Figure 3: Conestogo Dam Operational Rule Curve

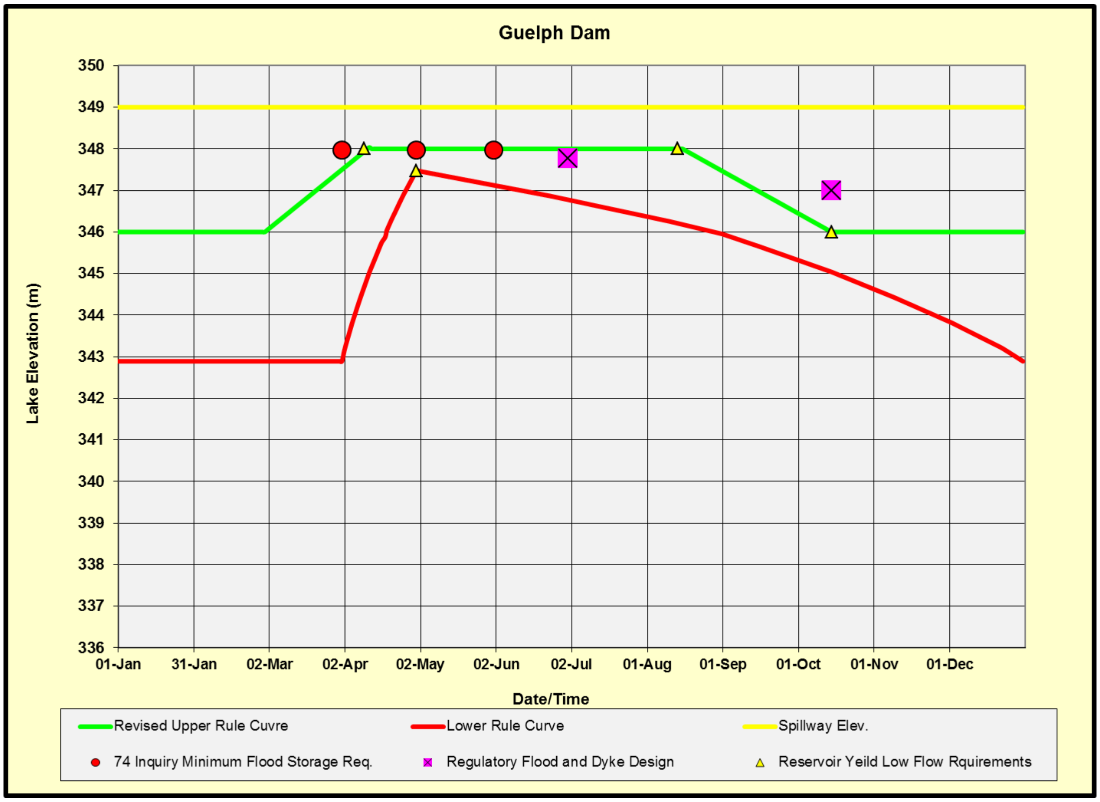


Figure 4: Guelph Dam Operational Rule Curve

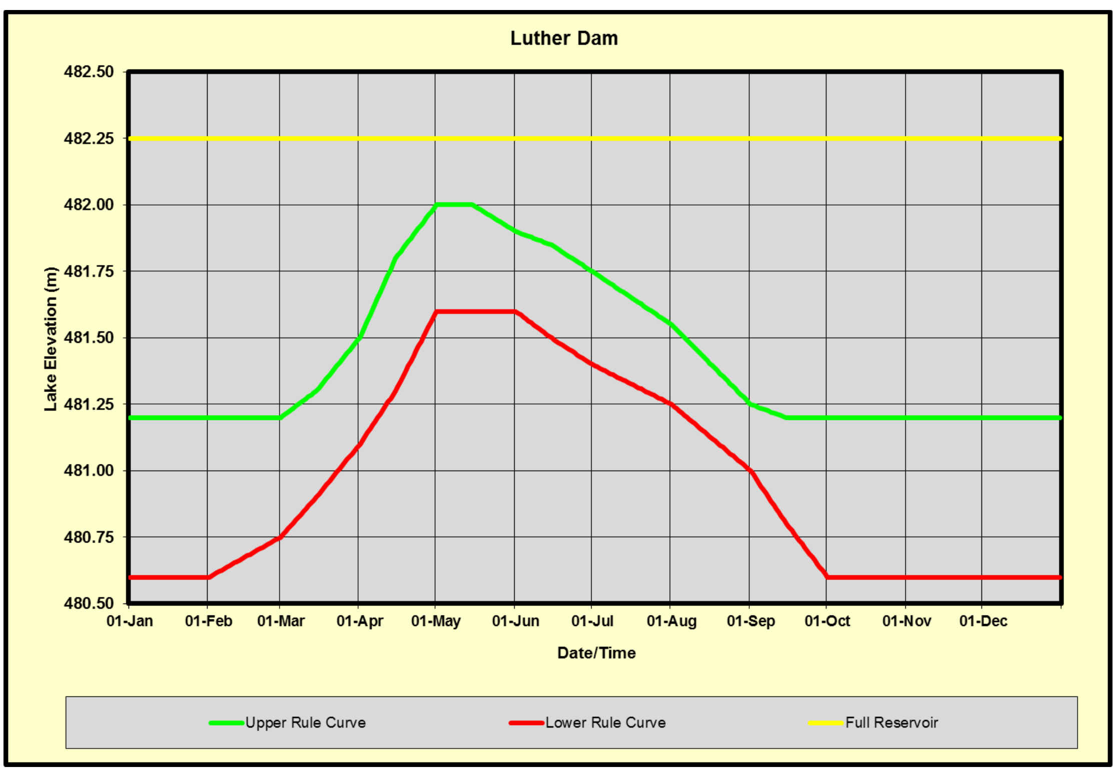


Figure 5: Luther Dam Operational Rule Curve

Appendix 3. Flow Reliability – Luther Reservoir and Legatt Flow Target

Flow Reliability

Luther Reservoir and Legatt Flow Target

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Prepared for: Ministry of the Environment
West Central Regional Office
August 2013

Introduction

In the Grand River watershed, flows in reaches downstream of large dams (Luther, Shand, Conestogo, Woolwich, Guelph) are regulated by the operation of these dams. The primary operating objective of several of the large dams is flood damage reduction (reduction of flows during floods) and low flow augmentation (addition of flows during low flow periods). The result of these operations is a more consistent flow in the river reaches downstream of these large dams. This consistent flow supports wastewater assimilation, municipal water supplies and ecological function.

Luther Dam was built in 1953 in the upper Grand River watershed. The primary purpose of the Luther reservoir is to provide flow augmentation to the Grand River (GRCA and MNR, 2012). While it does provide some benefits from a flood control perspective, these benefits are limited due to the small drainage area regulated by Luther Dam. The flow target at the Legatt gauge on the Grand River was adopted in 2004 by the Grand River Conservation Authority (GRCA) at $0.42m^3/s$. Additional information about the history of operations of the dam and considerations for future flow augmentation are given in the following sections.

Luther Dam Operating Policy

The existing rule curves and operating policy for Authority Reservoirs date back to early 1978. At that time, a committee made up of the Regional Engineer, Ministry of Natural Resources (MNR), the Regional Director, Ministry of the Environment and the Assistant General Manager, GRCA reviewed and recommended the present day general operating procedures and general operating guidelines. The water management structures in the Grand River watershed were analyzed following the inquiry into the 1974 flood. Please refer to “The Environmental Assessment of Water Control Structures in the Grand River Watershed” (1979) for more information. The GRCA adopted and implemented these policies and procedures. The current version of these procedures was approved by the GRCA General Membership in February 2004.

The rule curve for Luther Dam, Figure 1, was developed based on low flow augmentation and ecological considerations. The buffers between March 1st and September 30th define the operating range to meet downstream low flow targets. The lower buffer defines the lowest operating range for flow augmentation before reducing downstream flow augmentation targets. The upper operating limit of 482 metres is the maximum desired operating level. The early winter, January 1st to March 1st, and late fall, October 1st to December 31st, upper buffer curve is defined from ecologic considerations from the Luther Marsh Master Plan (1991). From a biological perspective, fluctuation in water levels is beneficial to emergent vegetation growth at the fringe of the marsh.

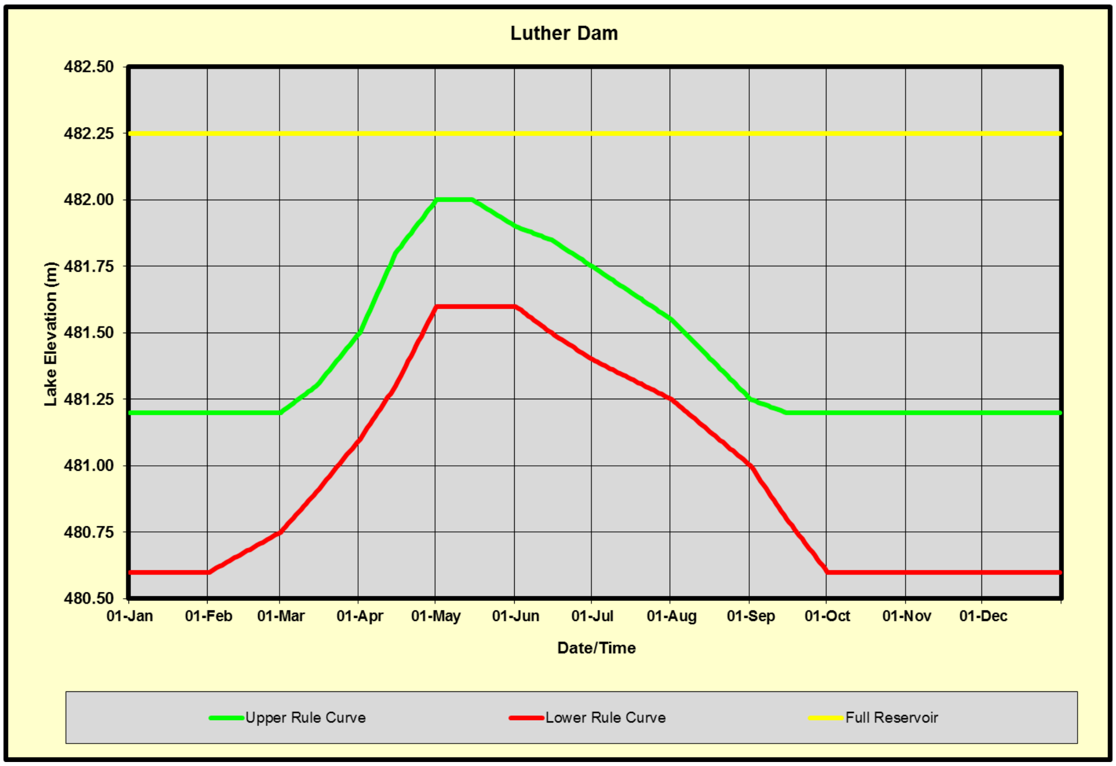

Figure 1: Luther Dam Operational Rule Curve

Currently, the lower rule curve has a minimum elevation operational elevation of 480.6 metres in the early winter and late fall. The reservoir could operate below this level. Below this elevation there is 7,750,000 m^3 of stored water that is equivalent to 90 m^3/s/days of flow augmentation. This volume translates into 214 days of flow augmentation assuming discharge from the dam was set to the low flow target of 0.42 m^3/s. Given the limited drainage area to Luther Marsh, it would take a couple of filling seasons to achieve normal operating levels, however it should be kept in mind there are no limitations to operating below 480.6 metres.

Flow Reliability

The design objective for Luther Dam is described in the 1957 Grand River Hydraulic Report prepared by the Conservation Branch of the Ontario government. The design objective of Luther Dam is described on page 118 of this report, which states "*The flooded area of the reservoir covers some 4,500 acres of a former peat bog which has been partially and unsuccessfully reclaimed for agriculture. Total storage is given as 10,000 acre feet, which is* *sufficient to provide, after allowance for losses, a flow of 50 cfs for the months of July, August and September*." The 10,000 acre feet of storage referred to in the 1957 document translates into an annual flow augmentation capacity of 0.39 m^3/s from the dam. Using the objective of 50 cfs for the three month of July, August and September translates into an annual augmentation from the dam of 0.36 m^3/s. The 0.42 m^3/s quoted for Grand Valley relies not only on the Dam to supply this discharge but also the local drainage area to Grand Valley. Also it's important to note that the valve installed at Luther in 1989 allows water to be used much more efficiently. The range of the current rule curve agrees with the active range referenced in the 1957 report.

The low flow target of 0.42m^3/s year round at the Legatt gauge was adopted by the GRCA in 2004. A comprehensive reservoir yield analysis was conducted prior to adopting the flow target. This is documented in a 2004 technical memo (Boyd, 2004). Reservoir yield analysis has not been redone since the 2004 analysis. An update of this analysis is anticipated as part of the regular update cycle for the water management plan.

Considerations for Climate Change

Ten future climate scenarios were run through the Grand River hydrologic model to investigate changes to stream flow with a changed climate (Shifflett, 2012). General results indicate that the winters would have higher precipitation and warmer temperatures, leading to more mid-winter melt events and higher stream flows. The low flow season would be longer with a weak trend to drier conditions and lower stream flows. Changes to the winter period would affect the ability of the reservoirs to be filled, while a longer and drier summer may affect the ability of the reservoirs to augment flows.

A selection of five climate change scenarios, Table 1, were further analysed using the Luther Reservoir Yield model to investigate considerations for the Legatt low flow target. Assessing the effects of climate change on the ability of the Luther Reservoir to provide flow augmentation is not a straight forward exercise due to a difference in the inflow calculation method and accuracy limitation in low flow modeling with the hydrologic model. A modified approach was used to assess the five climate change scenarios, using both the Luther Dam reservoir yield model and an analysis of the inputs and outputs.

Table 1: Description of Climate Change Scenarios

Scenario	Description
14 (CRCM CGCM3)	High precipitation and moderate increase in temperature. Summer precipitation near the long term average. Stream flow near the long term average
30 (CSIROMk3.5 SRB1)	High precipitation increases throughout most of the year resulting in high predicted stream flows. Moderate increase in temperature (2 degrees).
52 (HADCM3 SRA2)	Moderate scenario with minor increases in temperature and precipitation. Upper watershed had higher increases in precipitation. Summer precipitation was near long term average. Flows were near long term average.

65 (MIROC3.2hires SRB1)	Drop in annual precipitation and a 20% drop in summer precipitation. Higher temperature increases of 3.3 degrees annually. Very low summer stream flows.
66 (MICROC3.2medres SRA1B)	Yearly precipitation close to long term average, but a 20% drop in summer precipitation. High temperature increases (4 degrees annually). Low summer stream flows.

Results of the reservoir yield modeling indicate that a target flow at Legatt of $0.42m^3/s$ can be maintained in a future climate, but the hydrologic model results generally had higher inflows to the reservoir than were expected, leading to additional analysis to confirm the results. A further analysis comparing the changes to inflow and the amount of discharge needed to meet the Legatt target in different future conditions showed that, for the driest year in the two driest scenarios, there would be an increase in the need for augmentation of about 35% during the summer season. On an annual basis, inflows for those scenarios would decrease by about 20% for the same year, but total inflow would still be 4 times the augmentation needs. Changes to the operation of Luther Dam including modifications to the rule curve to hold on to more winter melt water would increase the reliability of meeting downstream summer flow targets in a changed climate, but results to date do not indicate that there would be difficulty in meeting the low flow target under the future climates that were analyzed.

7Q20 Equivalent Flow at Legatt

A $7Q_{20}$ is the minimum 7-day average flow with a recurrence period on average of once in 20 years and is equivalent to 95% reliability by occurrence. The $7Q_{20}$ is calculated using frequency analysis on high quality stream flow data. Frequency analysis is the process of using a past record of hydrologic events to determine future probability of occurrence of these events. In the case of the Legatt gauge the period of record since the adoption of the current flow target is too short for frequency analysis. In regulated systems the period of record should be at least as long as the return period (i.e. 20 years), to ensure established trends can be recognized and accounted for in the analysis.

An analysis based on a flow duration analysis have been used to determine $7Q_{20}$ or equivalent flows at the Legatt gauge on a seasonal basis and compared with the current flow target. The seasons are based on reservoir operations with Winter/Spring from January to May, Summer from June to September and the Fall season from October to December. Low flows for the Winter/Spring period were calculated using the winter months of January to March only. The flow series used for this analysis includes reservoir yield model output for the 1984 to 2002 period and observed data from 2004 to 2010. The method for using flow duration is described in "Flow Reliability: Regulated Reaches of the Grand River Watershed (Draft)" (Boyd and Shifflett 2013).

Results for the $7Q_{20}$ analysis are given in Table 2. The winter/spring season $Q_{99.6}$ flow was the same as the flow target and resulted in one occurrence in 27 years for 25 days below the flow target. The summer season $Q_{99.6}$ flow was slightly less than the flow target flow. Both values had 3 occurrences in 27 years, but the $Q_{99.6}$ was for a shorter period by 10 days. The fall period had the same $Q_{99.6}$ as the summer period, but for only one occurrence for a comparable length to the flow target. Based on the analysis of flow data proposed $7Q_{20}$ flows are: winter/spring 0.42m^3/s, summer 0.40m^3/s and fall 0.42 m^3/s.

Table 2: Number of year's 7-day flow dropped below estimated 7Q20 from 1984 to 2010

	Winter/Spring		Summer		Fall	
Gauge	**Target**	**Q99.6**	**Target**	**Q99.6**	**Target**	**Q99.6**
7Q20 equivalent	0.42	0.42	0.42	0.40	0.42	0.40
# of Occurrences (years)	1	1	3	3	1	1
Longest period below value (days)	25	25	28	18	32	29

Accuracy in Low Flow Measurements

Herman Goetz, the manager of the Water Survey of Canada (WSC) office out of Burlington, was consulted with respect to the accuracy of stream flow measurements and rating curves used to convert water levels at gauge stations to flow. Herman indicated traditional methods use 20 panels to divide the cross section where the flow is obtained. This method has been used for many decades. Research used to establish this method indicates measured flows can be expected to be within 5% of the actual flow using this method. Modern Acoustic Doppler Current Profilers (ADCP's) are starting to be used by WSC. Research is indicating the ADCP's can achieve measured flows within 2 to 3% of the actual flow. Based on the above manually measured flows can be expected to be within 5% of the actual flow.

Rating curves are used to estimate flow from water levels. The quality of the gauge control affects the accuracy of the flow versus level relationship. A gauge with a stable gauge control (cross section) that isn't subject to backwater from weed growth or subject to shifts due to erosion or deposition of sediment can be expected to produce accuracies within 5% similar to the flow measurement. The gauge control at the Legatt gauge is a natural stream cross section founded on till. The gauge control has been stable over several years with limited shifts to the rating curve.

For the Legatt gauge when the flow target is met, flows would be between 0.40 and 0.44 m^3/s when applying an accuracy of within 5%.

Accuracy in Reservoir Discharge Measurements

During a recent Lake and Rivers Act permit submission to the Ministry of Natural Resources (MNR) for work at Luther Dam, the MNR inquired about the accuracy of the discharge rating curves at Luther Dam. The accuracy of both the stop log and valve (sluice) rating curves were checked, Figures 2 and 3 present the results of this check. The rating curve used to estimate discharge from Luther dam was found to be accurate. Based on the information in Figures 2 and 3, the accuracy appears to be within 5%.

Stop Log Discharge Capacity

The stop log discharge was modelled using the sharp crested weir equation assuming two end contractions.

$$Q=C_2\ (C_1+(0.4x(H/P))x(L-0.2xH)\ x\ H^{1.5}+Q_{leakage}$$

C_1-Weir flow coefficient in imperial units C_1 =3.2 (text book value), a calibrate value of C_1 =3.35 was used based on fitting to manually measured discharges

C_2 –Conversion factor to convert weir coefficient to SI units C_2 =0.55

H- Effective head acting on weir calculated as reservoir elevation less the weir crest elevation

P-Distance from weir crest to weir sill

L- weir length 1.93 metres adjusted for two end contractions (-0.2xH)

$Q_{leakage}$- stop leakage manual measured leakage 0.08 m3/s

Above equation and coefficients referenced from the following web links
http://docs.bentley.com/en/HMFlowMaster/FlowMasterHelp-06-46.html
http://www.hydrology.bee.cornell.edu/BEE473Homework_files/ChutesWeirs.pdf

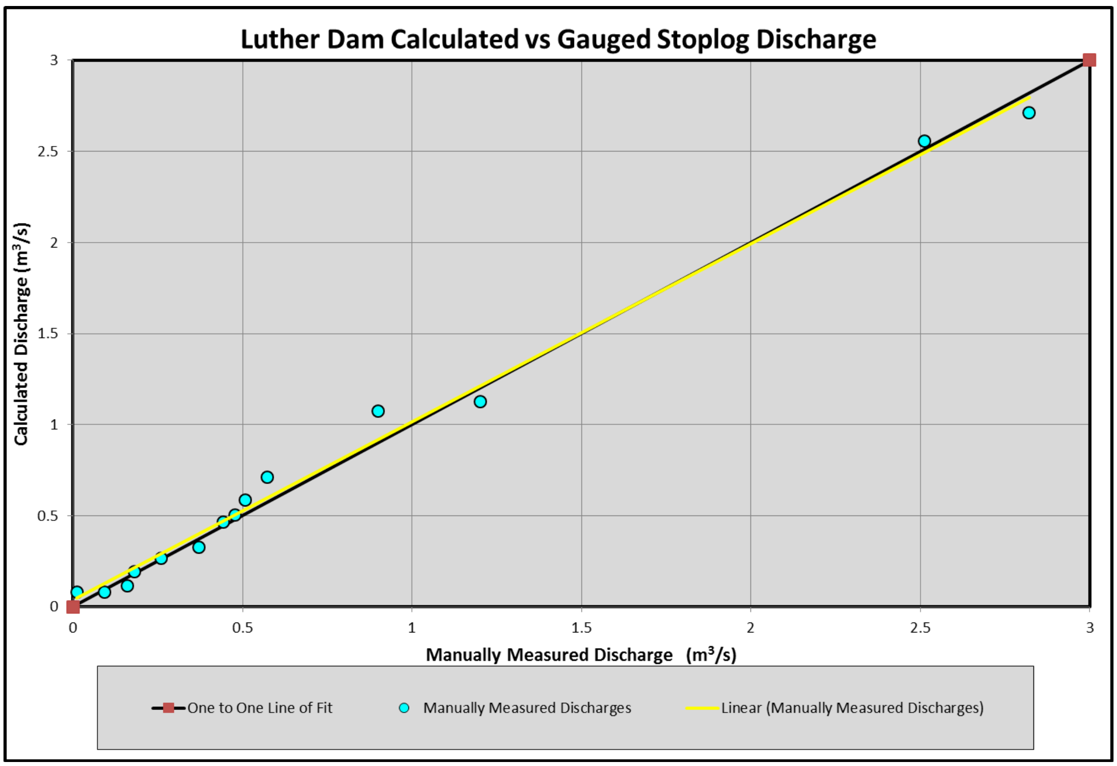

Figure 2: Luther Dam Stoplog Discharge Verification with Manually Measured Discharge

Sluice Discharge

The sluice discharge was modelled using the orifice equation assuming a sharped edged orifice.

$$Q=CxAx(2xgxh)^{0.5}$$

C- Coefficient of discharge for sharp edged orifices 0.62 a calibrated coefficient of 0.6 was used based on fitting to observed manually measured discharges.

A – Area of sluice height of opening 0.533 metres and width of opening 0.533 metres

g – Gravity acceleration constant 9.805 m2/s

h – Effective head acting on the centre of the orifice opening in metres

http://engineering.wikia.com/wiki/Orifice_equation

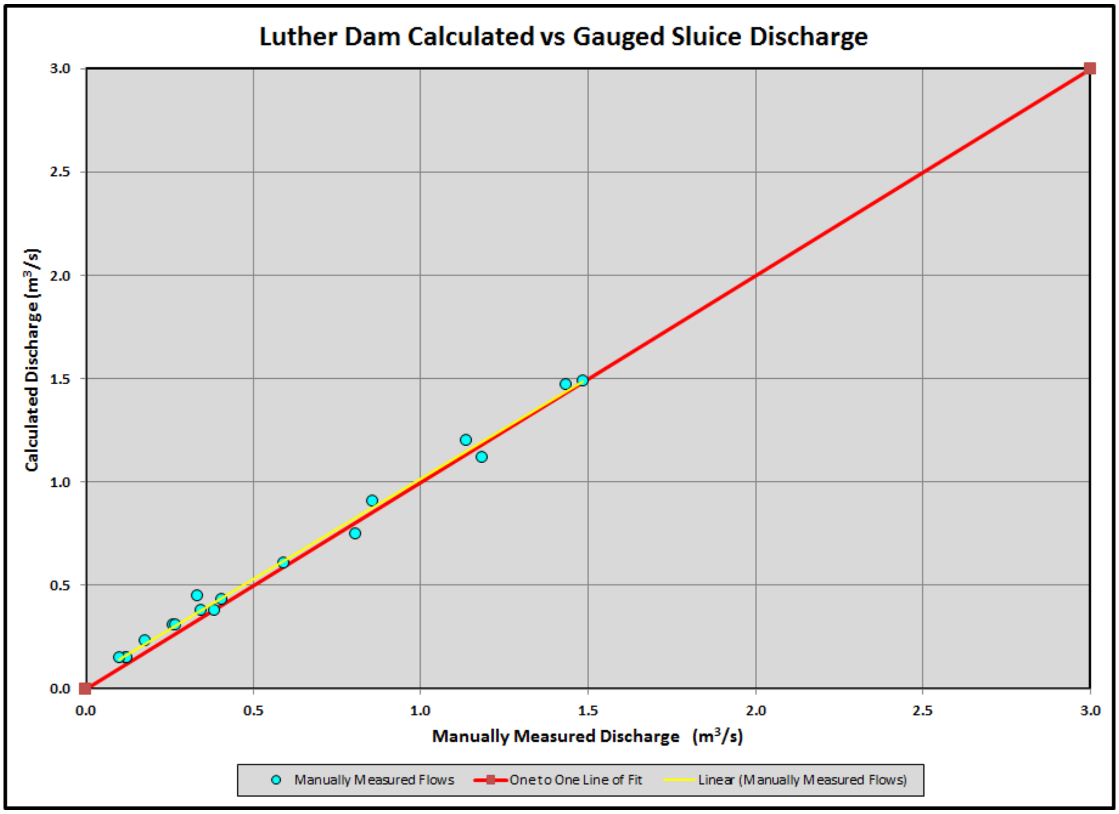

Figure 3: Luther Dam Sluice Discharge Verification with Manually Measured Discharge

Recommendations

Based on the information presented in this memo and the reservoir yield analysis completed for Luther Reservoir in 2004, a year round flow target of 0.42 m^3/s is appropriate for the Legatt gauge. Flow targets in the Grand River watershed are designed to be met at least 95% of the time. The target at Legatt has been met greater than 95% of the time since it was adopted in 2004.

Analysis of the flow record gives a $7Q_{20}$ equivalent at the Legatt gauge of between 0.40 and 0.42 m^3/s. To account for accuracy in stream flow measurements, a recommended $7Q_{20}$ equivalent for the Legatt gauge is 0.40 m^3/s year round. Currently available information on the effects of climate change to stream flow in the Upper Grand River watershed does not indicate issues with meeting the flow target in the future, but it is recommended that the target is reviewed periodically to assess changes in local stream flow over time.

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Appendix 4. Flow reliability for Luther Dam was completed in 2004 (Boyd 2004)

Table 6. Low flow operation targets for the large water management reservoirs.

Location	Operational Low Flow Target			Basis	Last Confirmed/ Revised
	Jan-Apr (m^3/s)	May-Sept (m^3/s)	Oct-Dec (m^3/s)		
Grand Valley	0.42	0.42	0.42	1986 Reservoir Yield Study	2004
Below Shand Dam[1]	2.8	2.8	2.8	1982 Basin Study	2013
Doon[2]	2.8[4]	9.9	7.1	1982 Basin Study	2013
Brantford		17		1982 Basin Study	2013
Below Conestogo Dam[1]	2.1	2.1	2.1	1982 Basin Study	2013
Below Guelph Dam[1]	0.57	0.57	0.57	1982 Basin Study	2013
Edinburg Road City of Guelph[3]	1.1	1.7	1.1	1982 Basin Study	2004/2013
Elmira	0.3	0.3	0.3	Operations Manual Woolwich Dam	1980

[1] Lessor of flow target or inflow to the dam

[2] Flow before the Mannheim surface water taking of 0.9 m3/s, Doon gauge is located downstream of taking

[3] Summer operating season for the Speed River is June 1 to Sept 30, fall/winter season is Oct 1 to May 31

[4] Winter low flow target estimated based on available winter augmentation storage below gate sill at Shand Dam